Arrow Energy Pty Ltd

**Bowen Gas Project**

# CSG Groundwater Management and Monitoring Plan – Project Stage 1

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October 2019

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# EXECUTIVE SUMMARY

Arrow Energy intend to develop, operate and decommission a coal seam gas field in the Bowen Basin, Queensland, described in the BGP EIS (March 2013) and SREIS (May 2014).

The Arrow Energy Bowen Gas Project (BGP) was approved by the Queensland Government on 8 September 2014 and the Australian Government on 27 October 2014. The Queensland and Australian Governments approved the project subject to conditions and recommendations.

This document is the Project Stage 1 Groundwater Management and Monitoring Plan (GMMP) for the BGP.

## Groundwater resources

The Project area, situated on the interior plains of the Bowen Basin, is oriented north-south and parallel with the ancient drainage pattern and greatest thickness of sediment successions.

The Middle Permian age Back Creek Group comprises sandstone, siltstone, shale and minor coal and is considered a semi-pervious lower boundary for groundwater flow to the overlying Late Permian age Blackwater Group coal measures. The Blackwater Group is overlain by the Mimosa Group, of which only the Rewan Formation occurs extensively in the middle of the basin; a semi-pervious barrier to vertical groundwater flow that acts as a confining unit across the BGP area and is a basal confining layer of the Great Artesian Basin (GAB).

The overlying Clematis Sandstone, a major GAB aquifer, and the Moolayember Formation, a GAB confining unit, occur as elevated outcrops in the Project area southeast of Glenden, and near the Project area southeast of Blackwater.

The Triassic and Permian age sedimentary successions are overlain by Tertiary age formations including isolated basaltic lava outcrops and areas of Suttor Formation and Duaringa Formation. Extensive Quaternary age alluvial deposits also occur along rivers, creeks and floodplains within the Project area.

The principal source of groundwater for extractive purposes are the alluvial aquifers, with minor sources including the basalt, sedimentary rocks and coal of the Blackwater Group and sedimentary rocks of the Back Creek Group (in the west of the basin where the Back Creek Group subcrops or outcrops).

There are no known or anticipated fault-controlled springs in the BGP area. GDEs in the project area, where present, will be dependent on the watertable aquifer.

## Groundwater modelling

Numerical groundwater modelling was used as a basis for predicting impacts to groundwater due to CSG production. Modelling for the GMMP built on work previously undertaken for the SREIS and the 2016 Underground Water Impact Report (UWIR) by incorporating a revised unstructured grid mesh under MODFLOW-USG code and updated calibration.[1] The revised mesh enabled significant improvement in resolution of model features in the MGP (Moranbah Gas Project) area.

In general, the extent of predicted drawdown has contracted from the SREIS predictions, primarily due to a diminished CSG production field under the current FDP.

The maximum drawdown for the cumulative case to the watertable aquifer is predicted to be spatially limited and generally less than 0.2 m.[2] No occurrence of maximum drawdown greater than 5 m is predicted for the remaining geological units, outside of the target coal seams.

### Uncertainty analysis

In addition to the calibrated model predictions, the null-space Monte Carlo (NSMC) method was used to quantify uncertainty in predicted impacts. A total of 350 model realisations were created which were constrained using calibration datasets, and enabled analysis of the output to provide a statistical distribution of the regional model predictions.

## Monitoring network and program

### Risk assessment

A risk assessment, based on the source-pathway-receptor model, was undertaken to assist in the identification of the groundwater monitoring targets for the monitoring network.

The findings indicated no risk of impact from the Action to existing groundwater users extracting from the watertable aquifer, or to consolidated aquifers other than the Late Permian age coal measures. Fifteen bores screening the Late Permian age formations were predicted to be at potential risk of impact from the Action over the life of the project, while 21 bores of unknown geological classification may also be potentially affected by drawdown, if screened within the Late Permian age formations.

Potential non-spring GDEs (terrestrial GDEs) and sites of cultural and spiritual significance in the Project area are not considered at risk of impact from the Action.

### Design

A groundwater monitoring network has been developed to comply with Commonwealth Approval Conditions 21 to 25, the UWIR, and specified Arrow EIS/SREIS commitments. A structured analysis was undertaken to identify where predicted groundwater drawdown may correspond to potential risks, and to rationalise the monitoring locations. In addition, the

[1] A Queensland Government requirement.

[2] The case that includes historical and forecast Moranbah Gas Project production plus the BGP production.

selection of monitoring locations takes into consideration the requirement to provide baseline data before development impacts occur, to inform modelling, and to enable analysis of groundwater hydrograph trends, as monitoring data is acquired over time.

## Specification and schedule

The groundwater monitoring network (excluding the 5 contingent monitoring points) consists of 30 monitoring intervals at 19 separate locations (comprising 11 single sites and 8 nested sites of 19 monitoring intervals). The exact number of bores required to achieve monitoring of the specified intervals will be determined during monitoring bore design and engineering. Each bore may have multiple monitoring objectives that target the monitoring and management of site-specific project risks.

In addition, four contingent monitoring locations (consisting of 5 monitoring intervals) will be installed only in circumstances where the criteria for contingency are met.

While all monitoring locations are intended to inform changes to the groundwater regime and the groundwater balance in the Project area, each location has been targeted to fulfil specific (primary and secondary) purposes to address the BGP GMMP Approval Conditions.

The identified locations will also supply ongoing monitoring data for groundwater model verification and re-calibration.

The monitoring bore installation schedule is phased according to the following:

- Monitoring bore locations with a primary purpose of baseline monitoring will be installed at least one year prior to the commencement of production in the corresponding development area to enable the collection and interrogation of baseline data.

- Monitoring bore locations where baseline monitoring is not required will be installed immediately prior to the commencement of production in the corresponding development area.

## Monitoring program

All functional GMMP monitoring points will be monitored for groundwater pressure/level. For the first 12 months, each monitoring point will be monitored for groundwater pressure/level, twice daily (via data logger), with 6-monthly manual readings. Following this period, the data will be reviewed to characterise temporal and spatial variations in groundwater levels. Where there is confidence that the observed trends are understood, the monitoring frequency will be reduced to 6-monthly manual readings.

Groundwater quality monitoring will be undertaken at specified groundwater monitoring locations across the Project area. All nested bore site intervals will be sampled and analysed for groundwater quality. The exception is MB1 which will be re-purposed from RH28/RH30. Due to well completion constraints, it will not be possible to sample from the intermediate and shallow intervals at this site. Should pressure data indicate the potential for inter-connectivity between the MCM and overlying units at this site, a shallow groundwater quality monitoring point will be established.

During the initial twelve months following bore installation, groundwater quality monitoring will be conducted on a 6-monthly basis and thereafter, annually.

All data generated in the GMMP will be collated electronically and stored in a dedicated project database. Data will be reviewed for transcription errors and consistency with historical data and where anomalies are identified, or trends that markedly deviate from model drawdowns, further data assessment and/or analysis will be triggered.

## Early warning system

Approval Condition 21(d) requires the proposal of early warning indicators, trigger thresholds, and limits for detecting impacts on groundwater levels. Collectively, this is the early warning system (EWS) (Table A).

**Table A EWS requirements**

| System | Early warning indicator | Trigger threshold | Limit |
|---|---|---|---|
| **Consolidated aquifers** | ✓ | ✓ | ✓ |
| **Unconsolidated aquifers** | ✓ | ✓ | ✓ |

The EWS for the BGP includes tiered investigation levels with escalating responses:

1. **Early warning indicators**, for early identification of potential groundwater drawdown issues to enable additional baseline monitoring data to be collected.
2. **Trigger thresholds**, for identifying the potential for groundwater drawdown (as a consequence of the Action) to affect groundwater users and enable monitoring and management measures to be implemented to mitigate the potential for impact.
3. **Limits**, that define groundwater levels of drawdowns not to be exceeded.

The EWS is based on comparing modelled groundwater drawdowns derived from the BGP GMMP groundwater model (AGE 2018) with staged early warning indicator levels, trigger thresholds, and drawdown limits, to inform escalating response actions. Because of the impact of historical and current coal-mining groundwater abstractions, a direct monitoring approach is contraindicated. Instead, groundwater monitoring observations inform this process indirectly by providing data to underpin and revise groundwater modelling.

Commensurate with Approval Condition 21(d), the EWS for the BGP GMMP is aligned with the requirements for preparation of the UWIR. The predictions for affected aquifers are made for:

- Water level declines, by more than the applicable bore trigger threshold, within three years following the report consultation day (immediately affected area, or IAA); and

- Water level declines, by more than the applicable bore trigger threshold, at any time (long-term affected area, or LAA).

These principals are integrated into the proposed EWS for the BGP GMMP in the form of the adopted tiered investigation levels and corresponding exceedance response actions.

Groundwater level and quality monitoring data collected from the monitoring network will be used to help consolidate the understanding of groundwater systems across the BGP and to periodically update the groundwater model supporting the GMMP. In turn, potential groundwater drawdown and impacts will be re-forecast for ongoing implementation of the EWS.

## Reporting, review and periodic plan updates

Arrow will maintain records of relevant activities carried out in accordance with the BGP GMMP. These records will be made available to the Department of the Environment and Energy (the Department) upon request.

Reporting for the GMMP will be in compliance with the Approval Conditions and include:

- Non-compliance reporting
- Exceedance reporting for the EWS
- Review and updates of the GMMP
- Annual reporting

Arrow will make public the results of data obtained from the water-related aspects of their monitoring network for the life of the project. Supply of data collected by Arrow, will be reported to the Office of Groundwater Impact Assessment (OGIA) associated with obligations under the UWIR, and to the Department and Queensland Government authorities, as requested.

The BGP GMMP has been subject to a formal peer review by a suitably qualified water resources expert in accordance with the Approval Conditions and a statement endorsing the findings of the content of the GMMP is supplied as an appendix to this report.

## Compliance with Approval Conditions

To demonstrate compliance, a table providing a summary of the approval conditions, cross-referenced to the relevant sections of the BGP GMMP where the conditions are addressed, is provided in Appendix A.

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# 1 INTRODUCTION

The Arrow Energy Bowen Gas Project (BGP) was approved by the Queensland Government on 8 September 2014 and the Australian Government on 27 October 2014. The Queensland and Australian Governments approved the project subject to conditions and recommendations. This document is the Project Stage 1 Groundwater Management and Monitoring Plan (GMMP) for the BGP.

## 1.1 Approvals and conditions

This GMMP addresses specific requirements for monitoring of groundwater and groundwater related impacts potentially resulting from the development of Project Stage 1 of the BGP. It also addresses EIS commitments and Queensland legislative requirements.

### 1.1.1 Australian Government approval conditions

The Australian Government approval (EPBC 2012/6377) for the BGP under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) requires the preparation of a GMMP, submitted in stages, to address potential impacts on groundwater resources. Each stage of the GMMP must correspond to a project stage, and be approved by the Minister for the Environment in writing, prior to the commencement of water or coal seam gas (CSG) extraction for the relevant stage.

Approval Conditions 21 to 23 set out specified requirements for the GMMP. These conditions are provided in Appendix A, together with a table cross-referencing specific Sections within this GMMP where each condition is addressed.

### 1.1.2 EIS commitments

A range of groundwater related commitments have been specified in the BGP Environmental Impact Statement (EIS) and Supplementary Report (SREIS). The BGP environmental commitments are tabled in Appendix O of the SREIS. Those that specifically relate to groundwater are reproduced in Appendix B herein.

### 1.1.3 Queensland Water Act monitoring requirements

Underground water obligations are also set out under the Queensland Water Act 2000 (Water Act), including the development of an Underground Water Impact Report (UWIR). The UWIR defines groundwater monitoring requirements through a Water Management Strategy (WMS) and (where relevant) a Springs Impact Management Strategy (SIMS).

Accordingly, this Project Stage 1 GMMP is structured to align the management and monitoring requirements under the Australian Government Approval Conditions, with the Queensland Government UWIR, thereby providing a consolidated approach to groundwater management and reporting.

The approach taken in addressing the approval conditions has involved the preparation of four technical memoranda. These were developed iteratively and provided to the appointed peer reviewer for progressive endorsement. The content of the memoranda is incorporated within this plan and the memoranda are included as appendices.

The technical memoranda are summarised in Table 1-1.

**Table 1-1 Summary of technical memoranda**

| Technical Memoranda | Approval Conditions addressed | Appendix |
|---|---|---|
| **Groundwater modelling** | 21(a) (part)<br>21(b) (part)<br>21(c) (part) | C |
| **Groundwater monitoring network** | 21(a)(i),(ii),(iii),(iv),(v)<br>21(c) | D |
| **Groundwater monitoring program and Early Warning System** | 21(b)<br>21(d)<br>21(e) | F |
| **GMMP review schedule** | 21(f)<br>21(g)<br>21(h) | G |

## 1.2 Project description

Arrow intend to develop, operate and decommission a coal seam gas field in the Bowen Basin, Queensland, described in the BGP EIS (March 2013) and SREIS (May 2014).

### 1.2.1 Revised field development plan (FDP)

The BGP (which has been revised since approval) involves an expansion of Arrow CSG production in the Bowen Basin (Figure 1-1), and comprises development in the same areas as set out in the EIS and SREIS (i.e. within tenements ATP742, ATP1103, and ATP1031). A phased development between 2019 and 2049 was presented, based on 4,000 wells and total water production of 153 GL.

A staged approach is presented to comply with the Approval Conditions: Project Stage 1 includes up to 1,408 CSG wells limited to the area in Attachment A of the Approval Conditions (refer Figure 1-2). Subsequent project stages may include between 1,409 and 4,000 CSG wells, located within the BGP tenements (refer Figure 1-1).

### 1.2.2 Project Stage 1

The Project Stage 1 GMMP is based on the following FDP:

- Red Hill Central (PL 486 within ATP 1103) commencing 2019;
- Mavis Downs (PCa152 within ATP1103) commencing 2021; and
- The remainder of the Project Stage 1 area presented in Figure 1-2, commencing 2030.

Red Hill Central lies within the footprint of BGP development case presented in the SREIS. It is located approximately 30 km north of the township of Moranbah and borders Arrow's existing

Moranbah Gas Project (MGP) to the south. Water production from Red Hill Central is currently forecast to occur from 2019 to 2025, with a total of 0.88 GL of water to be produced.

The Mavis Downs development is located to the south of PL223 on PCa152, a comparatively mature area in ATP 1103, approximately 24 km east of the township of Moranbah. This development borders the MGP to the east. Mavis Downs production is currently forecast to occur from 2021 to 2030, with a total of 0.67 GL of water to be produced from 17 wells.

Production from the remainder of the Project Stage 1 area, tentatively planned from 2030 to 2060, will comprise 1,360 wells and a total water production of 80.7 GL.

Table 1-2 provides a summary comparison between the SREIS development and the Project Stage 1 FDP used in preparing this GMMP. Figure 1-3 shows forecast water production for the Project Stage 1 GMMP FDP.

**Table 1-2 FDP comparison**

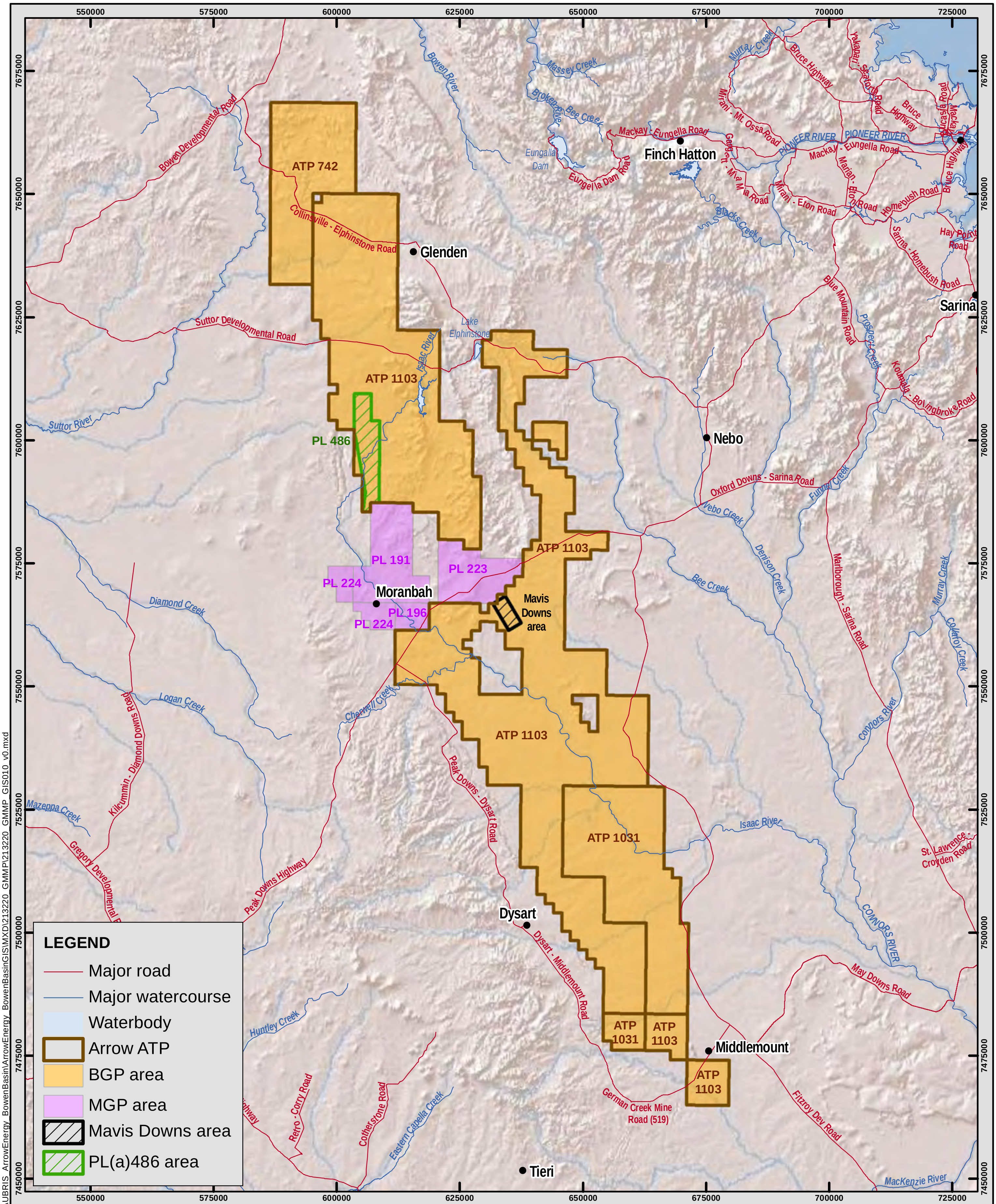
| FDP | | Approximate[1] number of production wells | Water production | | Timing | |
|---|---|---|---|---|---|---|
| | | | Total (GL) | Peak (GL/a) | Start | End |
| **SREIS BGP FDP** | | 4,000 | 153 | 10.4 | 2019 | 2049 |
| **Project Stage 1 FDP** | **Red Hill Central** | 31 | 0.88 | 0.16 | 2019 | 2025 |
| | **Mavis Downs** | 17 | 0.67 | 0.097 | 2021 | 2030 |
| | **Remainder of the Project Stage 1 area** | 1,360 | 80.7 | 3.8 | 2030 | 2060 |
| | **GMMP Total** | **1,408** | **82.25** | **4.057** | **2019** | **2060** |

**Note:**
*(1) Well locations and numbers for Red Hill, Mavis Downs, and the remainder of Project Stage 1 area are indicative only. Total well count, however, will not exceed 1,408 for Project Stage 1.*

The project description for the Project Stage 1 GMMP FDP also includes other infrastructure such as gas and water gathering systems. This has been previously described in the SREIS, which covers gathering lines at Red Hill Central (as well as a 13 km Ironbark gathering line), Mavis Downs and the remainder of the Project Stage 1 area.

In addition to the development detailed above, Arrow operates the MGP which has produced gas for the domestic market since 2004 and is forecast to remain operational until 2030. The impacts of historical and future production from the MGP on groundwater, have been considered during development of the Project Stage 1 GMMP.

ARROW ENERGY - BOWEN BASIN GAS PROJECT




Document: \\Abtfarcv01\data$\GIS\7043_ENAUBRIS_ArrowEnergy_BowenBasin\ArrowEnergy_BowenBasinGIS\MXD\213220_GMMPI213220_GMMP_GIS010_v0.mxd

Figure 1-1 Project area

Source:
Arrow Energy Pty Ltd
ESRI Online

Date: 17/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



NOT FOR CONSTRUCTION

ARROW ENERGY - BOWEN BASIN GAS PROJECT

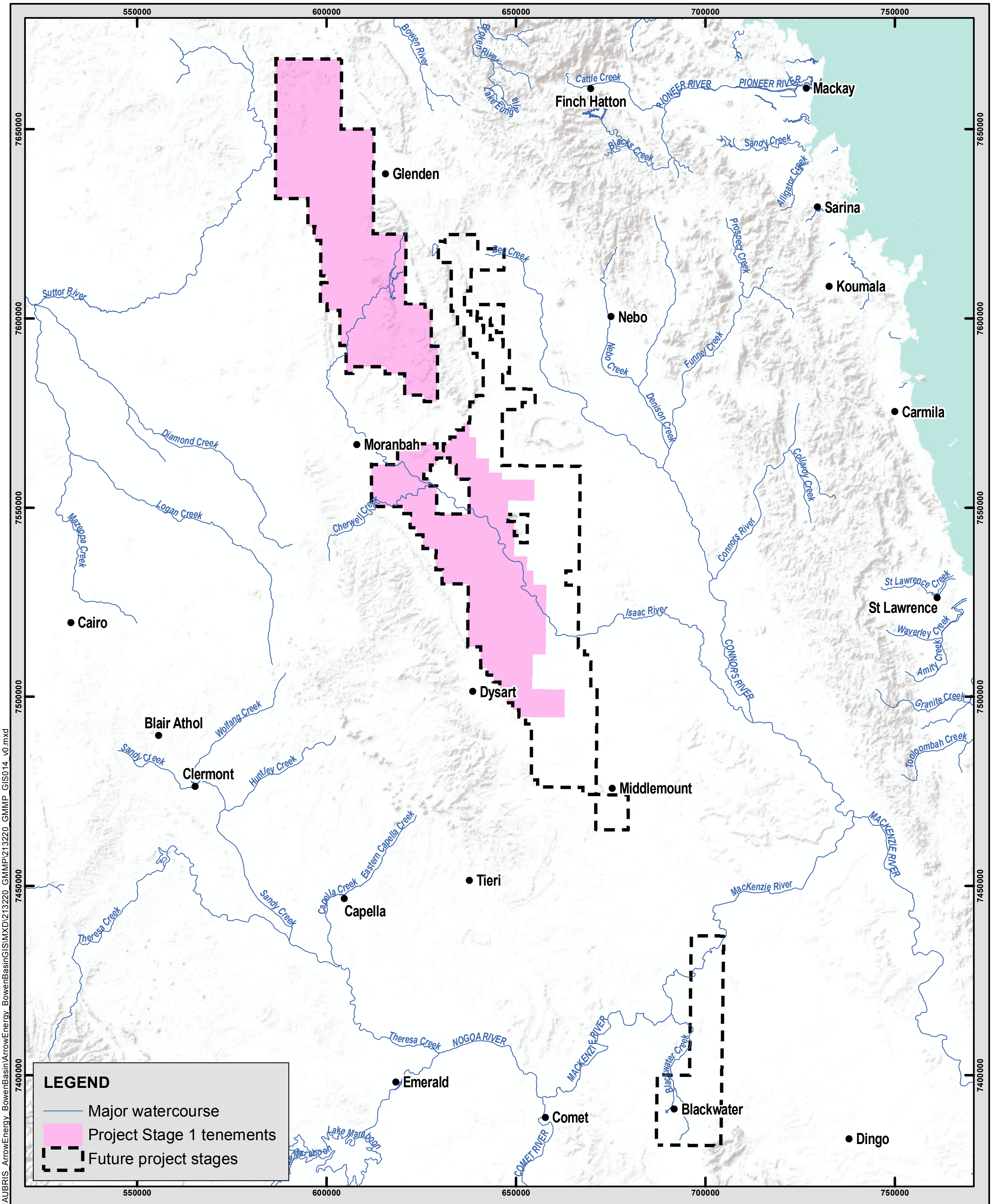



**Figure 1-2** **Project Stage 1 development area**

**Source:**
Arrow Energy Pty Ltd
ESRI Online

Date: 15/08/2019
Issued To: Arrow Energy
Author: helen.unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,296,233 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N



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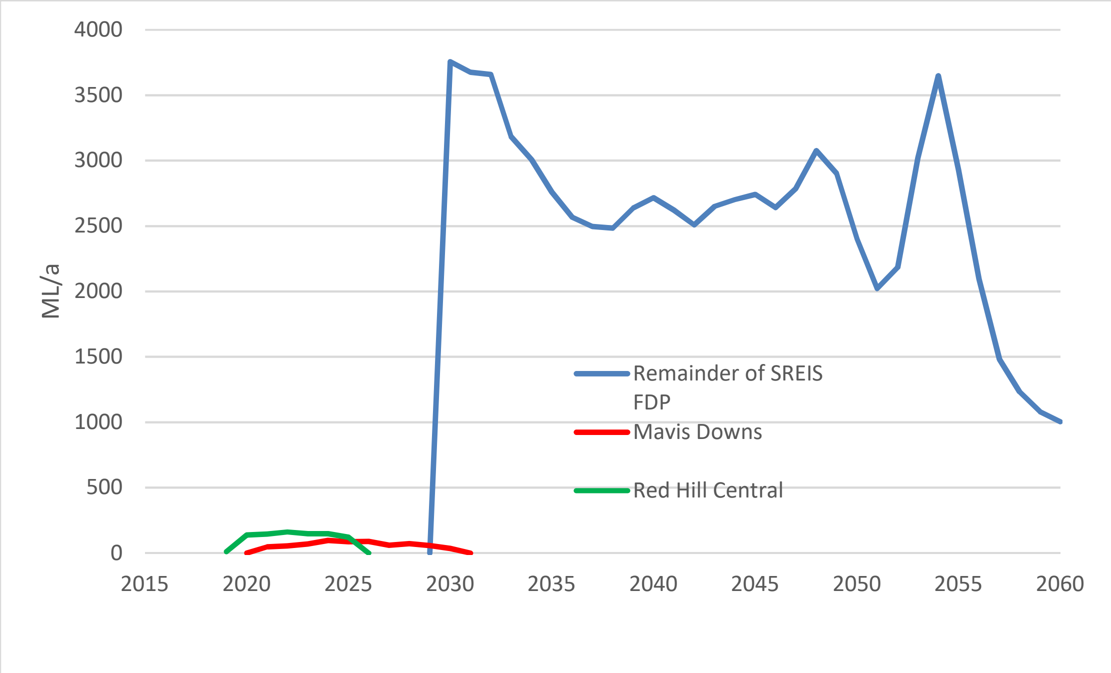
NOT FOR CONSTRUCTION

**Figure 1-3 Project Stage 1 GMMP FDP water production**




### 1.2.3 Commencement and cessation of production

Arrow will not commence the extraction of water or coal seam gas for Project Stage 1 until the Project Stage 1 GMMP has been approved by the Minister in writing. This GMMP will be implemented by Arrow, in compliance of Approval Condition 23.

## 1.3 Approach to developing GMMP

The BGP SREIS presented the results of a source, pathway and receptor assessment of potential groundwater impacts in the Bowen Basin. The comprehensive assessment included consideration of the effects of open pit and underground coal mining, faulting and subsidence on aquifer quality and flow characteristics. It included consideration of the potential effects of natural and induced seismicity on groundwater behaviour, particularly the potential for earthquakes and hydraulic well stimulation to affect faults and change groundwater flow paths.

The Project Stage 1 GMMP is designed to build on that work through a gap analysis to identify the changes that have occurred since publication of the SREIS, availability of new research or data and as a result of Front-End Engineering Design (FEED) including associated numerical modelling of the development cases considered in FEED. This modelling provides revised predicted drawdown contours to inform the assessment of risk to sensitive receptors, including groundwater dependent ecosystems (GDEs) and existing groundwater users. In addition, consideration of the proximity of proposed production wells to faults and existing mine developments is made in the context of potential risk to receptors, along with the potential for interconnectivity with overlying aquifers.

The outcomes of the risk assessment informed the identification of the groundwater monitoring targets that constitute the Project Stage 1 GMMP monitoring network. The selection of monitoring locations also takes into consideration the requirement to provide baseline data before development impacts occur, and to provide for the early detection of changes in the groundwater regime.

Preparation of the Project Stage 1 GMMP was also informed by GMMPs (or equivalent) prepared for other CSG developments in the southern Bowen and Surat Basins, studies undertaken by CSG operators and OGIA, including the Joint Industry Plan (JIP) for Environmental Protection and Biodiversity Conservation (EPBC) springs. It is consistent with the requirements of the Water Act 2000 including the UWIR which requires a SIMS and WMS. Early warning indicators and risk-based exceedance responses (or equivalent) have been established by the OGIA and other proponents in their GMMPs. These inform the basis for the development of trigger thresholds and impact responses for the BGP GMMP.

The Project Stage 1 GMMP details the monitoring frequency and reporting requirements including online publication of monitoring data, and details how monitoring data will be made available to relevant government agencies to inform the cumulative impact assessment of groundwater depressurisation.

## 1.4 Peer review

The GMMP required formal peer review by a suitably qualified water resources expert in accordance with Approval Condition 22 of the Australian Government approval. The peer reviewer was approved by the Minister for the Environment and was engaged in progressive reviews during preparation of the GMMP.

The peer review of the draft GMMP was submitted to the Minister together with a statement from the suitably qualified water resources expert endorsing the findings and the content of the GMMP. Details of the peer review and statement of endorsement are provided in Appendix H.

## 1.5 Definitions

Key terms relevant to the GMMP are defined in Table 1-3. Other technical terms in this document, where not specifically defined, are assumed to have the same meaning as defined in the BGP EIS/SREIS.

**Table 1-3 Definitions[3]**

| Term | Definition |
|---|---|
| **The Action** | The Bowen Gas Project, as approved by the Australian Government on 27 October 2014. |

[3] Where relevant, the terms are defined in relation to the BGP induced change.

| Term | Definition |
|---|---|
| **Background level** | Non-Arrow CSG influenced existing conditions (levels or quality). |
| **BGP area** | The BGP development area and surrounding land (within the extent of drawdown impact as a result of the Action). |
| **Bore trigger threshold** | Derived from the Queensland Water Act[4] for similar systems, being 5 m for consolidated aquifers and 2 m for unconsolidated aquifers. |
| **Consolidated aquifer** | Aquifer in a consolidated sedimentary formation. |
| **The Department** | The Australian Government Department administering the EPBC Act (currently the Department of the Environment and Energy). |
| **Early warning indicator** | A first-tier drawdown level that provides early indication of potential for an impact. |
| **Groundwater drawdown due to the Action** | Change in head relative to the background level arising from the Action. |
| **Groundwater limit[5] or drawdown limit[6]** | A groundwater level based limit not to be exceeded. |
| **MNES** | Matters of National Environmental Significance (water resources and the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin). |
| **Project Stage** | The development stage of the Project as described in the Approval Conditions. |
| **Trigger threshold** | A second-tier drawdown level that triggers response actions. |

[4] Taken from the bore trigger thresholds under the Queensland Water Act 2000.

[5] Refers specifically to Approval Condition 21(d).

[6] Refers specifically to Approval Condition 21(d).

# 2. ENVIRONMENTAL SETTING

The combined BGP tenements encompass an area of approximately 8,000 square kilometres of development and production land extending across the geological Bowen Basin from Glenden in the north to Middlemount in the south (Figure 1-1).

Land use in the study area has historically been dominated (approximately 92%) by cattle and sheep grazing (URS 2012). The Isaac and Mackenzie sub-catchment land use includes state forests, several national parks, agriculture and mining.

The following sections provide a brief overview of the BGP setting. Further detail is provided in the BGP EIS and SREIS.

## 2.1 Climate

The climate of the interior plains of the northern Bowen Basin is semi-arid and sub-tropical with summer-biased rainfall that averages between 550 and 650 mm/year. The majority of precipitation falls in the warmer months of the year (November to February).

Monthly climate statistics based on data collected from Bureau of Meteorology (BOM) operated stations located in the study area (Moranbah, Emerald Airport, and Blackwater Water Treatment Plant) were analysed as part of the EIS.

The study area has a mean maximum temperature range from 34°C in January to 24°C in July, and a mean minimum temperature range from 22°C in January to 10°C in July. Heat wave conditions can be expected between October and March and frosts between May and August.

February is statistically the wettest month and August and September the driest months. Long-term rainfall averages across the large basin-scale study area are similar from north to south, with an average annual rainfall of 615 mm recorded from 1972 to 2012 at Moranbah, and an average annual rainfall of 546 mm recorded from 1995 to 2010 at Blackwater.

Class A pan evaporation rates from the Emerald Airport BOM station range from 3.2 mm/day in June to 8.2 mm/day in December.

## 2.2 Hydrology

### 2.2.1 Drainage and river systems

The BGP tenements intersect two major river basins: (i) the Burdekin River Basin, which drains the Project area to the west to southwest and north, and (ii) the Fitzroy River Basin, which drains the Project area to the south and southeast (Figure 2-1). These large river basins contain a number of sub-catchments, namely the Suttor River (Burdekin), Bowen River (Burdekin), Isaac-Connors Rivers (Fitzroy), and Mackenzie River (Fitzroy) sub-catchments. The watershed between the Burdekin River and Fitzroy River basins is approximately located at the latitude of Burton (Figure 2-1).

ARROW ENERGY - BOWEN BASIN GAS PROJECT

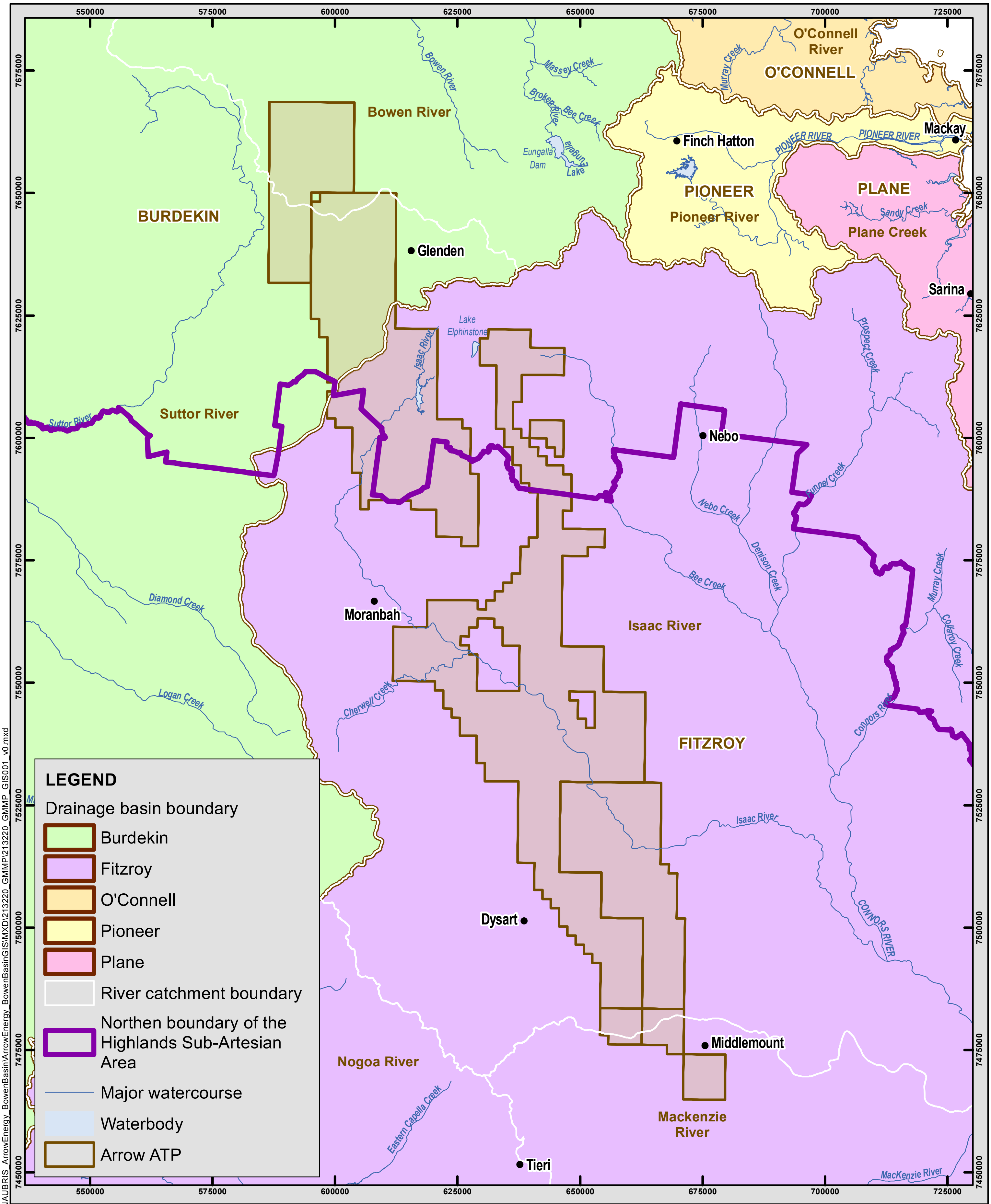



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**Figure 2-1** Surface catchments

**Source:**
Arrow Energy Pty Ltd
NRME

Date: 7/02/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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The plains of the Bowen Basin are bordered by the Peak and Denham Ranges to the west and northwest, and by the Broadsound Ranges and Connors Ranges to the east and northeast. The Connors Ranges are the main watershed with peaks up to approximately 1,220 m Australian Height Datum (m AHD) and an average altitude of approximately 600 m AHD. Flash flooding is most common along this easterly watershed; however, flash flooding can occur elsewhere as a result of summer-dominant storm activity (URS 2012).

The Fitzroy River Basin, south of Burton, contains most of the BGP tenement area; the bulk of which occurs in the Isaac-Connors River and Mackenzie River sub-catchments. The Isaac-Connors sub-catchment has the largest overlap with the contiguous Project area and it is approximately located between Burton and Middlemount. The main streams and tributaries in the Isaac-Connors sub-catchment include:

- Connors River and Funnel Creek, draining the wetter N-E part of the sub-catchment and the more northerly Bee, Nebo and Denison creeks; and
- The Isaac River, Philips and Stephens Creeks, which drain the drier western side of the sub-catchment.

The contiguous Project area south of Middlemount is situated in the Mackenzie River sub-catchment, which drains to the east. The Project area at Blackwater (ATP 2015) is also located within the Mackenzie River sub-catchment where it drains to the northeast. The Isaac-Connors and Mackenzie River sub-catchments combine and drain into the Fitzroy River at the junction of the Dawson and Mackenzie Rivers to the southeast (URS 2012).

Stream stages and flows have been recorded at approximately145 stream gauging stations in the study area. Stream flows, like rainfall, are summer dominant and highly variable with sporadic flood events brought on by summer-dominant storms. At the decadal time-scale, there is additional variability associated with moderate to strong droughts. Stream flow in the Project area is not spring fed as is generally true for the Bowen Basin.

Stream flows in rivers and creeks may be sustained for weeks to months after periods of heavy rainfall (SKM 2009) as the result of groundwater base flow (resulting from bank storage return flow), however during seasonal dry periods and droughts these rivers and streams stop flowing and become chains of waterholes (DERM 2009) with some larger pools being permanent (SKM 2009). While there are no naturally perennial rivers or streams in the study area, the Mackenzie River is artificially perennial or near-perennial due to the operation of dams and weirs (DERM 2009).

### 2.2.2 Lakes and wetlands

There are no known groundwater dependent wetlands within the BGP area. Lake Elphinstone, a listed Nationally Important Wetland, is located approximately 7 km east of the Project area to the south-east of Glenden (Figure 2-1) and represents a significant permanent natural surface catchment water feature that may be supported, in part, by groundwater.

The lake bed is described as consisting of unconsolidated Quaternary age alluvial fan and lacustrine sediments, and it is inferred that the lake may be supported or interact with shallow alluvial groundwater. While the lake bed itself is comprised of Quaternary age alluvium, this is underlain by sub-cropping Rewan Formation, and hence there is also potential for interaction with the intermediate groundwater system.

Lake Elphinstone is triggered under the EPBC Conservation Act (1999) as a Matter of National Environmental Significance (MNES) due to the potential occurrence of listed migratory species, including Latham's Snipe, Great Egret and Cattle Egret.

There are a number of other surface water bodies across the Project area; however, these correspond with major mining water storage or retention facilities and are not considered to be groundwater dependent.

## 2.3 Geology

### 2.3.1 Surface geology

The Bowen Basin covers an area of approximately 200,000 km$^2$, and spans over 600 km from Collinsville in the north to Rolleston in the south. It contains a clastic Permo-Triassic sedimentary sequence which attains a maximum thickness of 9,000 m in the Taroom Trough.

Surface geology across the Project area is diverse (Figure 2-2). Approximately half of the Project area is covered by Late Tertiary and Quaternary age unconsolidated sediments. This cover includes the Isaac River alluvial sediments, with thicknesses of between 10 to 50 m. The characteristics of the superficial Quaternary age alluvium reflect the nature of the source rocks, weathering, transport, and depositional conditions. Floodplain alluvium comprises poorly sorted sediments, including poorly consolidated sand, silt, clay and minor gravel.

The Tertiary age sediment cover includes thick, clay-rich laterite, a result of the laterisation of Permian age units during the Tertiary. In addition, Tertiary aged infill includes palaeochannel deposits and basalt flows, providing surficial cover across the Project area. The major Tertiary age formations mapped include the Duaringa and Suttor Formations.

Outcrops of consolidated formations are confined mainly to the northern portion of the Project area. The consolidated formations represented in surface outcrops include:

- Late Permian age Blackwater Group in the northernmost and north-eastern portion of the Project area:
    - Rangal Coal Measures (RCM)
    - Fort Cooper Coal Measures (FCCM)
    - Moranbah Coal Measures (MCM)
- Mid-Triassic age Moolayember Formation and Clematis Sandstone in the north-central portion of the Project area.
- Early Triassic age Rewan Group in the northern portion of the Project area.

The stratigraphy of the Bowen Basin is represented in cross-section underlying ATP1103 (Figure 2-3) and the MGP development area (Figure 2-4). Further discussion is provided in the context of hydrostratigraphy in Section 2.4.1.

### 2.3.2 CSG target formations

Late Permian age Blackwater Group formations are the CSG targets in the Bowen Basin, as summarised below.

**Moranbah Coal Measures**

The MCM form part of the Late Permian age Group III coals deposited in the third and final Bowen Basin formational phase, and includes coal, sandstone, siltstone and mudstone, and averages from 250 m to 300 m thickness. The formation is characterised by several laterally persistent, relatively thick coal seams interspersed with several thin minor seams. The predominant target seams in order of importance are the GM, P and QA2 seams. The typical thicknesses of these seams are:

- Q seam - split into three main plies, the QA1 (3.5 m thick), QA2 (3 m thick), and QB (1.75 m thick).
- P seam - consists of 3 plies and averages about 5 m in total thickness.
- GM seam - average 5 m thickness but splits and thins towards the southeast.
- GML seam - present in relatively small local pockets, with thicknesses up to 6.5 m.

**Fort Cooper Coal Measures**

The FCCM conformably overlies the MCM and is approximately 400 m thick. The FCCM is characterised by up to seven formations (6 to 60 m thick) rich in carbonaceous mud and thin coal seams, and its distinctive tuff beds. These formations are interbedded with 10 to 30 m thick siltstone and sandstone sequences.

**Rangal Coal Measures**

The final Late Permian age coal deposition phase in the Bowen Basin resulted in formation of Group IV coals including the RCM. Group IV coals were deposited under fluviatile, lacustrine and paludal conditions and comprise sandstone, calcareous sandstone, carbonaceous shale, mudstone, coal, tuff, and concretionary limestone.

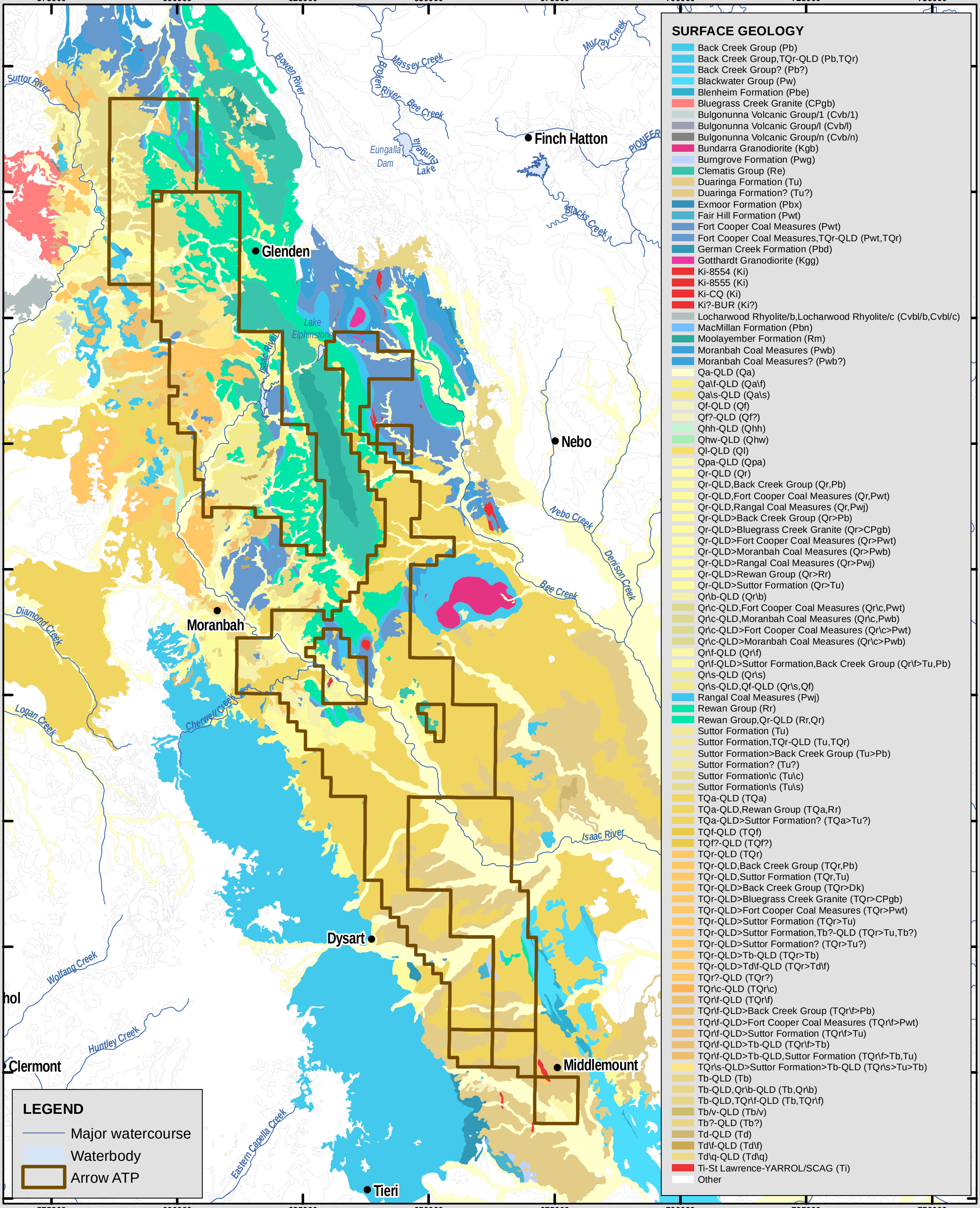


Figure 2-2 Surface geology

Source:
Arrow Energy Pty Ltd
DNRM (March 2017)

Date: 12/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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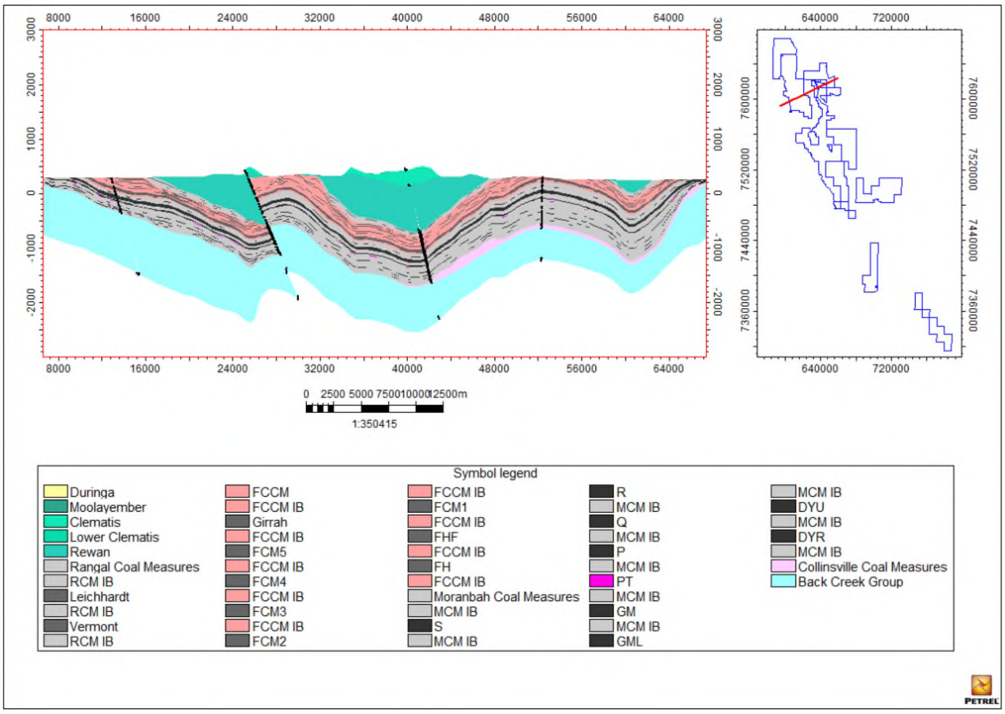


**Figure 2-3 Stratigraphy underlying ATP1103**

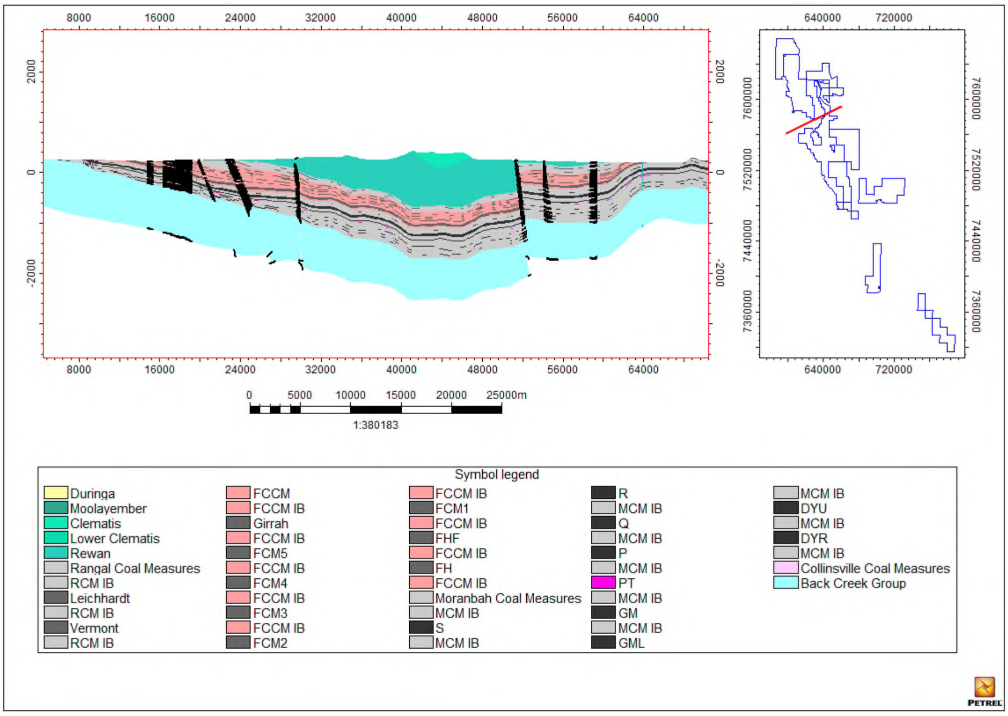


**Figure 2-4 Stratigraphy underlying MGP area**

## 2.4 Hydrogeology

### 2.4.1 Hydrostratigraphy

The hydrostratigraphic units relevant to the Project are classified in Table 2-1. The Middle Permian age Back Creek Group comprises sandstone, siltstone, shale and minor coal and is considered a semi-pervious lower boundary for groundwater flow to the overlying Blackwater Group coal measures. The Blackwater Group is overlain by the Mimosa Group, of which only the Rewan Formation occurs extensively in the middle of the basin.

The Rewan Formation ranges up to 800 m thick across the Bowen Basin (in the centre of deposition of the basin) with a typical thickness of approximately 300 m in the Project area. This formation is a semi-pervious barrier to vertical groundwater flow that acts as a confining unit across the Project area and is a basal confining layer of the Great Artesian Basin (GAB).

The Clematis Sandstone (a major GAB aquifer) and the Moolayember Formation (a GAB confining unit) occur as elevated outcrops in the Project area southeast of Glenden, and near the Project area southeast of Blackwater.

The Triassic and Permian age sedimentary successions are overlain by Tertiary age formations including isolated basaltic lava outcrops and areas of Suttor Formation and Duaringa Formation. Extensive Quaternary age alluvial deposits also occur along rivers, creeks and floodplains within the Project area.

**Table 2-1 BGP regional hydrostratigraphy**

| Age | Stratigraphic unit | Lithology | Typical thickness (m) | Hydrogeologic classification |
|---|---|---|---|---|
| **Quaternary** | Alluvium | Clay, silts, sand, gravel, floodplain alluvium | 15-35 | Unconfined (resource aquifer) |
| **Tertiary** | Suttor Formation | Clay, silt, sand, gravel, colluvium, fluvial and lacustrine deposits including cross-bedded quartz sandstone, conglomerate, claystone. | 0-120 | Confining unit |
| | Basalt | Olivine-rich weathered basalt remnants, moderately weathered and fresh basalts | 0-80 | Unconfined (resource aquifer); fractured rock aquifer |
| | Duaringa Formation | Mudstone, sandstone, conglomerate, siltstone, oil shale, lignite and basalt | 0-50 | Confining unit |
| **Triassic** | Moolayember Formation | Mudstone, lithic sandstone, interbedded siltstone, mudstone, sandstone and thin coal seams. | 0-200 | Confining unit - GAB |
| | Clematis Sandstone | Cross-bedded quartz sandstone, some quartz conglomerate, minor reddish brown mudstone. | 0-300 | Confined GAB aquifer |
| | Rewan Formation | Green lithic sandstone, pebble conglomerate, red and green mudstone, siltstone | 200-800 | Confining unit – base |

| Age | Stratigraphic unit | Lithology | Typical thickness (m) | Hydrogeologic classification |
|---|---|---|---|---|
| | | | | hydrogeological GAB |
| Late Permian | Rangal Coal Measures (RCM) and equivalents | Coal seams, carbonaceous shale and mudstone, tuff, siltstone and mudstone | 25-200 | Confined aquifer (coal) and confining unit (interburden) |
| | Fort Cooper Coal Measures (FCCM) and equivalents | Coal, brown and green sandstone, conglomerate, carbonaceous shale, tuff | 100-600 | Confined aquifer (coal) and confining unit (interburden) |
| | Moranbah Coal Measures (MCM) | Coal, sandstone, siltstone, mudstone, carbonaceous mudstone | 100-700 | Confined aquifer (coal) and confining unit (interburden) |
| Middle Permian | Back Creek Group | Sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite | 400-1200 | Confining unit |

### 2.4.2 Aquifer recharge

The dominant types of aquifer recharge in the Project area are (URS 2012):

- Diffuse and localised recharge of surficial aquifers (unconfined) that is rapid and responsive to rainfall patterns, and
- Diffuse recharge of confined aquifers that is slow and unresponsive to rainfall patterns.

Diffuse recharge is that rainfall recharge which occurs uniformly over the landscape, whereas localised recharge occurs near drainage lines, rivers and creeks.

### 2.4.3 Influence of faults and folds

A complex array of faults, with roughly north-west to south-east strike, is present in the Bowen Basin (URS 2012). The BGP EIS reports that the regional tectonic stress is mostly compressive such that thrust faulting and folding are dominant types, and furthermore that these faults and folds are 'tight' and act as hydraulic barriers that will 'compartmentalise' groundwater.

Since preparation of the EIS, further assessment of the nature of faulting within the Project area was undertaken, including consideration of a review of published and mapped faulting and other structures within the Bowen Basin. In addition, a study of the hydraulic properties of faults, including models for predicting the permeability of faults, was undertaken and documented in Appendix A of the SREIS (Coffey 2014).

Based on these assessments, compelling evidence was identified that faults in the Bowen Basin are generally of low permeability both parallel to, and normal to, the fault planes. This finding is consistent with and supported by other important lines of evidence and is presented in detail in Section 5.1 of the SREIS (Coffey 2014). In brief, this evidence includes:

- Arrow operational field evidence;
- Expected fault sealing, limited re-activation, and the geological age of faulting in the Bowen Basin;
- Lack of neotectonic activity in the Bowen Basin;
- The compressive Bowen Basin stress regime; and
- The expected low permeability of fault core rock.

A numerical groundwater modelling study was also undertaken, referred to in Section 6.5.2 of the Coffey (2014) report, to consider the effect of permeable faults as pathways to groundwater flow, should such features occur. The modelling results demonstrated that faults in the Bowen Basin behave as barriers to groundwater flow along and across fault planes near CSG wells. It was concluded that in the event that a fault zone or weathered dyke represents an existing preferential pathway for flow, these features would only represent a minor contributor to propagation of drawdown impacts across formations.

The occurrence and distribution of faulting is further discussed in Section 4.2.1 in the context of preferential pathways and the potential risk to receptors from the Action.

### 2.4.4 Groundwater use

Authorisation from DNRME is required to take groundwater in sub-artesian areas declared under the Water Act, Water Resource Plans, and the Water Regulation 2002. The majority of the Bowen Basin, south of Nebo, falls within the Highlands Sub-Artesian Area which is a declared groundwater management area. Stock and domestic bores within the Highlands Sub-Artesian Area do not require a DNRME water licence whilst other applications, including irrigation, industrial, mining and commercial do require licenses.

Within the study area, there are a relatively small number of licensed groundwater entitlements, which relate to use for industrial purposes to the north-east of Moranbah.

DNRME maintains a database of registered and licensed groundwater users, and registered monitoring bores. Arrow also maintains a database of landowner bores. Figure 2-5 presents the locations of registered and licensed water supply bores across the study area. Where information concerning the screened lithology of the bore was available, a geological unit has been assigned to the bore.

According to the BGP EIS (URS 2012), the principal source of groundwater for extractive purposes is alluvial aquifers, with minor sources including the basalt, sedimentary rocks and coal of the Blackwater Group and sedimentary rocks of the Back Creek Group (in the west of the basin where the Back Creek Group subcrops or outcrops).

ARROW ENERGY - BOWEN BASIN GAS PROJECT

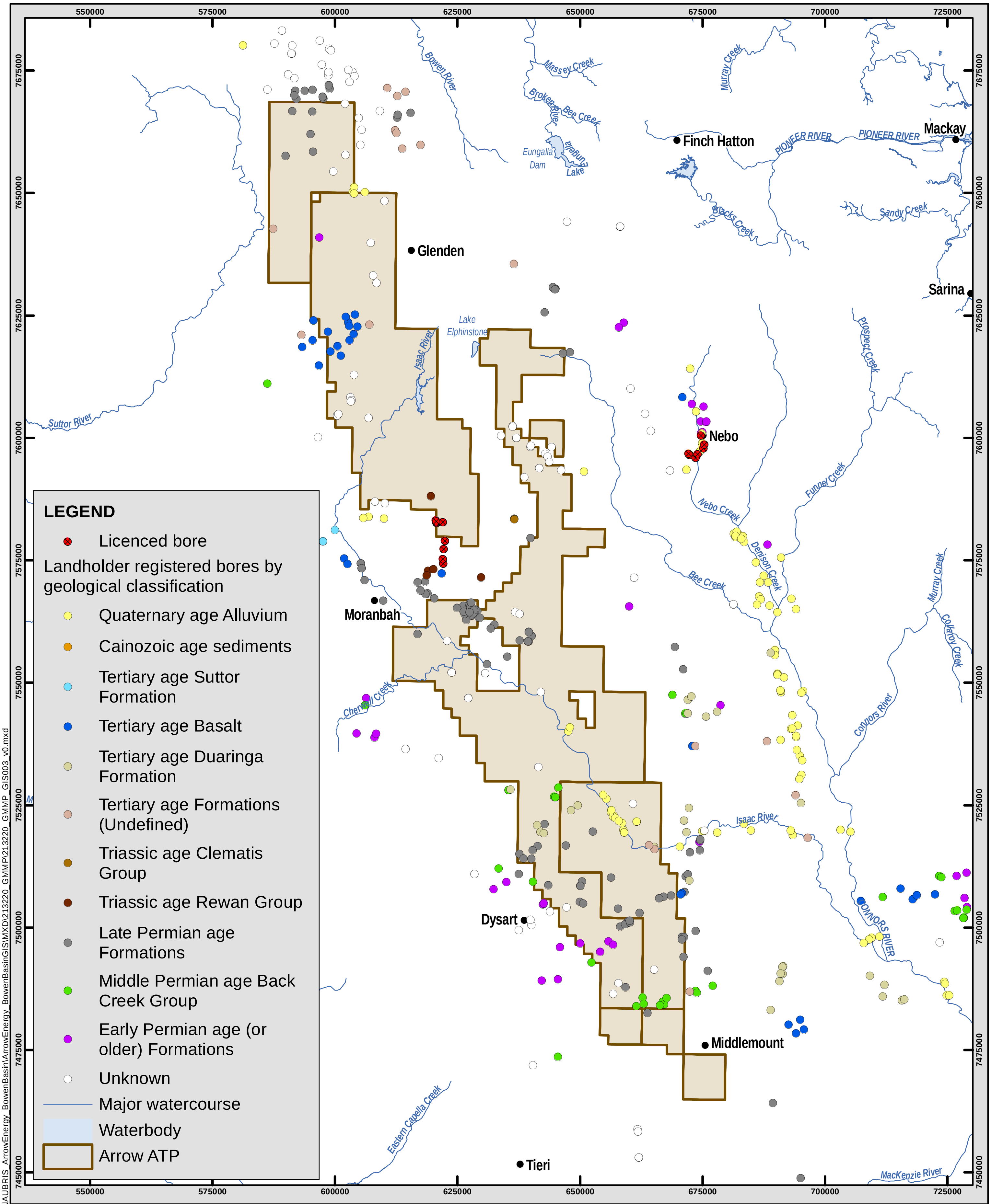


Figure 2-5 Water supply bores

Source:
Arrow Energy Pty Ltd

Date: 12/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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### 2.4.5 Groundwater dependent ecosystems

The identification of landscapes that may contain groundwater dependent ecosystems (GDEs) is documented in detail in the BGP EIS/SREIS. Types of GDEs that have been considered during the development of the GMMP include:

- Surface expression GDEs: springs, baseflow contribution to watercourses and groundwater dependent wetlands, including wetlands classified as a MNES under the EPBC Act (1999); and

- Non-spring GDEs: vegetation dependent on the subsurface presence of groundwater (i.e. deep-rooted vegetation), referred to in this document as terrestrial GDEs.

As concluded in the EIS (URS 2012), there are no known or anticipated fault controlled springs in the BGP area. GDEs in the project area, where present, will be dependent on the watertable aquifer.

The SREIS (Coffey 2014) did identify a range of actual and potential GDEs across the project area. To further refine these locations, a site visit was conducted in November 2015 to inspect locations identified as having the potential to support GDEs. Following the site visit, a detailed analysis of the potential for GDEs to be present across the project area was completed (Coffey 2015). The findings of the study are presented in the Groundwater monitoring network memorandum (Appendix D) and are summarised below:

- Depth to groundwater data and mapped vegetation communities indicate riparian vegetation along major watercourses may be supported by groundwater on a facultative basis (i.e. use groundwater but capable of functioning without it). Within the Project area this includes the following watercourses:
    - Upper Isaac River
    - Suttor Creek
    - Cherwell Creek
    - Phillips Creek

- Terrestrial vegetation away from immediate riparian environments is not considered supported by regional groundwater systems. This conclusion is based on:
    - Available depth to groundwater information and known rooting depth characteristics of the vegetation in these areas.
    - Site observation which includes rapidly diminished vegetation stature with distance from watercourse channels and/or as depth of the alluvial soil profile over basement rock diminishes.

- Groundwater baseflow contribution to stream reaches does not occur. This is supported by the ephemeral nature of all streams in the project area, rainfall correlated flow duration and depth to groundwater exceeding channel incision depth. Release of bank storage, which will occur following recession of surface flows, is not considered to represent groundwater baseflow contribution.

It is acknowledged that the riparian environments (i.e. terrestrial GDEs) described above as being potentially dependent on groundwater do not necessarily represent all groundwater dependent riparian environments across the Project area. Rather, they represent what has been identified to date. Where impact to the watertable aquifer near a watercourse is predicted by numerical modelling, the riparian environment should be adequately assessed to identify whether similar characteristics exist that indicate the potential for groundwater dependence.

The locations of the identified or likely GDEs considered for this GMMP, based on the Coffey (2015) field reconnaissance and desk study are presented in Figure 2-6. The known and potential GDEs (attributed as having high or moderate potential for groundwater dependency), as mapped in the Atlas of Groundwater Dependent Ecosystems are a publicly available data set developed under the National Water Commission's Raising National Water Standards Program. These GDEs are also illustrated in Figure 2-6.

## 2.5 Cultural and spiritual sites of significance

Cultural heritage studies were carried out to support the BGP EIS. Four significant sites with potential association with groundwater were identified based on their description as 'wells'. Three of these sites are located within the Project area (Figure 2-6).

# ARROW ENERGY - BOWEN BASIN GAS PROJECT

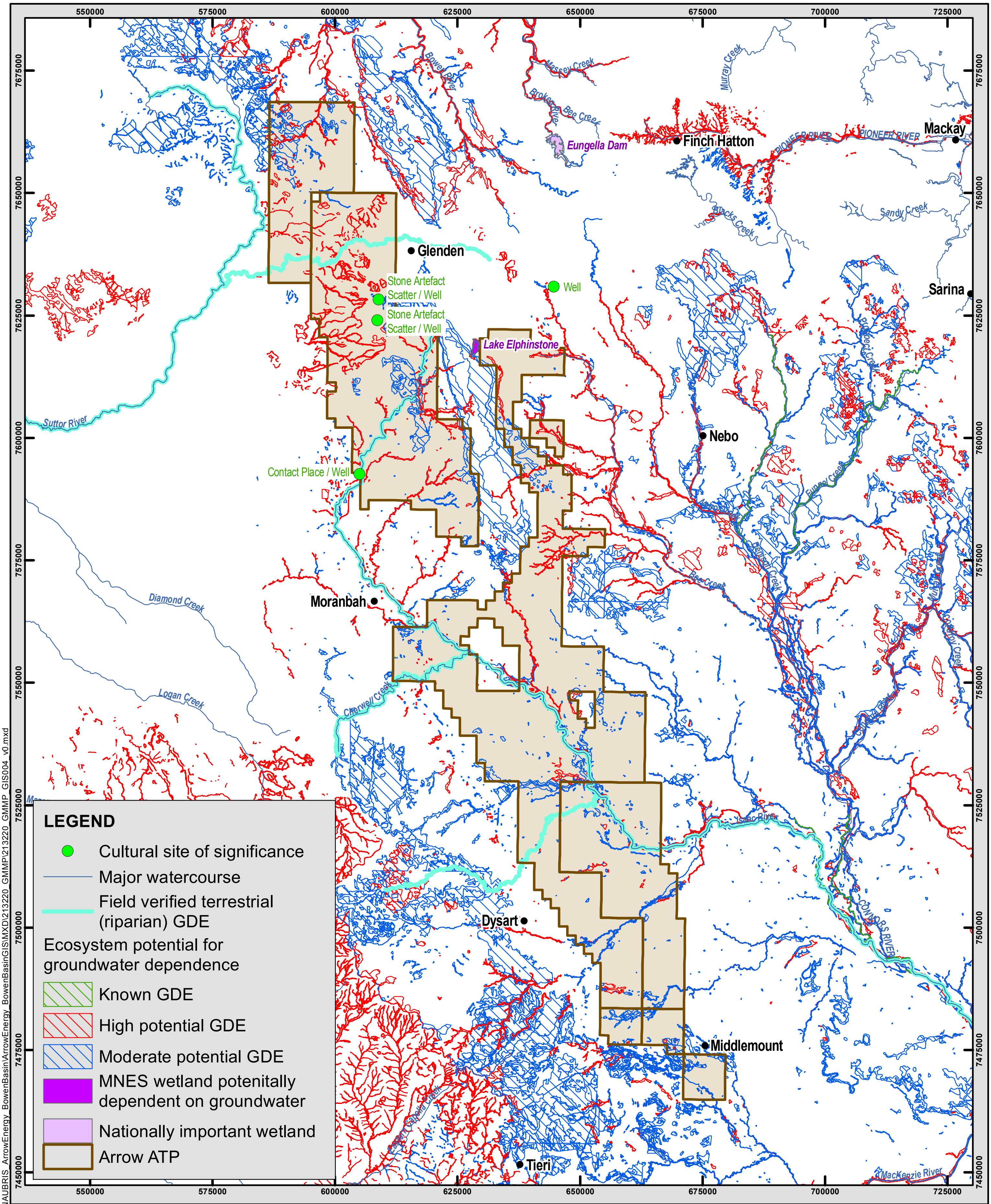


**Figure 2-6** **Identified and mapped GDEs and sites of cultural and spiritual significance**

**Source:**
Arrow Energy Pty Ltd
BOM GDE Atlas (June 2018)
URS (2013)

Date: 4/03/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N

arrow energy
go further



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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# 3. GROUNDWATER MODELLING

Numerical groundwater modelling was used as a basis for predicting impacts due to BGP CSG production. Previous groundwater modelling adopted for the BGP supported both the SREIS and the 2016 Underground Water Impact Report (UWIR). The groundwater model was updated in 2018 which is the basis for the Project Stage 1 GMMP. A detailed review of the current and previous groundwater modelling is provided in Appendix C and summarised below.

## 3.1 Introduction

Table 3-1 provides a summary of the modelling over time that has been undertaken. These models are discussed in Appendix C and briefly summarised below.

**Table 3-1 Evolution of BGP modelling**

| FDP | Total water production (GL) | Numerical model | Comments |
|---|---|---|---|
| **EIS** | 274 | 2012 Northern Bowen Basin (NBB) model (Ausenco-Norwest) | Modflow-Surfact numerical model |
| **SREIS** | 153 | 2012 NBB model (Ausenco-Norwest) | Modflow-Surfact numerical model |
| **UWIR** | 116 | 2016 Bowen UWIR model | Modflow-Surfact numerical model |
| **Project Stage 1 GMMP** | 82 (1) | 2018 GMMP model | Modflow-USG numerical model |

***Note:***
*(1) Project Stage 1 GMMP FDP including Mavis Downs and Red Hill Central development*

## 3.2 SREIS groundwater modelling

Numerical modelling for the SREIS FDP was previously undertaken by Ausenco-Norwest in 2012, using Modflow-Surfact code. This model (the 2012 NBB Model) was a Class-1 confidence level model, for predicting long-term impacts of the BGP on the generally low-value aquifers of the Northern Bowen Basin (Ausenco-Norwest 2012). The simulations undertaken allowed for BGP production until 2072, with an additional 50 years post-production recovery time.

CSG activity was simulated in this model by using the Modflow WEL package to represent associated water extraction.

A peer review of the model (CDM-Smith 2013) found that the model conforms to best industry practice, was fit for purpose, and fulfilled the appropriate portions of the Australian Groundwater Modelling Guidelines.

**Calibration and predictions**

Steady state and transient calibrations were undertaken and included data for the depressurisation of the MGP.

Predictive simulation included the calibrated base case that incorporated only BGP production. This was simulated both with and without discrete fault representation. A cumulative case was also simulated that included the BGP, MGP and third party (bore) users. Monte Carlo analysis was also undertaken to investigate model uncertainty (Ausenco-Norwest 2013).

The base case scenario modelled in the SREIS indicated that, as a result of the BGP, areas of drawdown exceeding 2 m would primarily remain within Arrow tenements, would be closely associated with CSG well distribution, and would occur mainly within the target CSG formation. Except for a single cell in the Blackwater ATP, no modelled drawdown exceeding 2 m occurred in Layer 1 of the model following the 50 year post-production recovery period (Ausenco-Norwest 2012).

## 3.3 2016 UWIR groundwater modelling

Pursuant to section 370 of the Water Act 2000, the Department of Environment and Heritage Protection (DEHP) directed Arrow to submit a single UWIR for its relevant Bowen Basin Petroleum Leases, to provide information on the potential decline in water levels in aquifers due to the taking of water during CSG production and testing.[7]

To support the 2016 UWIR, the 2012 NBB Model was updated with a revised FDP (refer Table 3-1). However, the set up and calibration of the model (hereafter referred to as the 2016 Bowen UWIR Model) was unchanged from the SREIS Model.

The model simulated forecast production within the MGP Area from 2016 to 2025, and the BGP UWIR FDP from 2019 to 2049. Simulated CSG production included:

- Historical production and production testing in PLs 191, 196, 223, 224, and ATPs 1103, 1031, and 742; and
- Forecast production wells in PLs 191, 196, 223, 224, and production wells for the BGP.

## 3.4 2018 GMMP groundwater modelling

AGE was engaged by Arrow to undertake revised numerical groundwater modelling to assess the regional scale groundwater impacts of the MGP, and the updated Project Stage 1 GMMP FDP (refer Section 1.2.1). The revised model incorporated recent developments in model code and processing.

[7] This contrasts with the Surat Basin UWIR, where the Office of Groundwater Impact Assessment (OGIA) are directed to prepare a UWIR that encompasses multiple CSG developers.

The 2018 update builds on the previous NBB modelling undertaken by Ausenco-Norwest and Arrow, by incorporating a revised unstructured grid mesh under MODFLOW-USG code and updated calibration. The model domain was identical to the previous NBB model. The flexibility of the revised mesh under MODFLOW-USG enabled a significant improvement in resolution of model features in the MGP area (refer Figure 3 in Appendix C).

Model layer elevations were based on the Ausenco-Norwest regional geological model (Ausenco-Norwest 2012) however an increased layer count resulted from splitting the original layer 18 (lumped Collinsville Formation-Back Creek Group) into 5 layers (2 coal seams, 2 interburden layers, and a basal Permian layer).

The approximate following cell dimensions were adopted:

- MGP area: 200 m hexagonal cells aligned to in-seam wells;
- BGP area: 1500 m rectangle cells (centred on CSG wells);
- Faults: 1000 m x 1000 m centred on either side of fault trace;
- Surficial aquifers: 1000 m x 1000 m centred either side of aquifer extents; and
- Major drainage systems: 500 m x 500 m centred along river lines near to the MGP.

**Boundary conditions and parameters**

Boundary conditions were adopted from the previous calibrated 2012 NBB Model.

Aquifer parameters from the calibrated 2012 NBB Model were translated into the new mesh as closely as possible, with the exception of coal seam hydraulic conductivity.

To better represent the depth-decline relationships for the coal seams, an approximated average depth-decline equation was applied to the groundwater model, on a cell-by-cell basis for the coal seams in the MCM and RCM. Figure 4 in Appendix C presents the depth-decline equations for the MCM (as derived from the BGP area production tests) compared with the 2012 NBB Model representation, and the 2018 model representation.

**Water production cases**

Three water production cases were considered, and these provided the basis for the simulations run under the updated model (AGE 2018). All three production scenarios included the existing MGP and comprised the following cases:

- Scenario 0: Historical MGP production only (2003 to Dec 2017)
- Scenario 1: Historical MGP + forecast MGP production to 2030
- Scenario 2: Historical MGP + forecast MGP production + BGP

In addition to the above production scenarios, simulations were run with:

- No Arrow CSG production (referred to as the ‘NC’ scenario), and
- CSG production matching the 2016 UWIR FDP (referred to as the ‘UWIR’ scenario – refer to Appendix C for more information).

Figure 3-1 presents the model wells on the updated model domain and shows the starting time for each production area in Scenario 2.

**Model calibration**

Initial calibration included a pre-development steady-state simulation using available groundwater level data, comprising a total of 482 monitoring points (AGE 2018).

The transient calibration utilised time-series data for the period 2000 to 2017, from 47 Arrow time-series monitoring locations (AGE 2018). Within the calibration dataset, frequency of observations varies between bores and therefore the number of available records for each bore also varies. To overcome this, observation data was weighted to normalise the error on a bore by bore basis (AGE 2018).

In addition, because insufficient information describing mining-related water extraction is available, bores potentially impacted by mining in the region had a reduced weighting, to minimise bias both in the calibration and in the uncertainty analysis, thereby minimising the potential to erroneously over-estimate impact due to CSG water extraction.

Pilot points were also used to help calibrate the model, and to explore uncertainty for the predictive analysis. A scaled Root Mean Square (RMS) error of 3.8 % was reported for the calibrated model (AGE 2018).

**Predictions**

Predictions of groundwater impact (i.e. drawdown) underpinning the monitoring network are based on the calibrated model case. This model version is ‘parameter adjusted’ to provide a close model fit to the available calibration data set, and therefore represents a plausible estimate of the ‘real world’ parameter distribution in the BGP area. Adoption of the calibrated realisation, as opposed to the 95$^{th}$ percentile ($P_{95}$) model version (i.e. used for identifying exceedances in the EWS (Section 5.1.3)), also helps to ensure that monitoring locations are not positioned at unreasonable distances from production areas. Monitoring points located at greater distance from the production areas would have limited ability to provide early warning data, due to responses arriving at a late stage following commencement of production. Furthermore, monitoring points sited in closer proximity to CSG development activities will provide useful water level data for the checking of model outputs and for future model calibrations, in contrast to more distal monitoring bores which may only detect minor or no drawdown responses.

Drawdown is presented for a range of scenarios in AGE (2018) including Scenarios 0, 1 and 2.

All drawdown represents composite maximum drawdown.[8] To represent maximum drawdown within the MCM and RCM, drawdown from each seam within the associated coal measure was combined and presented as a spatial composite of the maximum drawdown (AGE 2018).

The Immediately Affected Area (IAA) of an aquifer is the area within which water levels are predicted to decline due to CSG water extraction by more than the trigger threshold within three years of the consultation day for the UWIR report. The Long-term Affected Area (LAA) is defined by groundwater drawdown greater than 5 m at any time in the future.

Figure 3-2 and Figure 3-3 show the extent of the IAAs and LAAs respectively for the MCM and RCM.

IAAs and LAAs were not predicted for any other consolidated or unconsolidated formation (Arrow 2016 & 2019). Table 3-2 provides a summary.

**Table 3-2 Predicted IAA and LAA by formation (Scenario 2)**

| Formation | LAA present | IAA present | Figure |
|---|---|---|---|
| **Moranbah Coal Measures** | Yes | Yes | Figure 3-2 |
| **Rangal Coal Measures** | Yes | Yes | Figure 3-2 |
| **Alluvium – model layer 1** | No | No | Figure 3-5 |
| **Regolith – model layer 2** | No | No | Figure 3-6 |

The results show that drawdown greater than 5 m extends a maximum of 7.2 km from production within the MCM, which is comparable to drawdown simulated using the UWIR pumping rates (Scenario UWIR) (AGE 2018). In general, the extent of drawdown has contracted from the 2016 UWIR predictions, primarily due to a more refined CSG production field (AGE 2018).

Figure 3-4 presents the time to maximum drawdown (Scenario 2) for the MCM and indicates the year when maximum drawdown under the cumulative case is likely to occur.

Figure 3-5 and Figure 3-6 present the maximum drawdown (Scenario 2) in the alluvium and regolith (layers 1 and 2). It shows that the drawdowns in layer 1 are very limited and generally lower than 0.2 m. In layer 2 there is an isolated patch of saturated drawdown in the surficial systems, east of the BGP near Glenden, of up to 10 m that is considered a local model artefact due to layering and lack of lateral connection with discontinuous sections of layer 2.

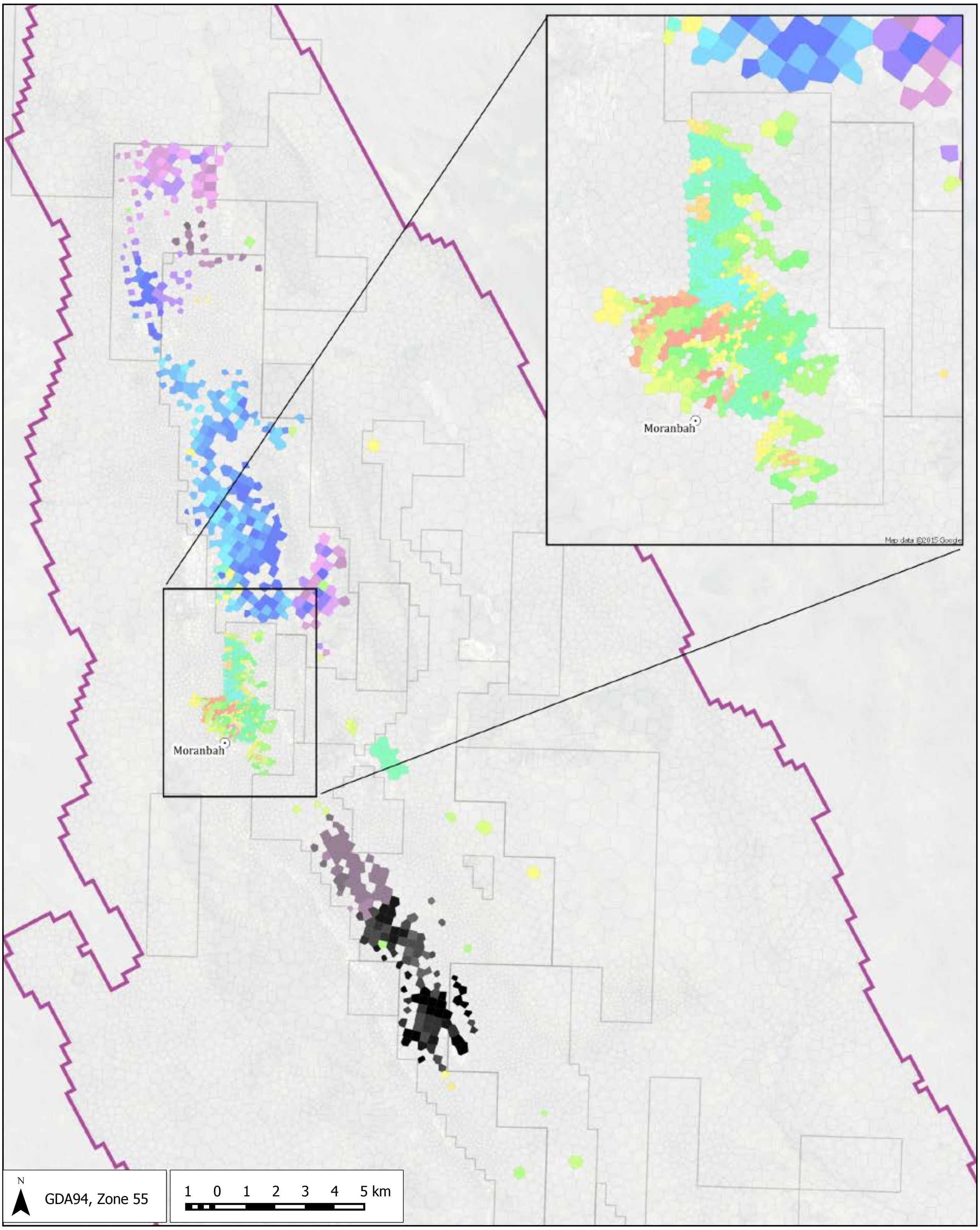
[8] Drawdown is queried across the entire simulation period and the maximum drawdown recorded for each model cell. Hence the drawdown represents a composite result from the entire simulation

## 3.5 Uncertainty analysis

The null-space Monte Carlo (NSMC) analysis method was used to quantify uncertainty in predicted impacts, through multiple model simulations with differing parameter realisations, and accepting only results from the realisations that could be adequately calibrated.

A total of 350 model realisations were created, with differing values of the non-unique pilot point parameters. Model realisations were constrained using calibration datasets. Realisations that failed to converge or could not achieve adequate calibration were rejected. The process achieved 208 successful model realisations, the output from which was analysed to provide a statistical distribution of the regional model predictions (AGE 2018).

Figures 12 and 13 in Appendix C presents the composite drawdown (Scenario 2) from all realisations assessed in the uncertainty analysis, expressed as the $5^{th}$, $50^{th}$ and $95^{th}$ drawdown percentile for the MCM and RCM (cumulative case).




**LEGEND**

- Populated place
- 2018 AGE mesh
- 2018 AGE model outline

WEL start (year)

2003, 2004, 2005, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023, 2024, 2030, 2031, 2032, 2034, 2035, 2036, 2038, 2039, 2040, 2042, 2043, 2044, 2046, 2047, 2048, 2050, 2051, 2052, 2054, 2055, 2056

**Figure 3-1** **Model domain and production areas**

**Source:**
Australasian Groundwater and Environmental Consultants Pty Ltd, 2018

Date: 19/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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ARROW ENERGY - BOWEN BASIN GAS PROJECT

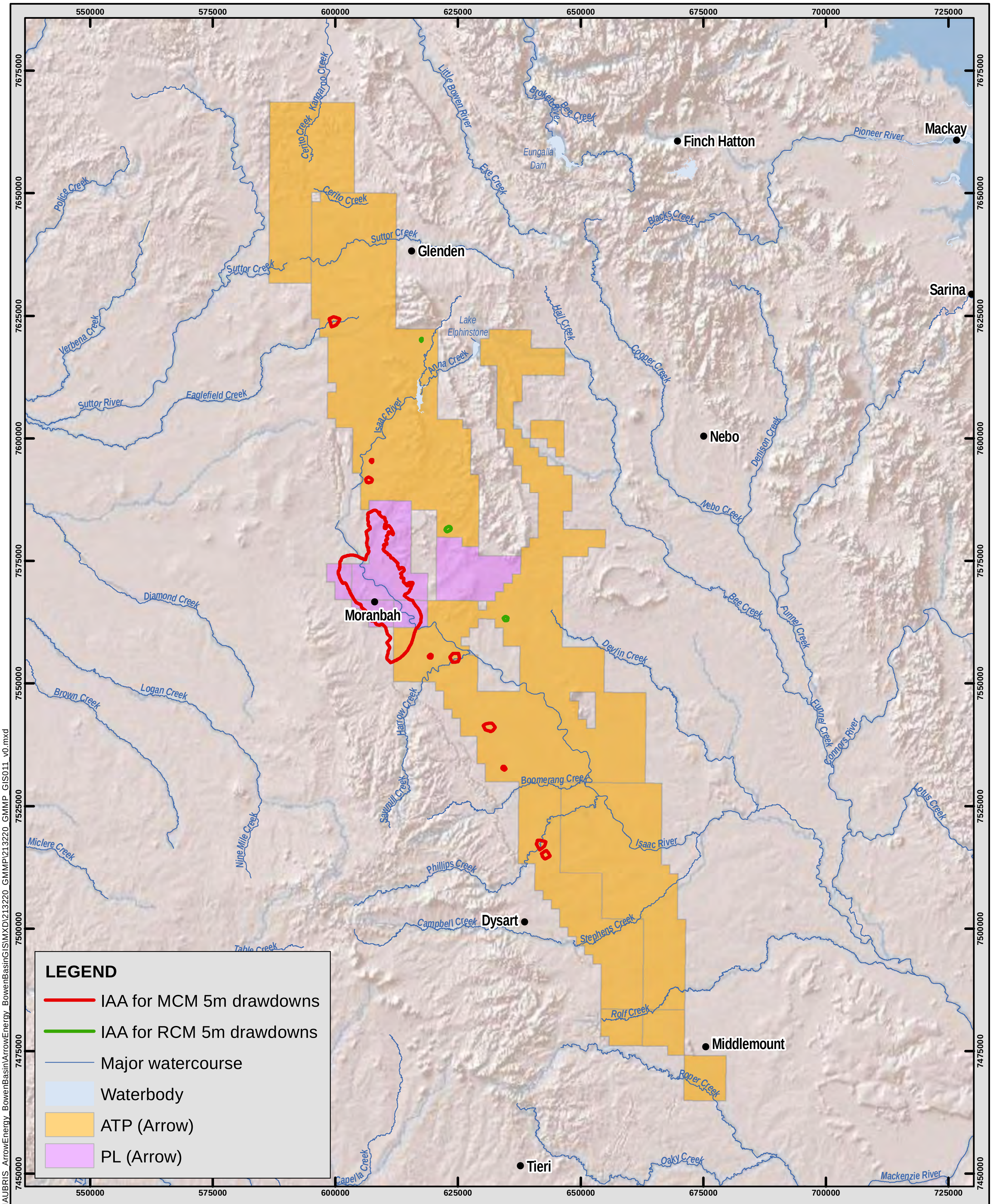


Figure 3-2 Predicted extent of IAAs

Source:
Arrow Energy Pty Ltd
DNRM

Date: 5/03/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N

arrow energy
go further



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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ARROW ENERGY - BOWEN BASIN GAS PROJECT

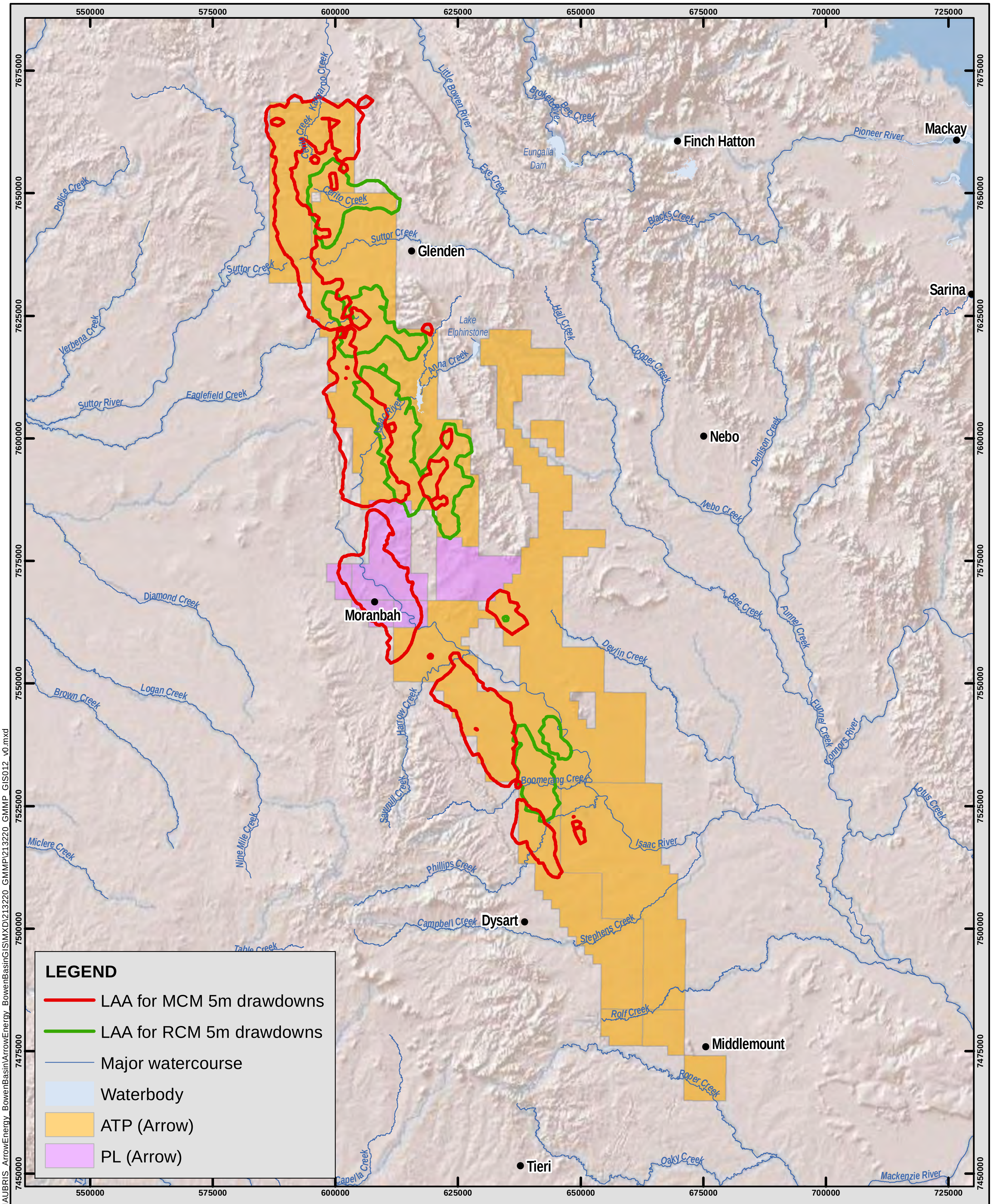


Figure 3-3

Predicted extent of LAAs

Source:
Arrow Energy Pty Ltd
DNRM

Date: 5/03/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N

arrow energy go further



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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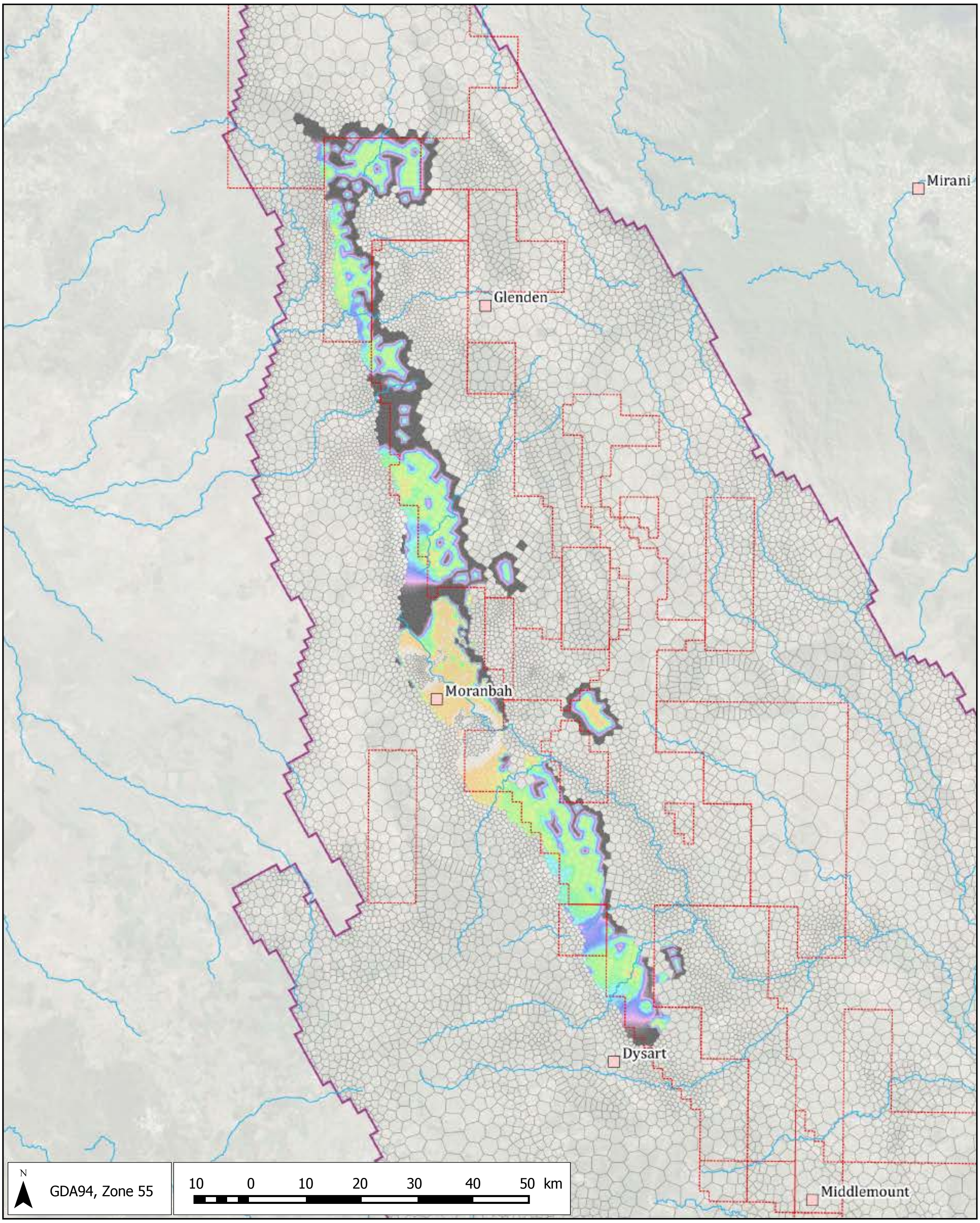


**LEGEND**

| | | Year | |
|---|---|---|---|
| Populated place | | 2018 | 2118 |
| Petroleum exploration lease | | 2028 | 2143 |
| Model mesh | | 2053 | 2163 |
| Model boundary | | 2078 | 2183 |
| Major drainage | | 2098 | |
| drawdown_L15_timing_ct | | | |

**Figure 3-4** Time to max drawdown GM Seam - Moranbah Coal Measures

**Source:**
Australasian Groundwater and Environmental Consultants Pty Ltd, 2018

Date: 19/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

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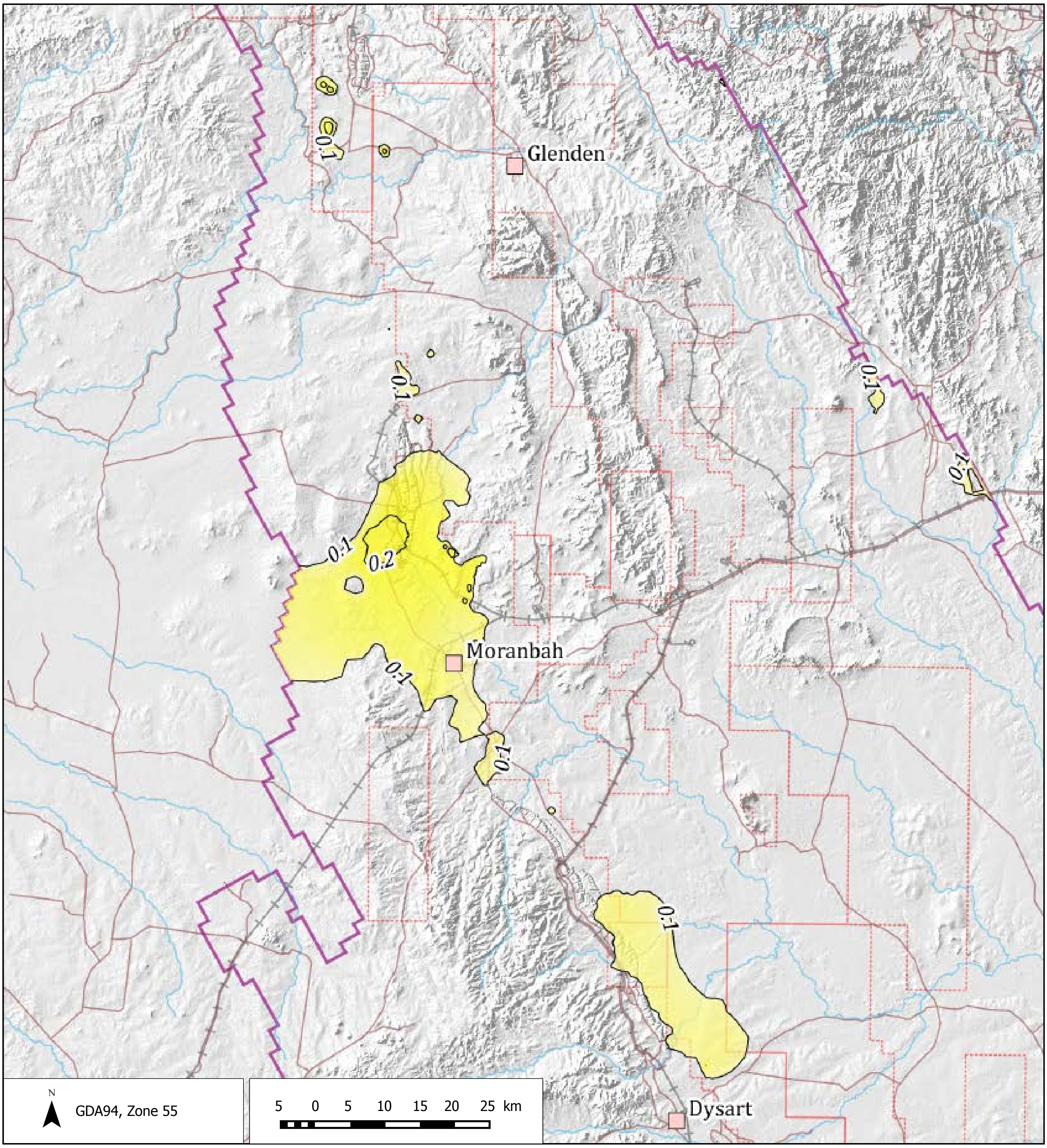


**LEGEND**

- Populated place
- Petroleum exploration lease
- Model boundary
- Major drainage
- Road
- Rail

Drawdown (m)

| | |
|---|---|
| 0 | 20 |
| 0.1 | 50 |
| 0.2 | 100 |
| 1 | 200 |
| 10 | 500 |

**Figure 3-5** **Max drawdown in the alluvium (Scenario 2 - layer 1)**

**Source:**
Australasian Groundwater and Environmental Consultants Pty Ltd, 2018

Date: 19/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

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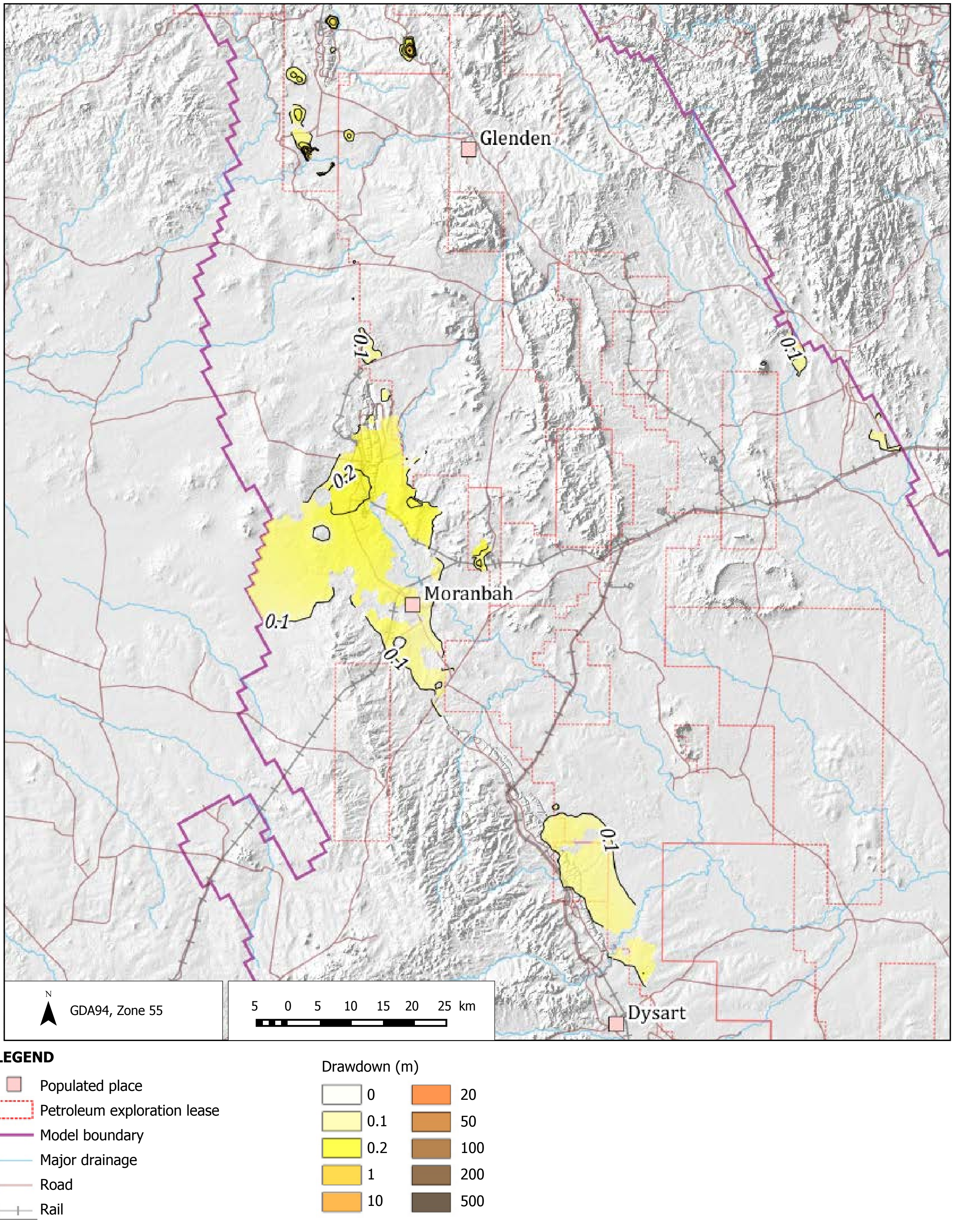


**Figure 3-6** **Max drawdown in the regolith (Scenario 2 - layer 2)**

**Source:** Australasian Groundwater and Environmental Consultants Pty Ltd, 2018

Date: 19/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich



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# 4. MONITORING NETWORK AND PROGRAM

## 4.1 Baseline groundwater monitoring assessment

To assist in the development of the Project Stage 1 GMMP and its implementation, a baseline groundwater monitoring assessment was conducted to enable the background groundwater level and quality of key aquifers, and their trends, to be characterised prior to any potential for impacts from CSG development being experienced.

The approach and findings of the baseline groundwater monitoring assessment are presented in Appendix E and a summary is provided in this section.

### 4.1.1 Baseline data

The baseline assessment relies on monitoring data from the following sources:

- Existing and publicly available monitoring data as supplied and interpreted in the BGP EIS (URS 2012) and SREIS (Coffey 2014);
- Ongoing monitoring data collected from the UWIR WMS groundwater monitoring network located in the MGP area, consisting of 8 shallow and 8 deep monitoring bores (Arrow Energy 2016 & 2018); and
- Groundwater monitoring data collected from baseline water bore assessments conducted by Arrow, consisting of 99 water bores across a range of aquifers.

### 4.1.2 Findings

Groundwater level and quality data collected between 2012 and 2018 as part of the UWIR WMS groundwater monitoring network in the MGP, and the baseline water bore assessment program, has provided a dataset from which background groundwater conditions in key hydrogeological units including the Quaternary age alluvium, Tertiary age basalt and sediments, Triassic age Rewan Formation, Late Permian age coal seams and the Middle Permian age Back Creek have been characterised in selected areas (Appendix E).

At present, there is no evidence that CSG production in the MGP area is influencing groundwater levels in the Quaternary age alluvium, weathered Tertiary age basalt, Tertiary age sediment or weathered Late Permian age FCCM aquifers where these bores are installed. For the deeper formation monitoring bores, groundwater levels in the Permian age MCM are shown to be responding to CSG and associated groundwater production activities in the MGP area. Nested monitoring points also indicate a level of connectivity with the overlying FCCM and possibly the underlying Middle Permian Back Creek Group at these locations.

The groundwater quality baseline assessment demonstrated a high degree of variability between monitoring locations which is likely attributable to the spatial heterogeneity and low permeability of the hydrogeological system. A similar conclusion was derived from the studies supporting the BGP EIS and SREIS. The groundwater quality review did not identify any temporal trends in groundwater quality across the bore network.

The outcomes of the baseline groundwater monitoring assessment have assisted, together with the risk assessment (Section 4.2), in identifying monitoring locations for the BGP GMMP monitoring network, presented in Sections 4.3 and 4.4. On the basis of the baseline assessment, monitoring locations have been selected to capture the range of variability expected at the local scale, and importantly, will provide useful water level data for the checking of model outputs and for future model calibrations, as part of the implementation of the Early Warning System (EWS) for the GMMP (Section 5).

Longer term groundwater level and quality monitoring across the network will assist in further characterising background groundwater level and quality trends and any potential for deviations.

## 4.2 Risk assessment

### 4.2.1 Approach

The risk assessment approach adopted for the identification of the groundwater monitoring targets that form the monitoring network, is based on a source-pathway-receptor model. Under this model, a source of potential impact must be linked by a complete exposure pathway to a sensitive groundwater receptor for an impact to be realised, necessitating the requirement for monitoring and/or management.

**Source of potential impact**

The source of potential impact considered for the development of the Project Stage 1 GMMP is primarily groundwater drawdown associated with the depressurisation of target coal seams for the BGP. As described in the EIS (URS 2012) and SREIS (Coffey 2014), this may result in both direct and indirect impacts.

Other potential sources of impact to groundwater values associated with CSG development (i.e. field development and operations, hydraulic stimulation and management of produced water) will be monitored and managed under the relevant Environmental Authority conditions for the project.

The drawdown assessment criteria adopted to represent the source of potential impact in the assessment framework are listed in Table 4-1, according to each receptor considered.

**Table 4-1 Adopted drawdown assessment criteria**

| Receptor | Drawdown assessment criteria |
|---|---|
| **Existing groundwater bores (consolidated aquifers)** | Model predicted 5 m LAA |
| **Existing groundwater bores (unconsolidated aquifers)** | Model predicted 2 m LAA |
| **Surface expression GDEs and sites of cultural or spiritual significance** | Model predicted 0.2 m LAA, in the source aquifer |

| Receptor | Drawdown assessment criteria |
|---|---|
| **Non-spring (terrestrial) GDEs** | Model predicted 1.0 m LAA, in the watertable aquifer |

***Note:***
*LAA – Long term affected area, has the meaning in section 387 of the Water Act and means the area of an aquifer where the water level is predicted to decline, because of the exercise of underground water rights, by more than the bore trigger threshold at any time.*

Significant open cut and underground longwall mining has resulted in an altered landscape across the northern Bowen Basin, changing the hydrogeological regime of the region. There is potential for cumulative groundwater impacts to occur, where depressurisation of target coal seams during CSG extraction propagates to existing surface and underground mining operations. The monitoring network will include monitoring locations considered necessary for the identification of multiple impact sources to differentiate impacts generated by the BGP and impacts caused by existing coal mining operations.

**Exposure pathways**

Exposure pathways are mechanisms that have the potential to propagate the effects of groundwater depressurisation and lead to environmental or other impacts. Two types of pathways of groundwater depressurisation have been considered in the context of CSG production associated with the BGP: (i) formation hydraulic interconnectivity and (ii) interconnection via preferred pathways.

The pathway for propagation of groundwater depressurisation impacts in a layered aquifer system is through leakage across confining layers that separate permeable formations. (i.e. formation hydraulic interconnectivity). This leakage occurs due to the inherent, but typically low permeability of the confining layer, and the difference in hydraulic head across the layer. The rate of leakage will also be dependent on the thickness (or absence) of the confining layer.

The Rewan Formation is considered a regional aquitard and is present across the majority of the study area (Section 2.4.1). Its spatial extent is represented in the numerical groundwater model (AGE 2018) and therefore the drawdown predictions reflect the control the Rewan Formation has on aquifer connectivity between the target coal seams and overlying Quaternary, Tertiary and Triassic age formations.

The presence of geological structures, primarily faults and its attendant fracture zone, as well as permeable conduits such as weathered dykes, may provide preferred pathways that could facilitate the vertical propagation of CSG drawdown impacts from the coal measures to adjacent aquifers (i.e. interconnection via preferred pathways). As discussed in Section 2.4.3, assessments to date indicate that faults in the Bowen Basin are generally of low permeability both parallel to and normal to the fault planes. In the event that a fault zone or weathered dyke represents an existing preferential pathway for flow, it was concluded that these features would only represent a minor contributor to propagation of drawdown impacts across formations.

**Sensitive groundwater receptors**

Groundwater receptors that may be affected by the depressurisation of the target coal seams were classified in the EIS under the following categories:

- Existing groundwater users (Section 2.4.4): Groundwater is used for extractive purposes across the Bowen Basin (Figure 2-5). Within the study area, there are a relatively small number of licensed groundwater entitlements, which relate to use for industrial purposes to the north-east of Moranbah.

- GDEs (Section 2.4.5): As concluded in the EIS (URS 2012), there are no known or anticipated fault controlled springs in the BGP area. GDEs in the project area, where present, will be dependent on the watertable aquifer. Depth to groundwater data and mapped vegetation communities indicate riparian vegetation along major watercourses may be supported by groundwater on a facultative basis (i.e. use groundwater but capable of functioning without it). These watercourses may include: Upper Isaac River, Suttor Creek, Cherwell Creek and Phillips Creek (Figure 2-6).

- Cultural and spiritual sites of significance (Section 2.5): Cultural heritage studies were carried out to support the BGP EIS. Four significant sites with potential association with groundwater were identified based on their description as ‘wells’, three of which are located within the study area (Figure 2-6).

### 4.2.2 Findings

The predicted LAAs were assessed in consideration of the location of potential groundwater receptors and the associated drawdown assessment criteria (Table 4-1) to identify where these may be at risk from CSG depressurisation activities from all of Arrow’s current and future developments. Potential risks to each type of receptor in the Project area are discussed further in the sections below.

**Existing groundwater users**

Figure 4-1 presents the location of water supply bores across the Project area in relation to the predicted 5 m LAAs for consolidated aquifers. No LAAs (predicted drawdown > 2 m) for unconsolidated aquifers (the watertable aquifer) are predicted in the Project area, and accordingly existing groundwater users extracting from the watertable aquifer are not considered at risk of impact from the Action.

The LAAs for consolidated aquifers (predicted drawdown > 5 m) other than the Late Permian age coal measures (i.e. Tertiary age units, Triassic age Rewan Formation, Early Permian to Mid Permian age Formations), where predicted, do not intercept any water supply bores screened in the corresponding formations (Figure 4-1). Water supply bores installed into consolidated aquifers are therefore not considered to be at potential risk of impact from the development.

In the MGP, four bores inferred as screening the Late Permian age formations intercepted by the 5 m LAA for the MCM (Figure 4-1). However, based on an interrogation of bore card information on the Queensland Government Groundwater Database, these bores have been either re-classified in shallower formations or identified to be mine monitoring bores. Therefore, the four bores are not predicted to be at potential risk of impact from the development.

Existing water supply bores at potential risk of impact from the Action are described below in the context of the development area (Figure 4-1):

- Red Hill Central - two bores of unknown geological classification intercepted by the 5 m LAA for the MCM. Based on an interrogation of bore card information on the Queensland Government Groundwater Database, one of the bores has been identified to be a mine monitoring bore.

- Mavis Downs - two water supply bores of unknown geological classification intercepted by the 5 m LAA for the MCM.

- BGP FDP northern and southern development areas – 11 water supply bores screening the Late Permian age formations and 17 water supply bores of unknown geological classification intercepted by the 5 m LAAs for the MCM and RCM.

**Groundwater dependent ecosystems**

The predicted 0.2 m and 1.0 m LAAs for the watertable aquifer are presented in Figure 4-2, together with identified and mapped occurrences of GDEs and sites of cultural and spiritual significance.

There are no predicted occurrences of 1.0 m drawdown in the watertable aquifer associated with Arrow's current and future developments. Potential non-spring GDEs (terrestrial GDEs) in the Project area are therefore not considered at risk of impact from the development.

Localised areas of predicted 0.2 m drawdowns in the watertable aquifer are identified in and adjacent to ATP 742, in proximity and to the west of the MGP and to the northeast of Dysart in ATP 1103 (southern BGP FDP area) (Figure 4-2). As there are no known or anticipated fault controlled springs in the BGP area, nor does groundwater baseflow contribution to stream reaches occur, such features are not considered at risk of impact from Arrow's current or future development.

**Cultural and spiritual sites of significance**

The predicted 0.2 m LAA for the watertable does not intersect any locations identified as potential sites of cultural and spiritual sites of significance (Figure 4-2). These sites are therefore not considered at potential risk of impact from Arrow's current and future developments.

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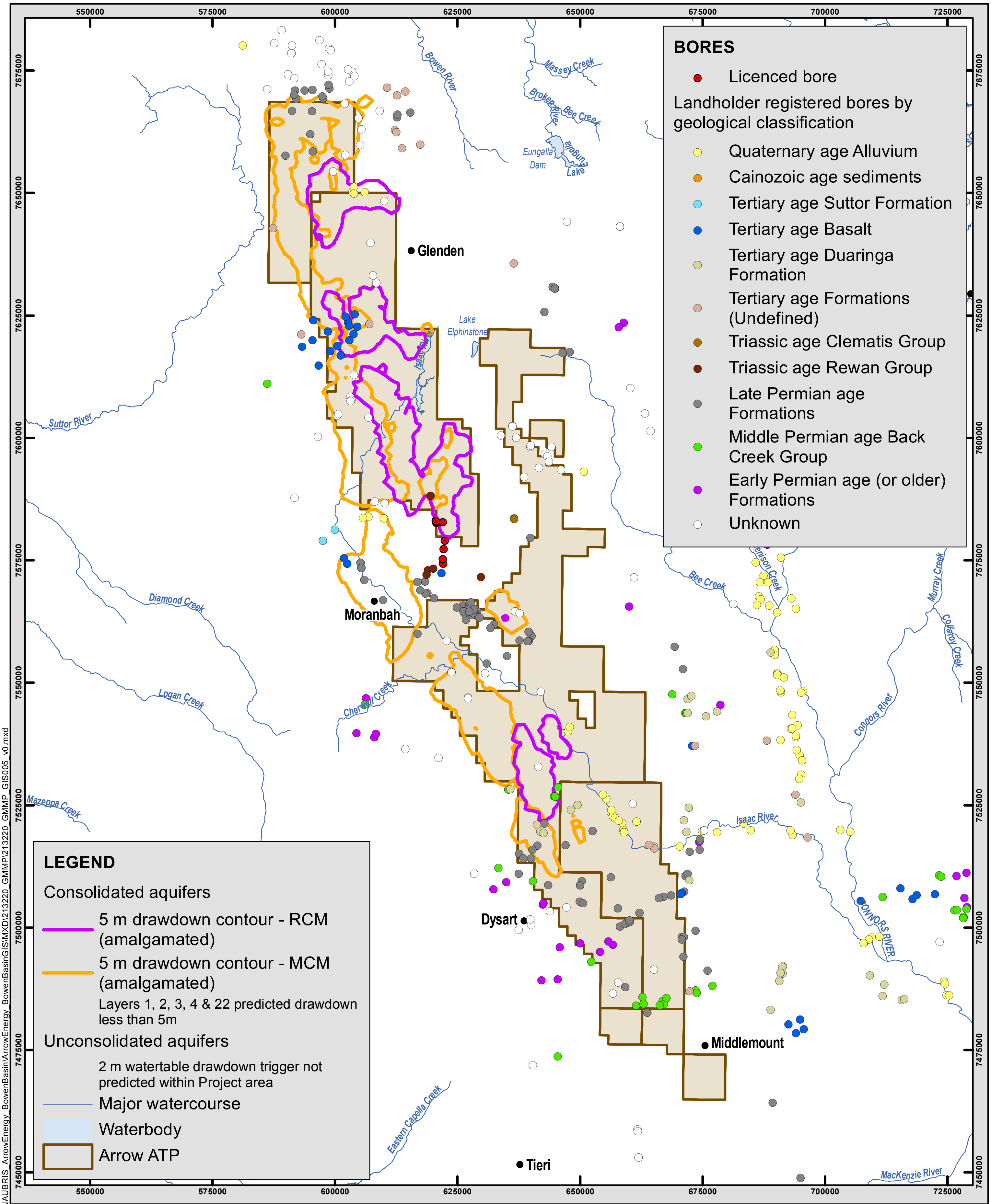


**Figure 4-1** **Potential for predicted LAA drawdowns to impact water supply bores in consolidated and unconsolidated aquifers**

**Source:**
Arrow Energy Pty Ltd

Date: 13/03/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N

arrow energy
go further



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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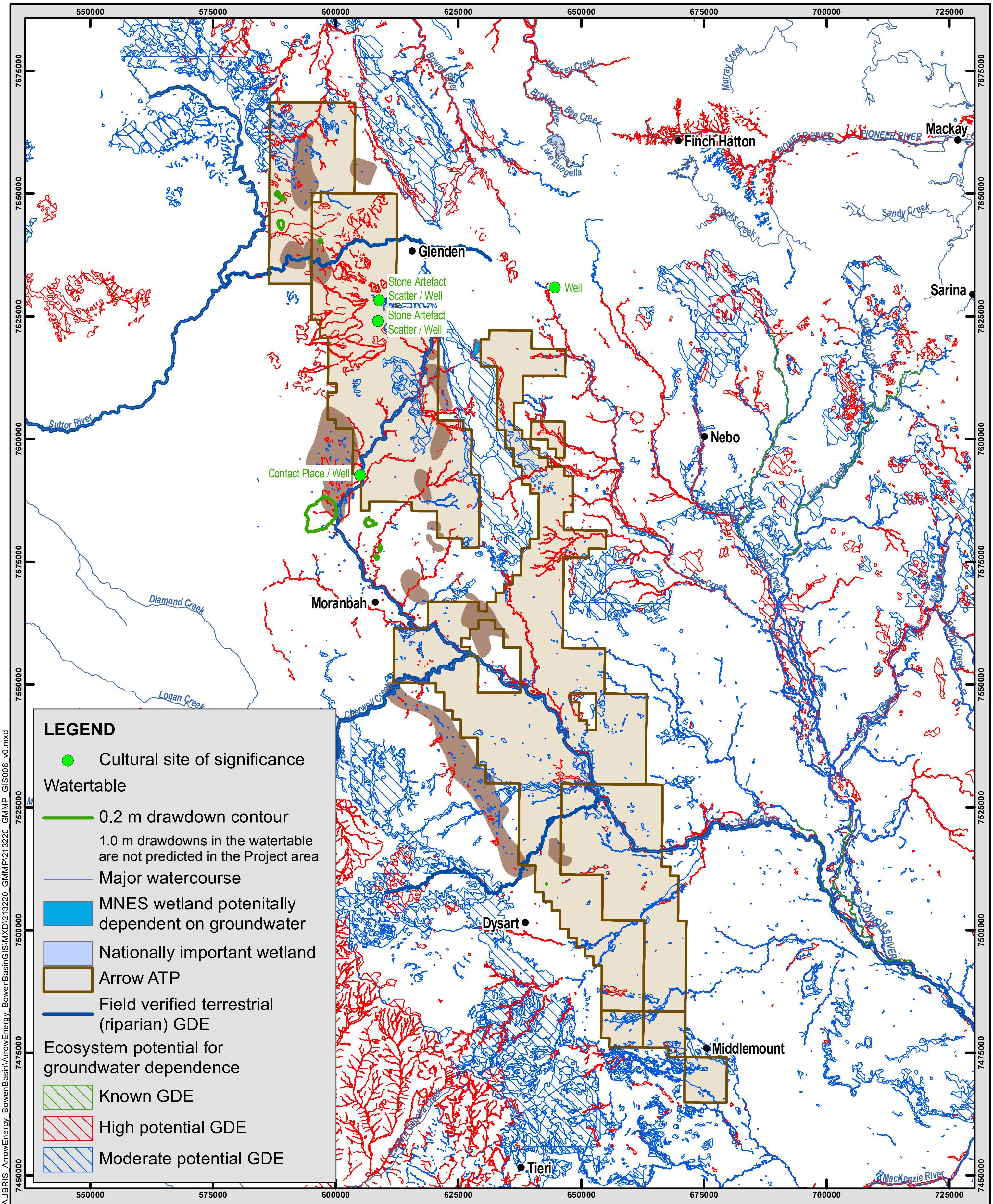


**Figure 4-2** **Potential for predicted LAA drawdowns to impact identified and mapped GDEs and sites of cultural and spiritual significance**

**Source:**
Arrow Energy Pty Ltd, Coffey
BOM GDE Atlas (June 2018)
URS (2013), AGE (July 2018)

Date: 20/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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## 4.3 Design and rationale

A groundwater monitoring network has been developed to comply with Commonwealth Approval Conditions 21 to 25 and specified Arrow EIS/SREIS commitments. A structured analysis was undertaken to identify where predicted groundwater drawdowns may correspond to potential risks and to rationalise the monitoring locations[9]. In addition, the selection of monitoring locations takes into consideration the requirement to provide baseline data before development impacts occur, and to enable impact detection through analysis of groundwater hydrograph trends as monitoring data is acquired over time.

Design of the groundwater monitoring network is underpinned by numerical groundwater modelling that simulates BGP groundwater abstraction and predicts the degree and extent of aquifer depressurisation in a spatial and temporal context (Section 3). In turn, geospatial analysis has been used to enable the magnitude, extent and timing of depressurisation to be related to the location of connected environmental features and existing water users, thereby providing an informed basis for establishing monitoring locations (Section 4.2).

This approach is considered conservative, because the groundwater modelling predicts impacts at greater timeframes than the three-yearly period between GMMP reviews (refer Section 6.2.3) thereby ensuring that adequate time is afforded for implementation of additional monitoring capability, prior to any impacts arising. In addition, monitoring data from the established network is available to inform any ongoing recalibration of the groundwater model, thus enabling the assessment of potential for impacts to be updated.

In summary, in designing the monitoring network consideration has been afforded to the following:

- Current baseline groundwater level and quality trends in the Project area (Section 4.1) and the acquisition of ongoing baseline data;
- Spatial extent and timing of predicted aquifer depressurisation;
- Geological formations that require monitoring and potential migration pathways;
- Potential changes to the groundwater balance;
- Matters of national environmental significance (MNES);
- Environmental features that require monitoring; and
- Groundwater level or pressure impacts that are anticipated to occur in the context of connected receptors.

[9] The terms 'monitoring location' and 'monitoring site' are used interchangeably throughout this GMMP. They describe a location where one or more groundwater monitoring bores are installed.

The approach and rationalisation to designing the monitoring network as it relates to Approval Condition 21(a), (b) and (c) for the monitoring of impacts on water resources associated directly or indirectly with the BGP is presented in Table 3.1 of the Groundwater monitoring network memorandum (Appendix D).

The Project Stage 1 GMMP monitoring network is supported by the existing UWIR WMS groundwater monitoring network in the MGP area; a regional aquifer groundwater monitoring network consisting of 8 deep and 8 shallow bores. This monitoring network is described in the baseline groundwater assessment of Appendix E.

In addition to the GMMP monitoring network, Arrow will supplement the monitoring network data with additional data acquired from the mining and landholder bore baseline assessments conducted under the UWIR (as required by the Water Act) and with baseline assessment data for the LAAs required as part of the WMS (which incorporates water bores predicted to be impacted on land outside the tenures).

### 4.3.1 MNES

Approval Condition 21(c) requires a rationale for the design of the monitoring network with respect to the nature of potential impacts and the location and occurrence of matters of national environmental significance (MNES).

Lake Elphinstone is identified in the EIS/SREIS as a MNES. No other MNES with known or potential groundwater-dependence are identified either within the study area, or beyond the Project area where indirect impacts are predicted to occur.

While Lake Elphinstone is not predicted to be impacted by groundwater depressurisation associated with the Action, in consideration of Approval Condition 21(c), a nested monitoring location is proposed within Arrow Energy tenure some 9 km west of the lake, to enable early detection of changes to shallow groundwater levels prior to any impact being experienced at Lake Elphinstone. Baseline and ongoing groundwater level monitoring at a nested site location west of Lake Elphinstone will enable the early detection of potential shallow groundwater level and connectivity changes prior to any potential impacts being received at the lake.

Should the early detection of impacts be identified at this monitoring site, or revised modelling indicates a risk of depressurisation impacts to Lake Elphinstone, a second contingent nested monitoring location will be installed immediately east of the lake to monitor and manage Project related impacts to this MNES feature. Further detail is provided in Section 4.4.

## 4.4 Specifications and schedule

The groundwater monitoring network (detailed in Table 4-2 and summarised in Table 4-3) is specified separately for each of the Red Hill Central development, Mavis Downs development and the remainder of the Project Stage 1 area (northern and southern development areas) due to their differences both in a spatial and temporal context.

The location of the identified groundwater monitoring sites are presented in the following figures, which are separated for the Red Hill Central and Mavis Downs area (a), northern development area (b) and southern development area (c):

- Figure 4-3 (a, b, c) – Rangal Coal Measures
- Figure 4-4 (a, b, c) – Moranbah Coal Measures
- Figure 4-5 (a, b, c) – Unconfined alluvium
- Figure 4-6 (a, b, c) – Tertiary/basalt/Moolayember Formation
- Figure 4-7 (a, b, c) – Fort Cooper Coal Measures
- Figure 4-8 (a, b, c) – Triassic formations

Several monitoring sites appear on more than one map, due to the ambiguity of target formations (for example Quaternary and Tertiary horizons may also be unconfined alluvium), and these will be confirmed as additional drilling is undertaken.

Approval Condition 21(a) is fulfilled for Project Stage 1 with a monitoring network (excluding 5 contingent monitoring intervals, but including 5 supplementary bores) consisting of 30 monitoring intervals, at 19 separate locations (comprising 11 single sites and 8 nested sites of 19 monitoring intervals).[10] The exact number of bores required to achieve monitoring of the specified intervals will be determined during monitoring bore design and engineering. Each bore may have multiple monitoring objectives that target the monitoring and management of site-specific project risks.

While all monitoring locations are intended to inform changes to the groundwater regime and the groundwater balance in the Project area, each location has been targeted to fulfil specific (primary and secondary) purposes and knowledge gaps to address the Project Stage 1 Approval Conditions. Selected monitoring sites were also identified for baseline data to ensure a sufficient level of coverage across the Project area and within key aquifers is achieved.

Single and nested monitoring sites are identified. Nested sites are useful where inter-formation connectivity monitoring is considered warranted, for example, in cases where the Rewan Formation may be absent, or where the proximity to inferred faults which may provide interconnection by preferred pathways.

Interconnection due to faulting is monitored at MB9, MB11 and MB15, and at contingent sites MB6 and MB13. These sites are highlighted on the monitoring network figures where they are plotted. These monitoring locations are considered adequate based on the assessments of faulting previously undertaken (refer Section 2.4.3) where compelling evidence was identified that faults in the Bowen Basin are generally of low permeability both parallel to, and normal to, the fault planes. This was further supported by numerical groundwater modelling (refer Section

[10] A nested location is a monitoring location where more than one interval is monitored.

6.5.2 of Coffey, 2014) where it was concluded that in the event that a fault zone or weathered dyke represents an existing preferential pathway, these features would only represent a minor contributor to propagation of drawdown across formations.

While groundwater modelling indicates that inter-formation connectivity is unlikely to contribute to impacts to connected receptors within overlying formations, pursuant to Approval Condition 21(a)(ii), sites have been targeted in the Project Stage 1 GMMP for monitoring the potential influence of these primary and secondary exposure pathways. The monitoring bore installations at these sites will also provide additional information to support or revise the conceptualisation of the Rewan Formation in the groundwater model as necessary.

Selected monitoring sites are located close to surface and underground coal mines across the Project area for the primary or secondary purpose of identifying and differentiating cumulative groundwater drawdown impacts arising due to the combined groundwater dewatering activities associated with coal mining and CSG operation. This approach relies on the comparison between modelled Project area drawdown and observed (monitored) drawdown, which will assist in developing an understanding of the proportion of groundwater level drawdown that can be attributed to coal mine dewatering, relative to that arising from the Action.

Each development area in the BGP (i.e. Red Hill Central, Mavis Downs and the remainder of the Project Stage 1 area) is assigned monitoring sites for groundwater quality monitoring (Section 4.5.2). Both field and laboratory based quality monitoring will assist in aquifer characterisation and baselining, serving as a benchmark against which potential impacts can be assessed.

The identified locations will also supply ongoing monitoring data for groundwater model verification and re-calibration. In accordance with Approval Condition 21(f), the network will be periodically reviewed as the project development plans evolve, permitting changes to be made to the monitoring network and program, if necessary, based on any future revision to gas development or model outputs. For example, in circumstances where ongoing modelling indicates that a reduced level of impact is predicted, monitoring locations specified as contingent may be re-located, or deleted in certain cases.

It is also recognised that ultimate location of the monitoring bores will be subject to site and access constraints that may lead to re-positioning.

Table 4-2 presents the indicative schedule of the groundwater monitoring network. The installation schedule is phased according to the following:

- Monitoring locations with a primary purpose of baseline monitoring will be installed at least one year prior to the commencement of production within 10 km of the monitoring location to enable the collection and interrogation of baseline data.

- Monitoring locations where baseline monitoring is not required will be installed immediately prior to the commencement of production in a development area that is within 10 km of the monitoring location.

- Contingent locations will be installed in circumstances where the criteria for contingency (refer Section 4.4.1) are met.

Should the GMMP be required to be updated or the monitoring network required to be updated in the future, then all proposed monitoring locations, including the contingent monitoring locations, will be revised accordingly. Criteria for contingent bore locations will be provided accordingly.

### 4.4.1 Criteria for contingent bore locations

Four monitoring locations are identified as contingent monitoring locations, and will contribute to adaptive management for the Project Stage 1 GMMP, and for later project stages that may be considered. Monitoring intervals at these locations are: MB4, MB6, MB13-D, MB17-I and MB17-S). The following are specific criteria for installation of these monitoring intervals.

**MB4 -** Monitoring site MB4 is intended as a contingent location for the purposes of monitoring watertable levels in the unconfined alluvium in proximity to the Isaac River, a potential area of riparian vegetation and site of cultural or spiritual significance. While the watertable is not predicted to be impacted in this area, MB4 will be installed if either of the following conditions arise:

- Ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or
- Monitoring at MB1-S indicates the potential or likelihood of watertable level impacts as a consequence of the BGP.

**MB6 -** Monitoring site MB6 is intended as a contingent location for the purposes of assessing inter-aquifer connection in the presence of inferred mapped geological faults. Based on the current FDP and assessment of Project related drawdowns, MB6 will be installed if either of the following conditions arise:

- Ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or
- Monitoring of other sites in the northern development area indicate the potential or likelihood of preferential groundwater flow occurring across formations by way of geological faults.

**MB13D -** Monitoring site MB13D is a nested monitoring point to accompany shallow monitoring point MB13-S, and will complement the monitoring of this potential secondary exposure pathway. Based on the current FDP and assessment of Project related drawdowns, MB13-D will be installed under contingency of the following conditions:

- Ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or
- Monitoring of MB13-S and/or other monitoring points in the southern development area indicate the potential or likelihood of preferential groundwater flow occurring across formations by way of geological faults.

**MB17** - Monitoring site MB17 is a nested monitoring location (designated as contingent monitoring points MB17-S and MB17-I) that would be installed immediately east of the Lake Elphinstone to monitor and manage any Project related impacts to this MNES feature. MB17-S and MW17-I will be installed under contingency of the following condition:

- If impacts are detected at MB11-S; or
- If revised modelling indicates a risk of depressurisation impacts to Lake Elphinstone.

If one or more of the following criteria are triggered as part of the review, a revised GMMP will be produced:

- Revised modelling indicates potential impacts to a terrestrial GDE (i.e. modelled 1 m LAA in the water table aquifer or greater drawdown is predicted coincident with a potential or known terrestrial GDE).
- Revised modelling indicates potential impacts to a surface water feature.
- Revised modelling indicates a material change to forecast impacts (i.e. a predicted IAA or LAA in an aquifer that is not forecast in the current GMMP).
- CSG development is proposed for areas outside the Project Stage 1 area.
- CSG development is proposed to utilise greater than 1,408 production wells.

Where the above criteria are not triggered (and a GMMP update is not required) the results of the three-yearly review will be documented in an annual report (refer Section 6.2.4).

As part of the GMMP review following the release of a new UWIR every three years, the risk assessment will be reviewed to identify if any surface water features or terrestrial GDEs are at risk based on the outcomes of the UWIR. Any risk assessments undertaken will be reviewed to determine risk and the need for monitoring.

If the revised risk assessment indicates that surface water features may be at risk due to changes in groundwater –surface water connectivity resulting from the Action:

- Arrow will include in the updated GMMP a monitoring system that will be developed to provide for the early detection of changes in groundwater-surface water connectivity.

If the revised risk assessment or the UWIR (1m LAA in a water table aquifer) indicate that terrestrial GDEs may be at risk from the Action:

- Arrow commits to include in the updated GMMP an early warning system (EWS) for terrestrial GDEs that will include:
  - Details of a monitoring system to be implemented for the identified at-risk terrestrial GDEs, and the timing of the implementation of the system.
  - A detailed EWS for terrestrial GDEs.

- Mitigation measures for managing any impacts that might arise.

Where the findings of the above risk assessment indicated that a GMMP update is not required, then the findings will be documented in an annual report (refer Section 6.2.4). Where findings from a revised risk assessment determine that additional monitoring is not required, this will be adequately documented.

Table 4-2 BGP Project Stage 1 monitoring network specification

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| **MB1 (1)**<br><br>**(existing Red Hill bore RH28/RH30) (2)** | S – Quaternary / Tertiary<br><br>I – RCM<br><br>D – MCM | Red Hill Central | Baseline data capture<br><br>Coal mine cumulative impact monitoring<br><br>Model reference point | Groundwater quality (8) | 2019 |
| **MB2 (1)**<br><br>**(existing Red Hill bore RH60)** | MCM | | Baseline data capture<br><br>Formation hydraulic interconnectivity<br><br>Model reference point | | Current |
| **MB3 (1)**<br><br>**(existing Red Hill bore RH51)** | MCM | | Baseline data capture<br><br>Formation hydraulic interconnectivity<br><br>Model reference point | | Current |
| **MB4 (3)** | Unconfined alluvium | | Groundwater level monitoring in proximity to potential riparian vegetation and a site of cultural and/or spiritual significance<br><br>Model reference point | | Contingent |

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| **MB5** | Tertiary / Triassic | Mavis Downs | Baseline data capture<br>Coal mine cumulative impact monitoring<br>Model reference point | Groundwater quality | 2020 |
| **MB6** (3) | Quaternary / Tertiary | BGP FDP (northern development area) | Interconnection via preferred pathway/faulting<br>Model reference point | | Contingent |
| **MB7** | S – Tertiary<br>D – RCM | | Baseline data capture<br>Model reference point | Groundwater quality | 2029 |
| **MB8** | Quaternary / Tertiary | | Formation hydraulic interconnectivity<br>Coal mine cumulative impact monitoring<br>Model reference point | Groundwater quality | 2030 |
| **MB9** | S – Quaternary / Tertiary<br>I – RCM<br>D – MCM / FCCM | | Baseline data capture<br>Formation hydraulic interconnectivity | Groundwater quality | 2029 |

| Monitoring location | Monitoring interval and target formation [4,5,6] | Development area | Primary purpose [7] | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| | | | Interconnection via preferred pathway/faulting<br>Monitoring all aquifers<br>Model reference point | | |
| **MB10** | Tertiary | | Model reference point | Groundwater quality | 2030 |
| **MB11** | S – Quaternary / Tertiary or Rewan Formation<br>D – RCM | | Baseline data capture<br>Formation hydraulic interconnectivity<br>Interconnection via preferred pathway/faulting<br>Model reference point | Groundwater quality<br>Coal mine cumulative impact monitoring<br>MNES monitoring | 2029 |
| **MB12** | Quaternary / Tertiary | | Baseline data capture<br>Coal mine cumulative impact monitoring<br>Formation hydraulic interconnectivity<br>Model reference point | | 2028 |

| Monitoring location | Monitoring interval and target formation [4,5,6] | Development area | Primary purpose [7] | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| **MB13** | S – Quaternary / Tertiary (if present)<br>D – Blackwater Group (RCM / FCCM / MCM) [3] | BGP FDP (southern development area) | Interconnection via preferred pathway/faulting<br>Model reference point | Groundwater quality | 2028<br>Contingent |
| **MB14** | S – Quaternary / Tertiary<br>I – RCM<br>D – MCM / RCCM | | Baseline data capture<br>Formation hydraulic interconnectivity<br>Monitoring all aquifers<br>Model reference point | Coal mine cumulative impact monitoring<br>Groundwater quality | 2029 |
| **MB15** | S – Unconfined alluvium<br>I – Tertiary / Triassic | | Baseline data capture<br>Interconnection via preferred pathway/faulting<br>Model reference point | Groundwater level monitoring in proximity to potential riparian vegetation<br>Groundwater quality | 2029 |
| **MB16** | Tertiary | | Baseline data capture<br>Formation hydraulic interconnectivity<br>Model reference point | Coal mine cumulative impact monitoring<br>Groundwater quality | 2029 |

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| **MB17** (3) | S – Unconfined alluvium<br><br>I – Rewan Formation | ATP 1103 (in proximity to Lake Elphinstone) | MNES monitoring<br><br>Groundwater-surface water connectivity<br><br>Formation hydraulic interconnectivity<br><br>Model reference point | Groundwater quality | Contingent |
| **Supplementary monitoring bores**[9] | | | | | |
| **AEN1214** | Rangal Coal Measures | BGP FDP (northern development area) | Monitor changes to water availability for water users and the environment.<br><br>Baseline data capture | | Existing |
| **AEN1036** | Blackwater Group | BGP FDP (southern development area) | Monitor changes to water availability for water users and the environment.<br><br>Baseline data capture | | Existing |
| **AEN1050** | Quaternary alluvium | Red Hill Central & Mavis Downs development area | Monitor changes to water availability for water users and the environment.<br><br>Baseline data capture | | Existing |

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| **GW001** | VWP 1 – alluvium<br><br>VWP 2 – Fort Cooper Coal Measures | Red Hill Central & Mavis Downs development area | Monitor changes to water availability for water users and the environment.<br><br>Baseline data capture<br><br>Formation hydraulic interconnectivity | Coal mine cumulative impact monitoring (including changes to project area water balance) | Existing |
| **GW007** | SP 1 – alluvium<br><br>SP 2 – Fort Cooper Coal Measures | Red Hill Central & Mavis Downs development area | Monitor changes to water availability for water users and the environment.<br><br>Baseline data capture<br><br>Formation hydraulic interconnectivity | Coal mine cumulative impact monitoring (including changes to project area water balance) | Existing |

***Notes:***

*(1) RH60 (now MB2) and RH51 (now MB3) are existing bores in the Red Hill development area that have been re-purposed and instrumented for groundwater level monitoring purposes in the BGP GMMP. RH28/RH30 (now MB1) requires conversion and instrumentation for monitoring across the three intervals. This activity is planned for 2019.*

*(2) Additional field investigations are required to determine whether MB1 will be re-purposed from RH28 or RH30.*

*(3) Contingent location. Monitoring location will only be installed under contingency of the conditions described in Section 4.4.1.*

*(4) Surficial aquifer assumed based on outcrop geology mapping. Refinement of surficial target aquifer may require refinement at the local scale.*

*(5) The exact number of bores required to achieve monitoring of the specified intervals will be determined during monitoring bore design and engineering.*

*(6) S: shallow monitoring point, I: intermediate monitoring point, D: deep monitoring point (monitoring points and monitoring intervals have the same meaning).*

*(7) Model reference point refers to the use of the groundwater level monitoring data in the regular review of numerical model outputs and to serve as input to the numerical groundwater model, if necessary.*

*(8) MB1 will be re-purposed from RH28/RH30. Due to well completion constraints, it will not be possible to sample from the intermediate and shallow intervals at this site. Should pressure data indicate the potential for inter-connectivity between the MCM and overlying units at this site, a shallow groundwater quality monitoring point will be established.*

*(9) Bores AEN1214, AEN1036 and AEN1050: Monitoring at these sites is predicated on a site visit to determine suitability of the bore for monitoring purposes, and access from landholder. Bores GW001 and GW007: Ongoing monitoring at these sites is contingent on access and BMA mine development. In the event access is no longer granted for these sites then a suitable nearby replacement will be implemented that meets the same monitoring requirements (target formation and purpose).*

**Table 4-3 Summary of the BGP monitoring network sites according to purpose**

| | Purpose (1) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Development area** | **Baseline** | **Groundwater quality** | **Formation hydraulic interconnectivity** | **Interconnection via preferential pathway** | **Coal mine cumulative impact** | **Riparian vegetation** | **Site of cultural and/or spiritual significance** | **Gw-Sw connectivity** | **MNES** | **Water availability for water users/environment / water balance** | **Monitoring all aquifers (2)** | **Model reference point** |
| **Red Hill Central** | 5 | 1 | 3 | - | 3 | (1) | (1) | - | - | 2 | - | 3 (1) |
| **Mavis Downs** | 2 | 1 | - | - | 1 | - | - | - | - | 1 | | 1 |
| **BGP FDP (northern development area)** | 5 | 5 | 4 | 2 (1) | 3 | - | - | - | 1 | 1 | 1 | 6 (1) |
| **BGP FDP (southern development area)** | 4 | 4 | 2 | 2 | 2 | 1 | - | - | - | 1 | 1 | 4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ATP 1103 (in proximity to Lake Elphinstone)** | - | (1) | (1) | - | - | - | | (1) | (1) | | | (1) |
| **Total across BGP** | **16** | **11** (1) | **9** (1) | **4** (1) | **9** | **1** (1) | (1) | (1) | 1 (1) | **5** | **2** | **14 (3)** |

***Notes:***

*(1) The purpose of the contingent monitoring bores is separated in the table with the number of locations listed in brackets.*

*(2) Sites classified as “monitoring all aquifers” are nested sites with intervals across the Quaternary / Tertiary (S), RCM (I) and MCM (D).*

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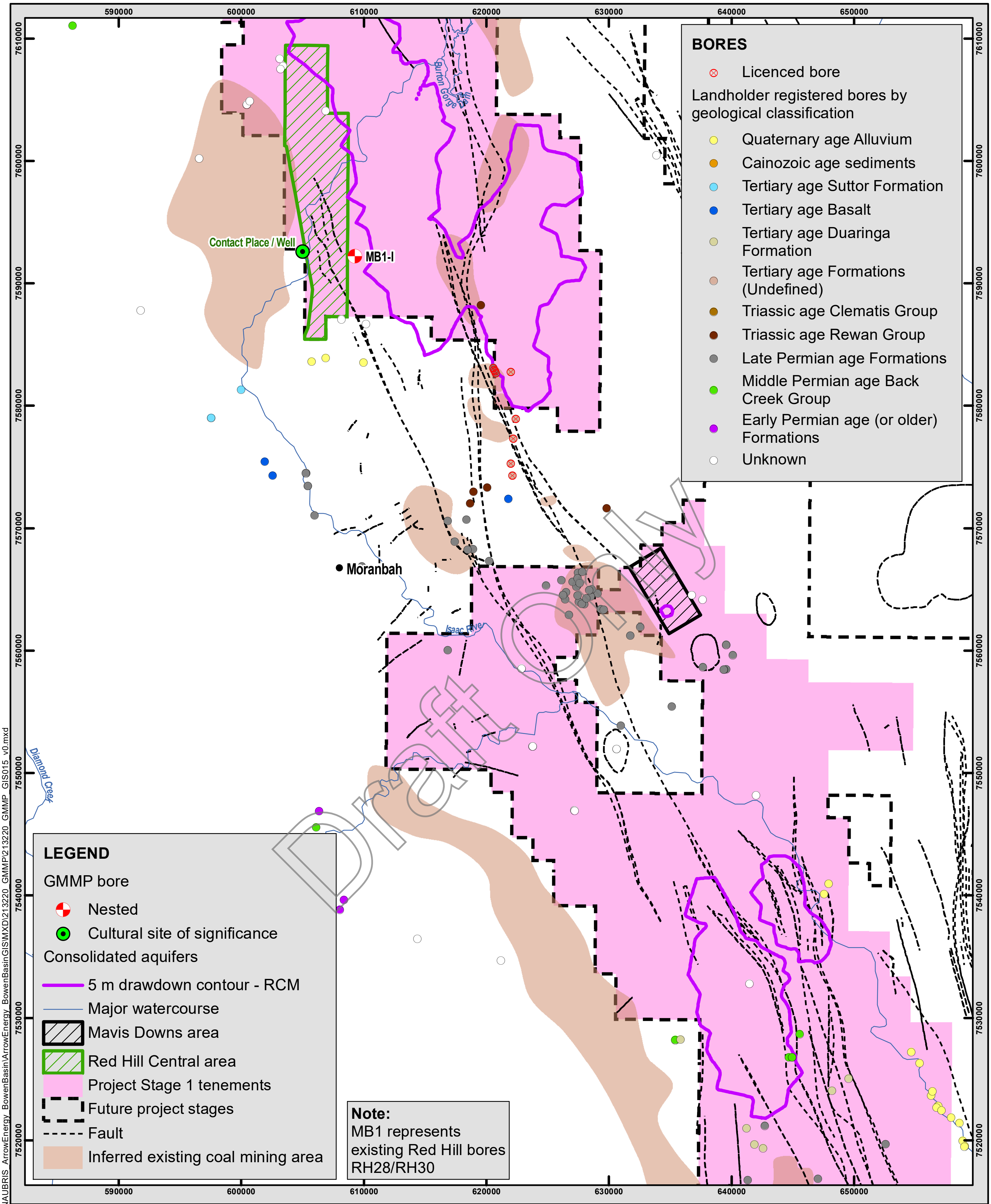


**Figure 4-3a** **RCM monitoring bore network - Red Hill Central & Mavis Downs development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 28/08/2019
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Author: Helen.Unkovich

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Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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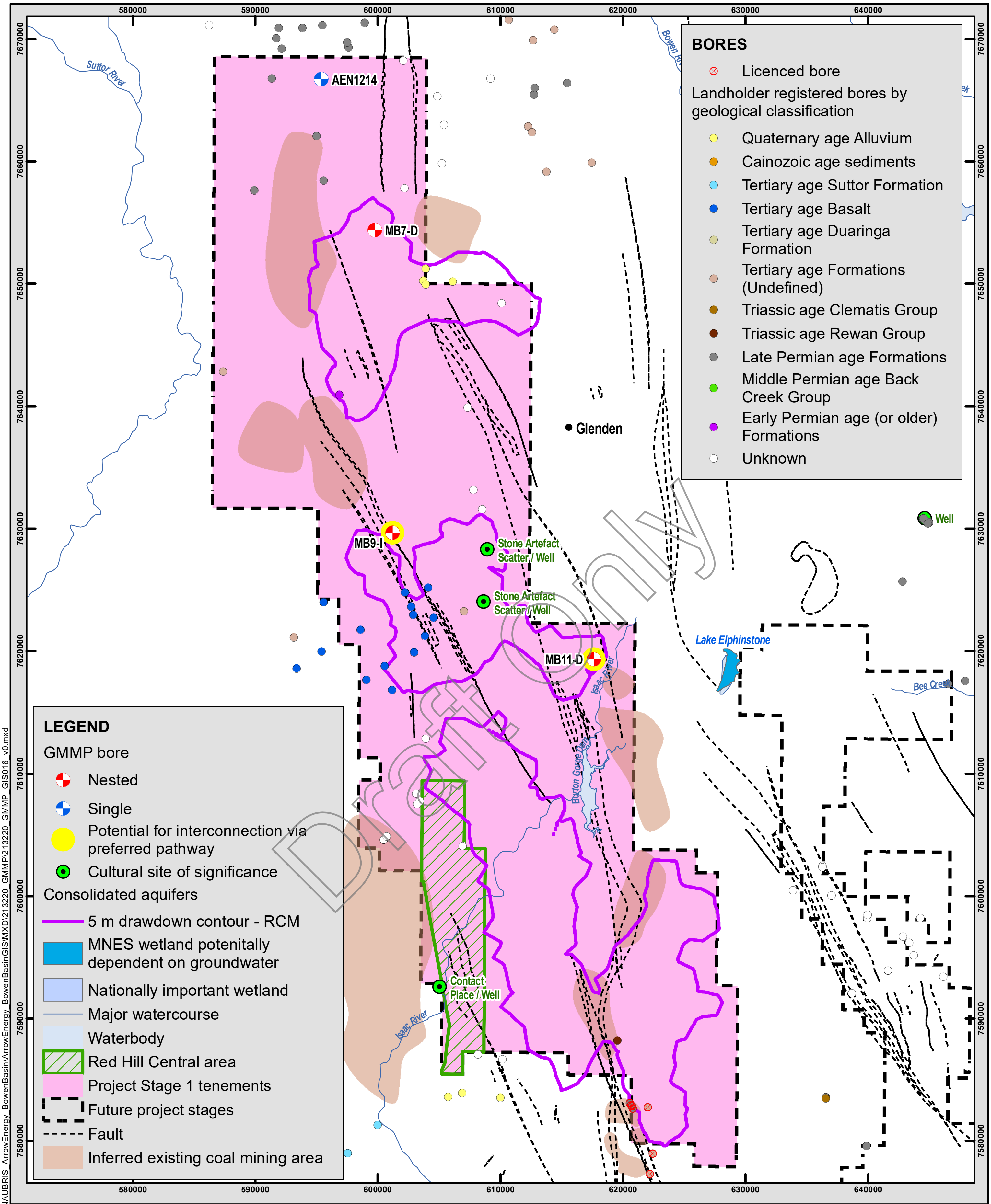


**Figure 4-3b** RCM monitoring bore network - Stage 1 northern development area

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 28/08/2019
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Author: Helen.Unkovich

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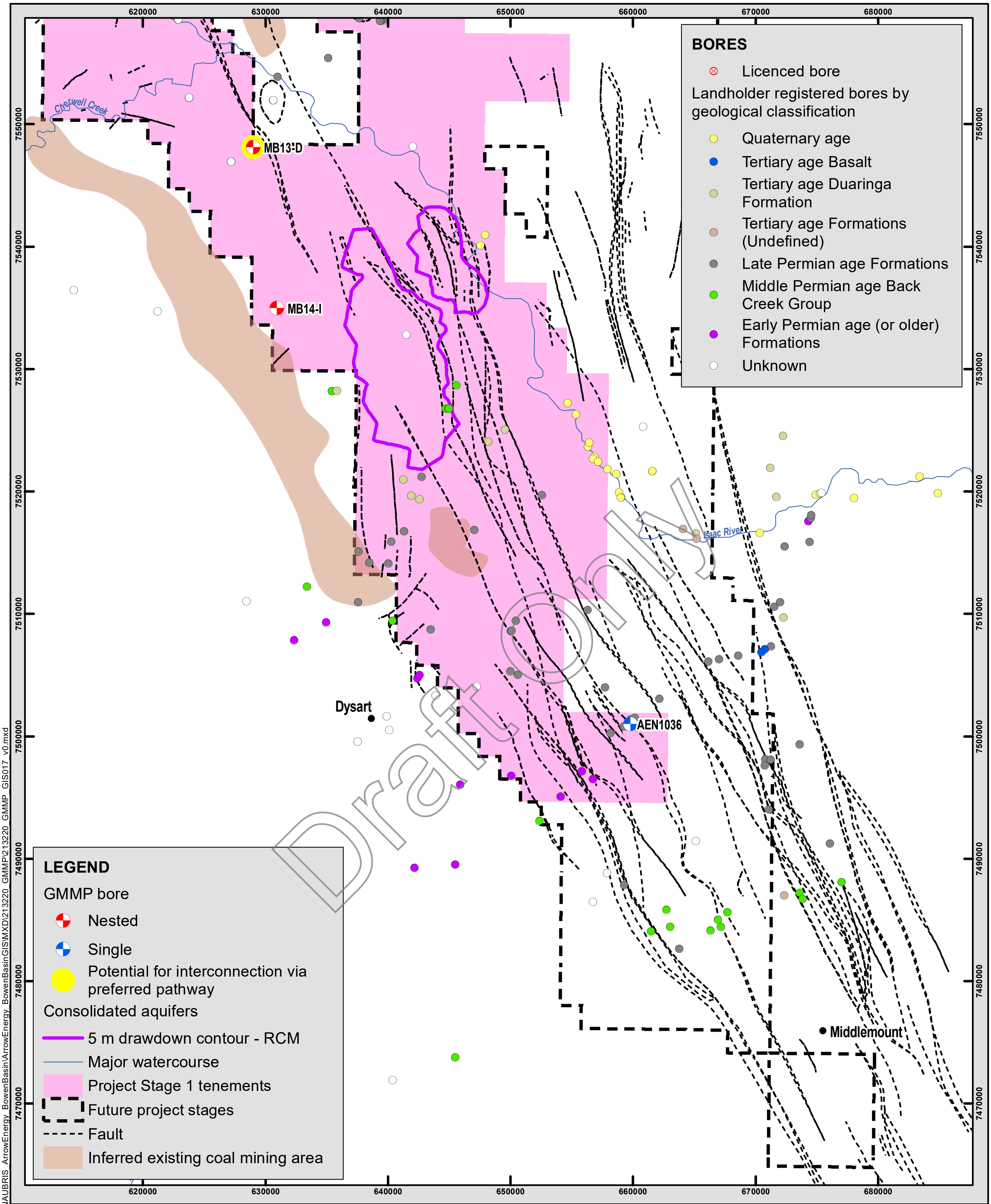


**Figure 4-3c** RCM monitoring bore network - Stage 1 southern development area

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

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Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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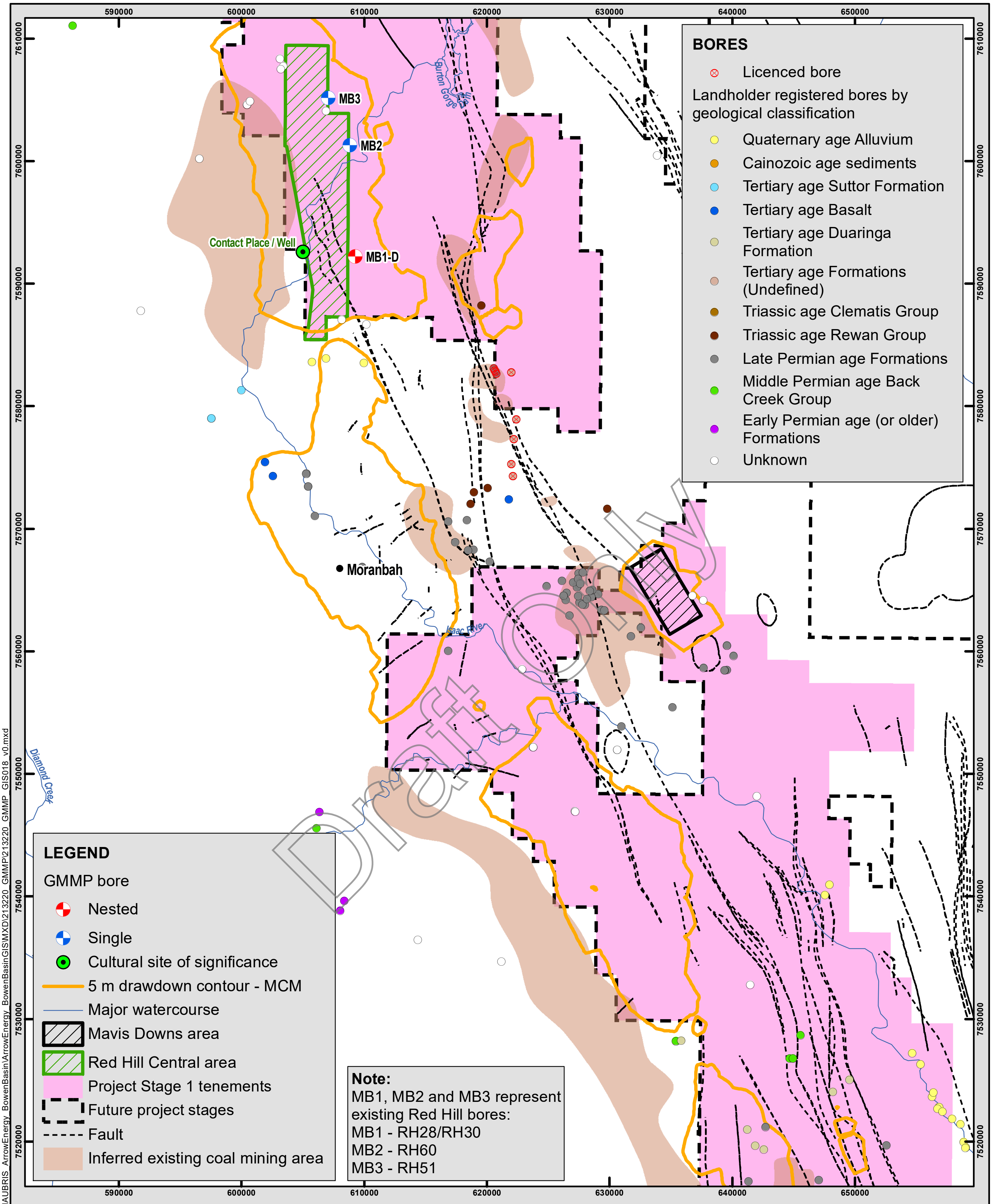


**Figure 4-4a** MCM monitoring bore network - Red Hill Central & Mavis Downs development area

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 28/08/2019
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Author: Helen.Unkovich

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Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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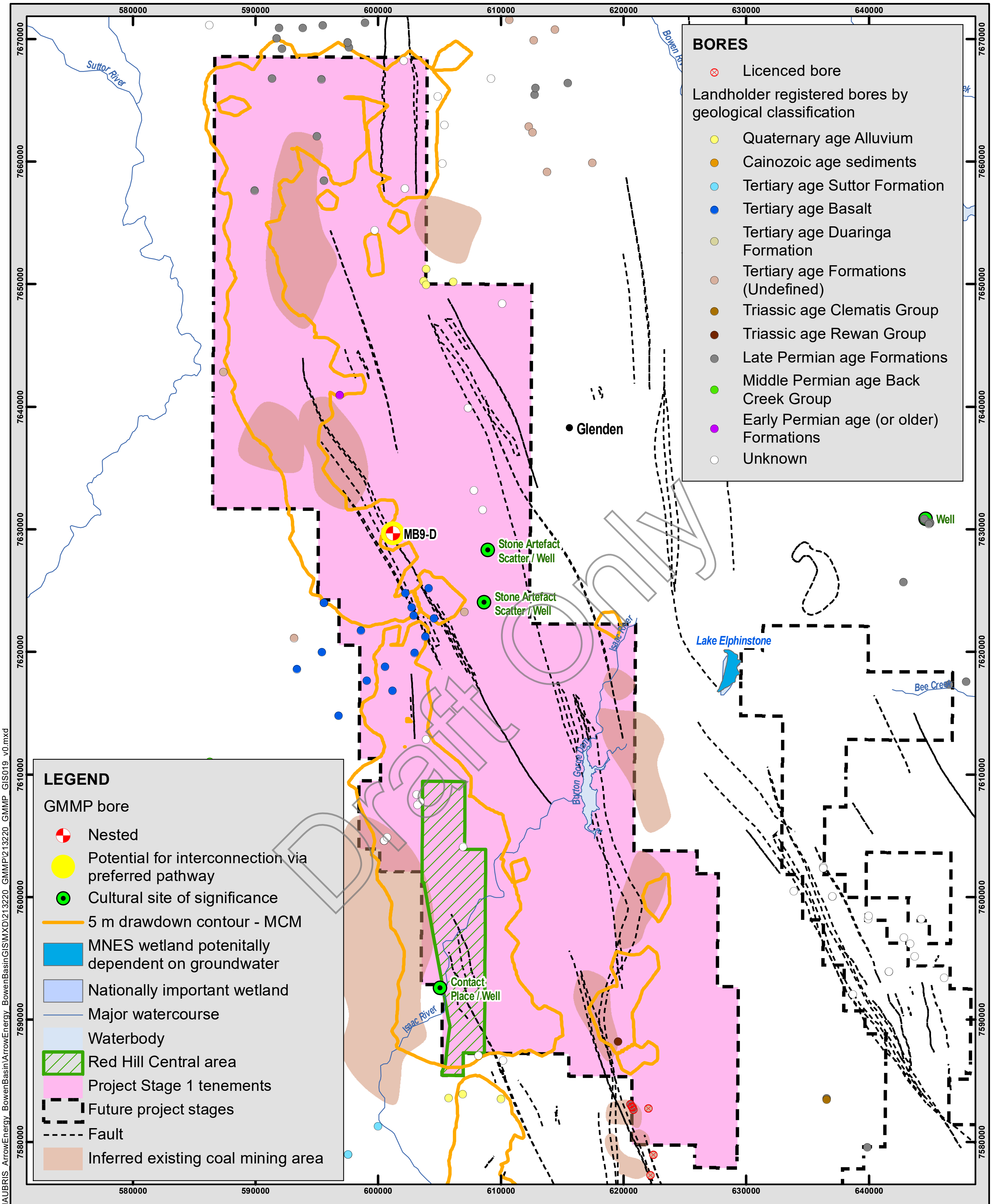


**Figure 4-4b** MCM monitoring bore network - Stage 1 northern development area

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

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Coordinate System: GDA 1994 MGA Zone 55

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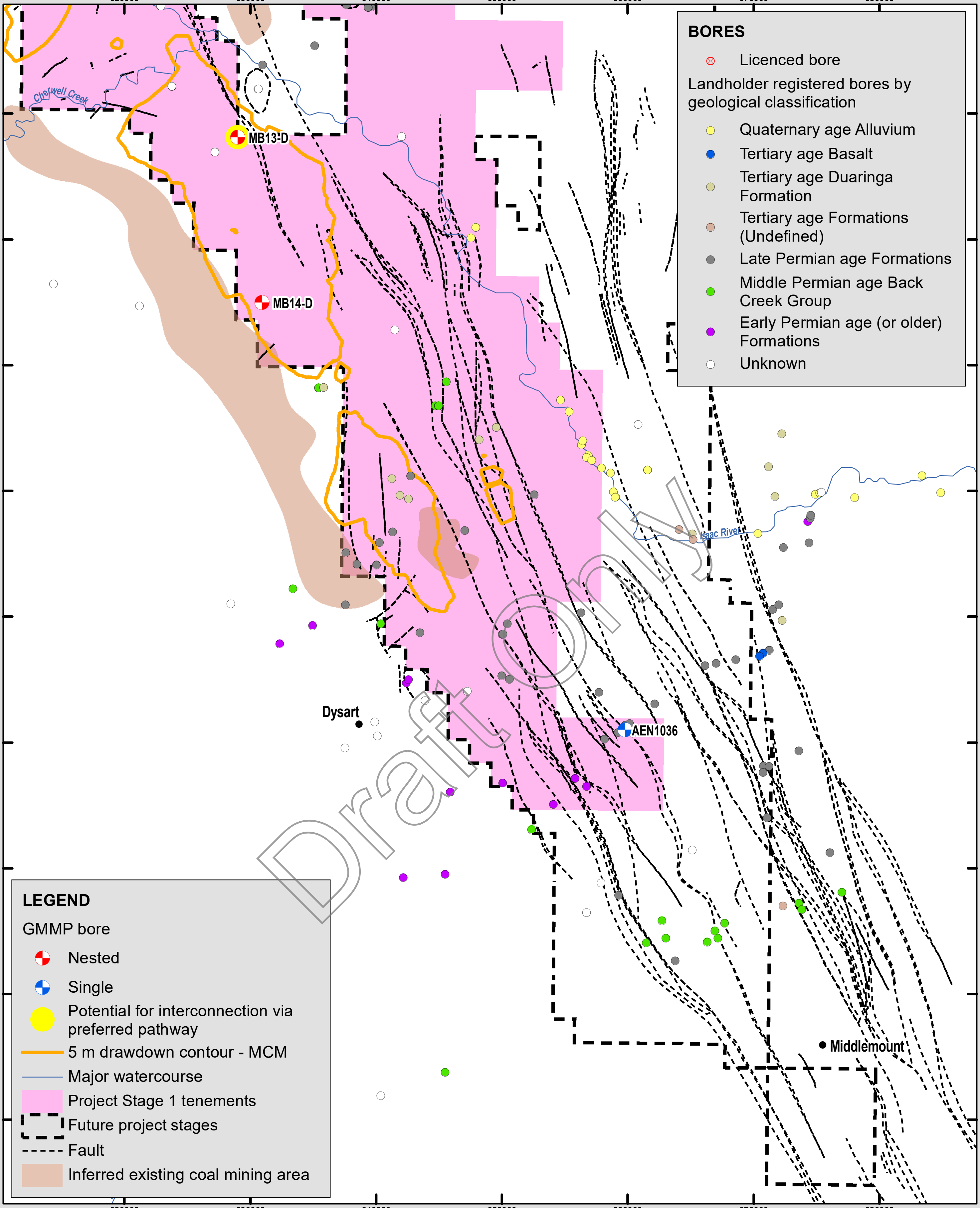


**Figure 4-4c** **MCM monitoring bore network - Stage 1 southern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 28/08/2019
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Author: Helen.Unkovich

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Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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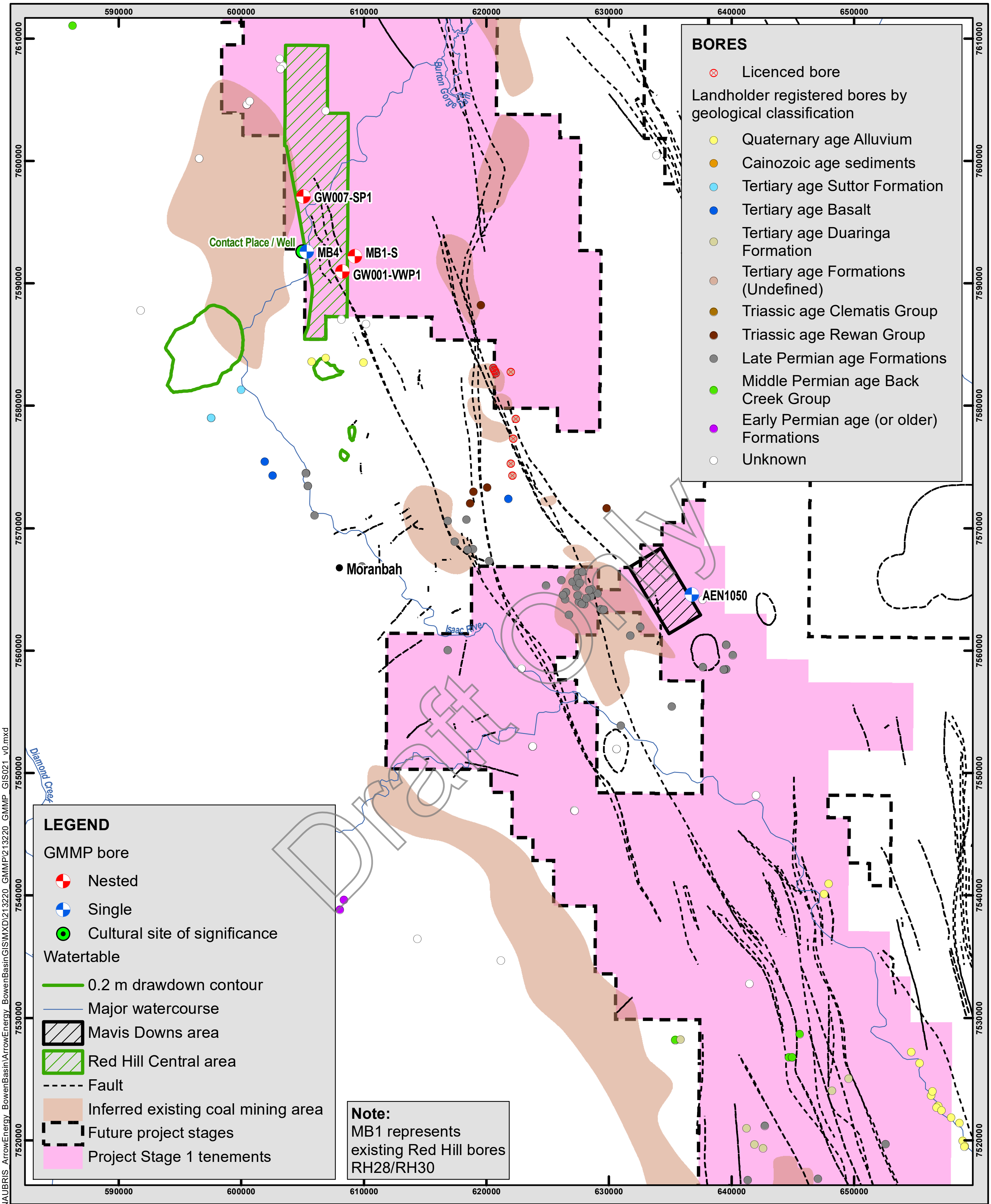


**Figure 4-5a Unconfined alluvium monitoring bore network - Red Hill Central & Mavis Downs development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 28/08/2019
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Author: Helen.Unkovich

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Coordinate System: GDA 1994 MGA Zone 55

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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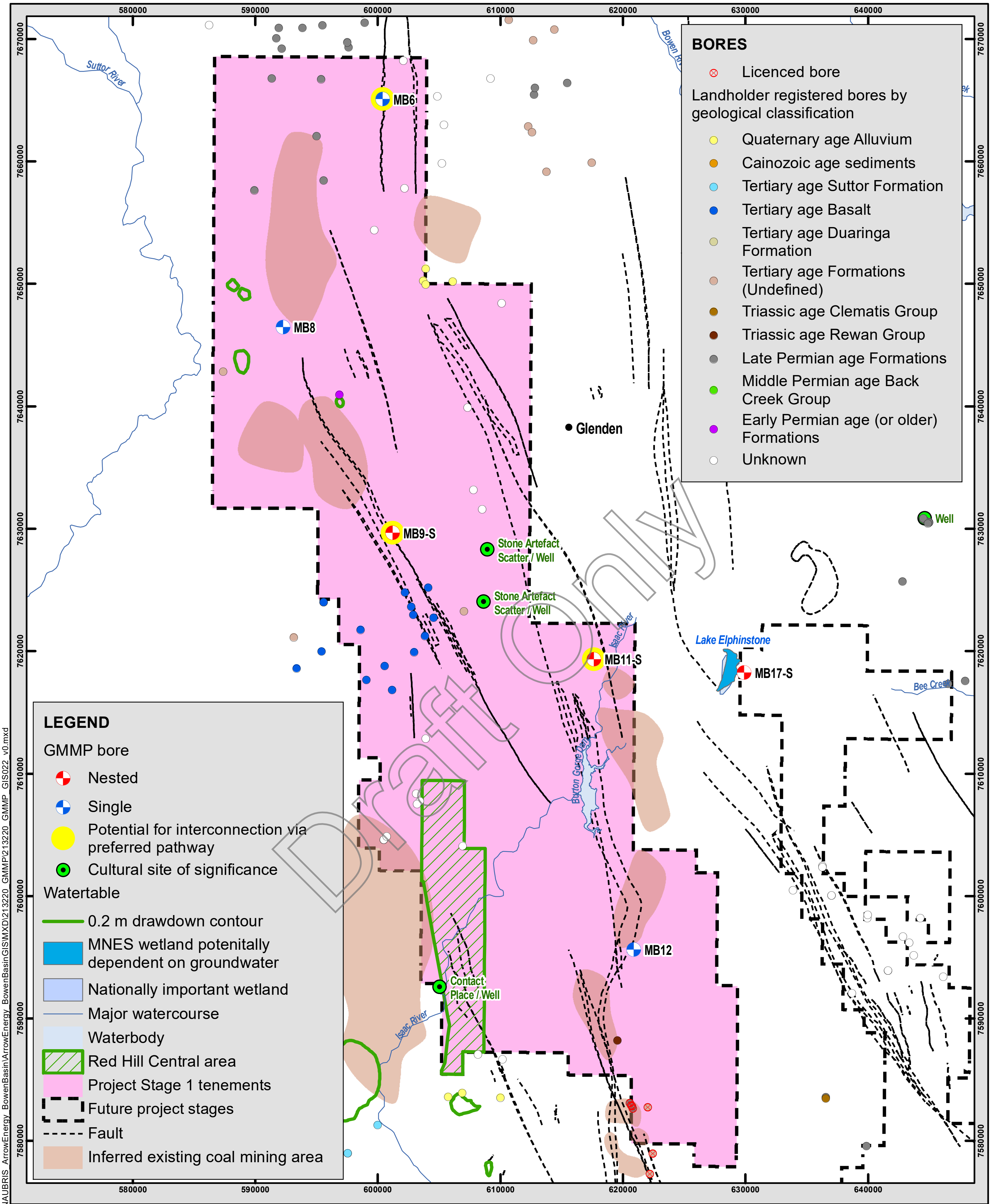


**Figure 4-5b** **Unconfined alluvium monitoring bore network - Stage 1 northern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 28/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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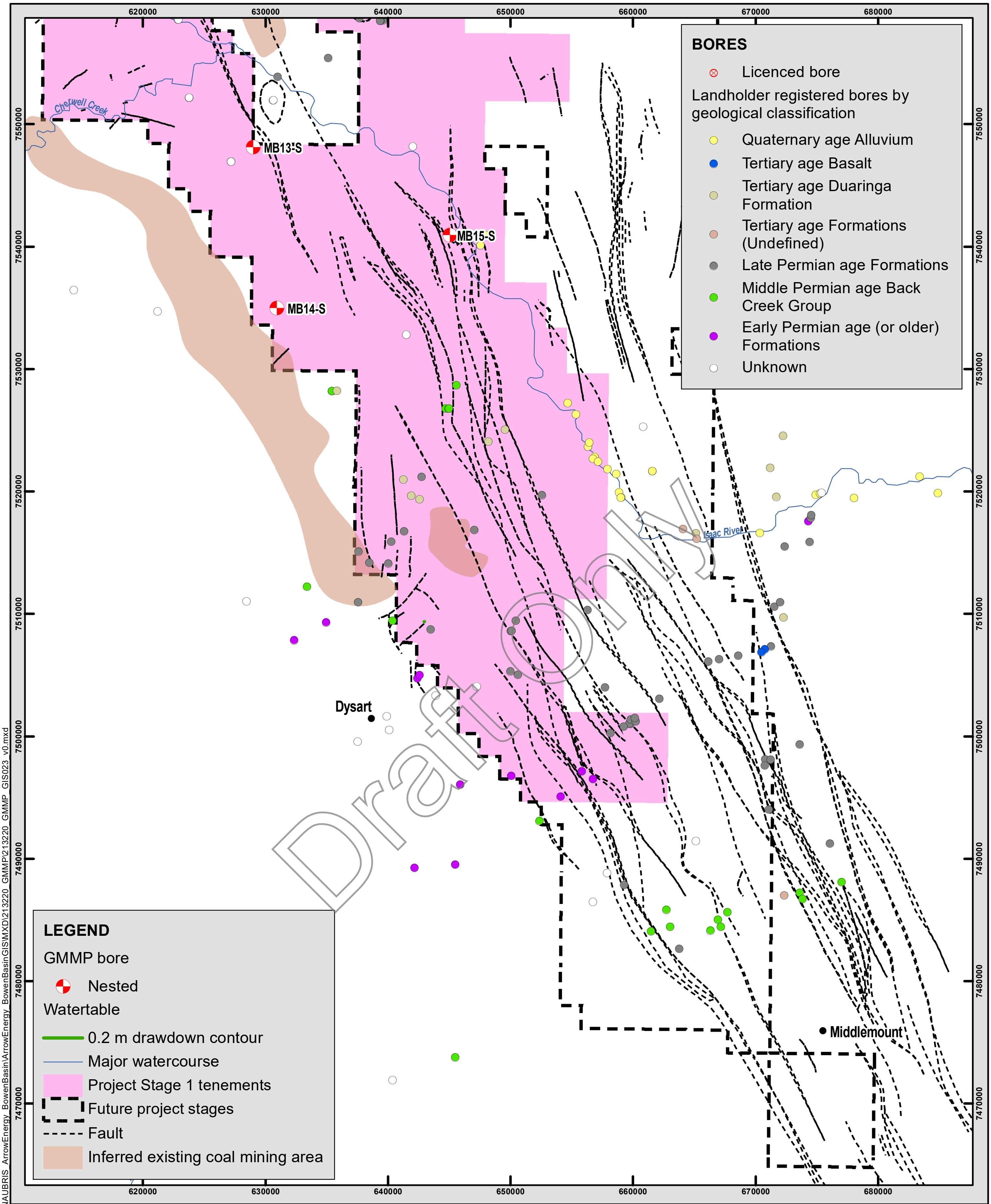


**Figure 4-5c** **Unconfined alluvium monitoring bore network - Stage 1 southern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

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Author: Helen.Unkovich

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Coordinate System: GDA 1994 MGA Zone 55

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ARROW ENERGY - BOWEN BASIN GAS PROJECT

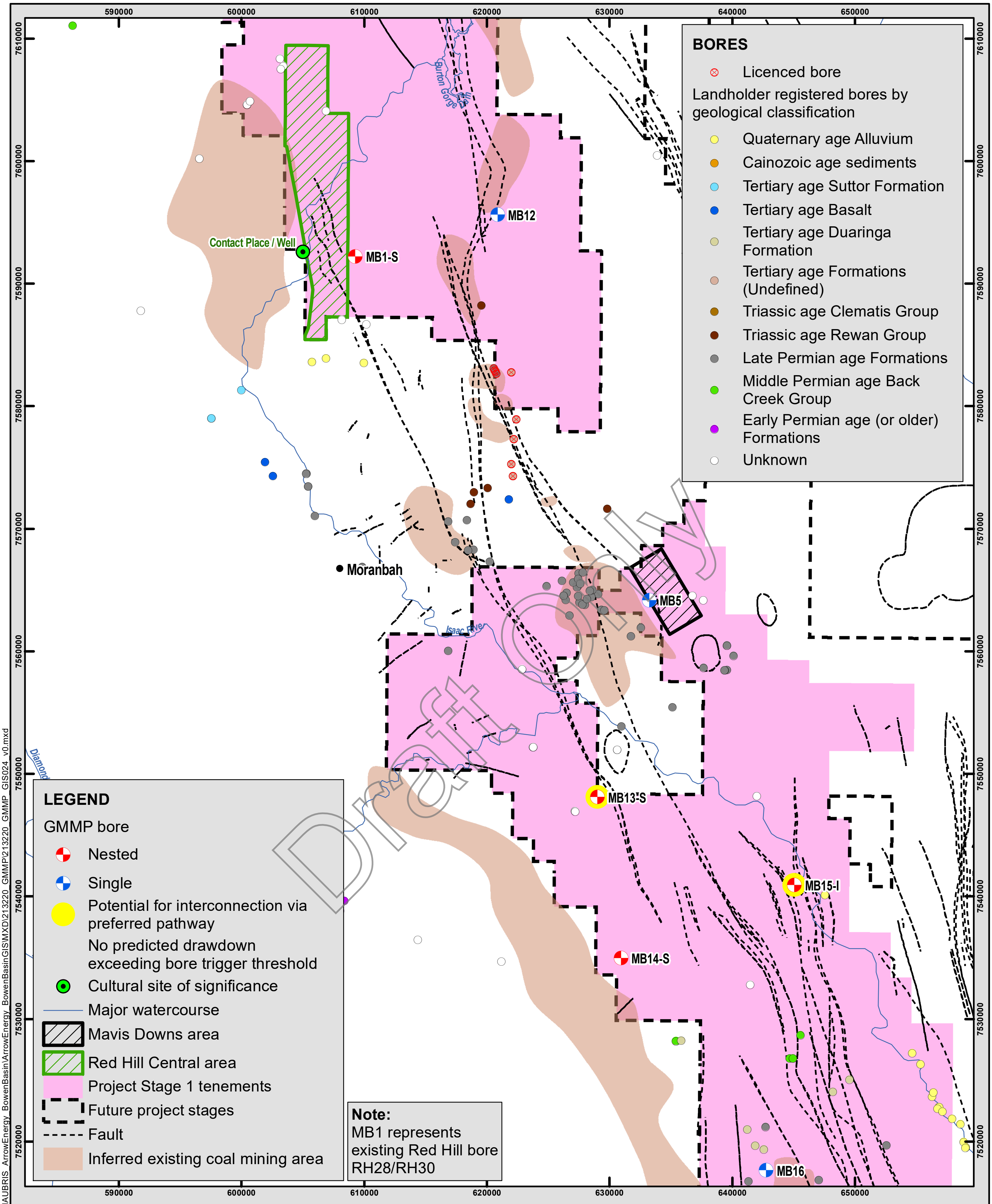


**Figure 4-6a Tertiary monitoring bore network - Red Hill Central & Mavis Downs development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

N

arrow energy
go further



The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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NOT FOR CONSTRUCTION

ARROW ENERGY - BOWEN BASIN GAS PROJECT

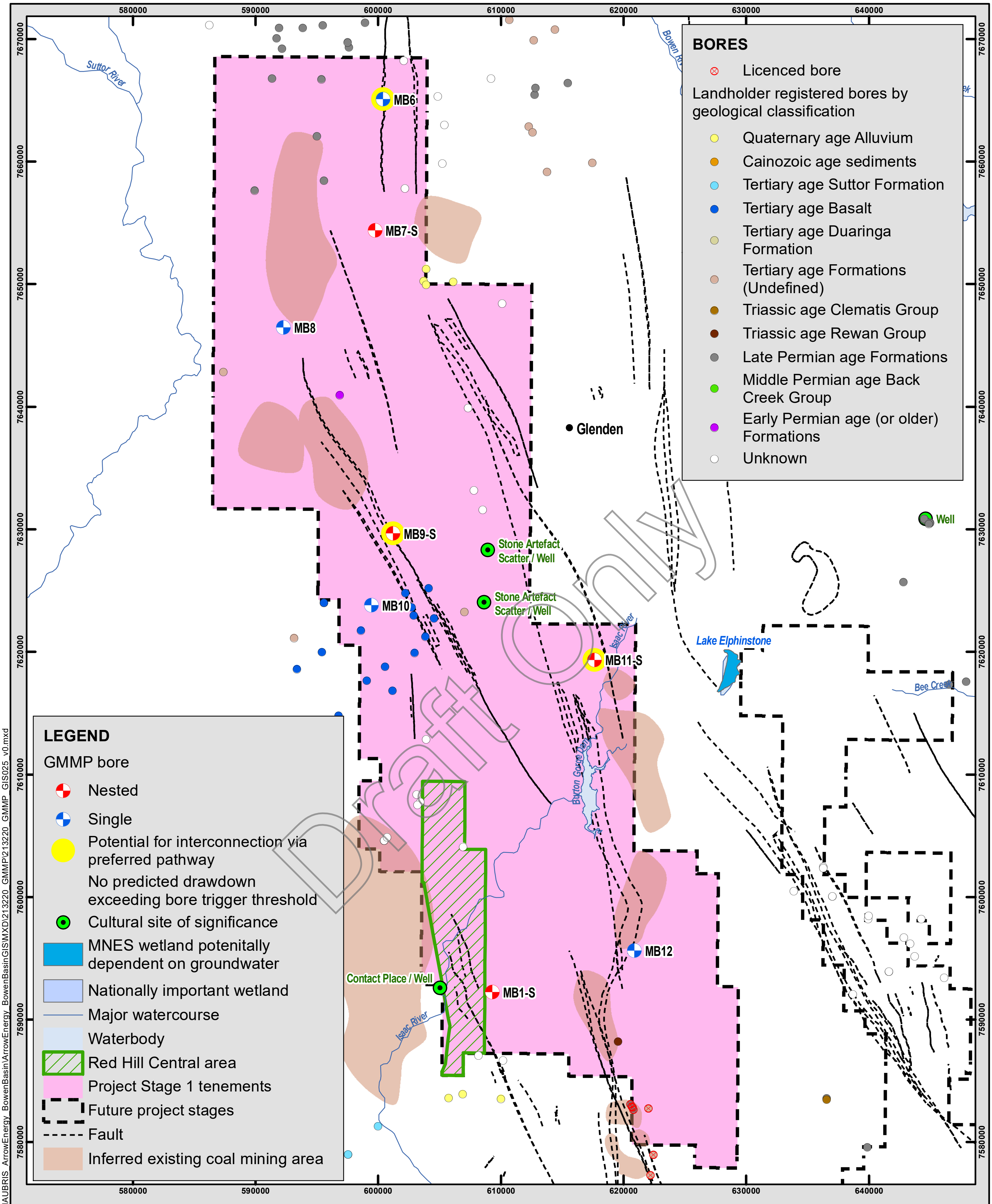


**Figure 4-6b** **Tertiary bore network - Stage 1 northern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
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Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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**NOT FOR CONSTRUCTION**

**ARROW ENERGY - BOWEN BASIN GAS PROJECT**

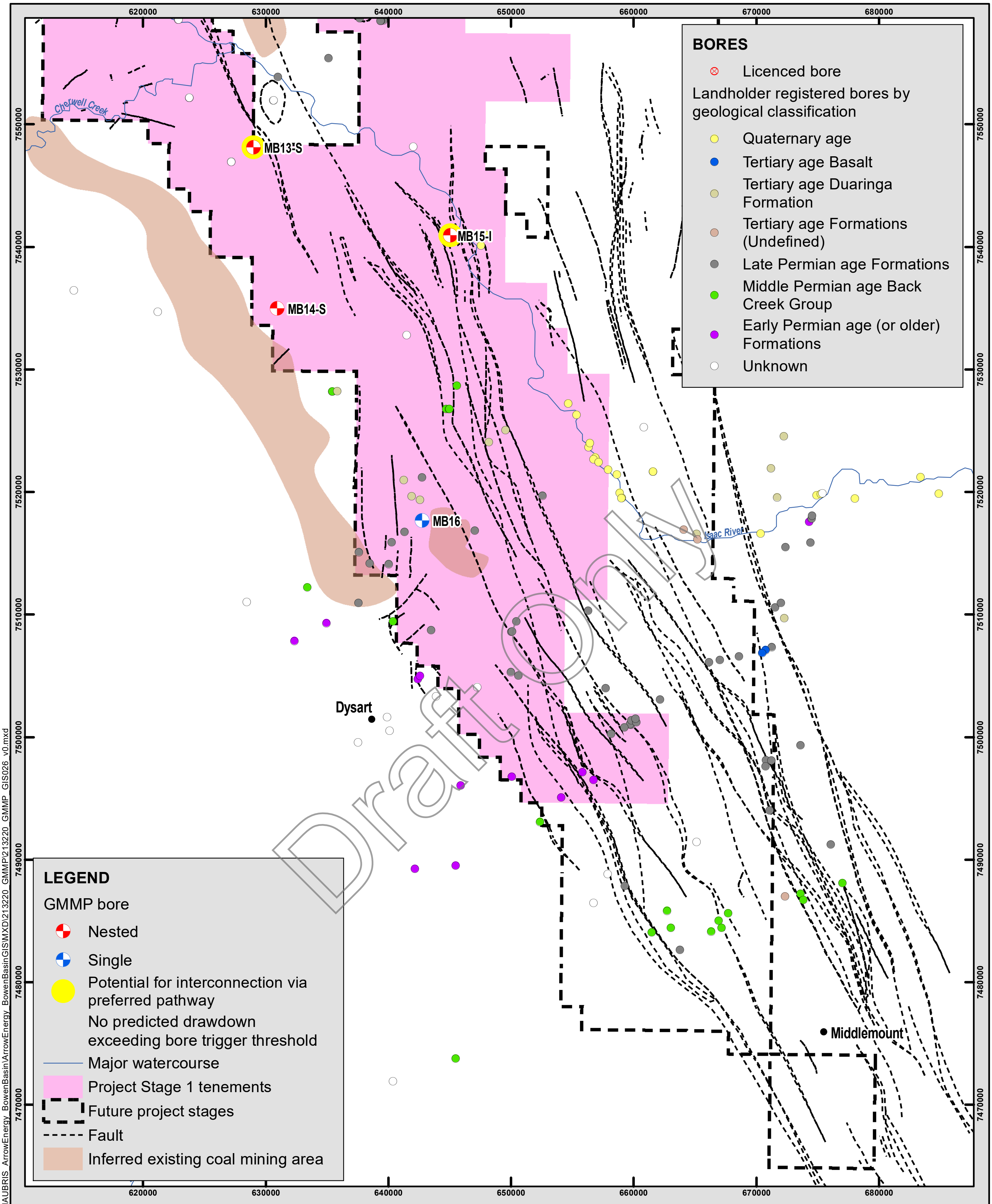


**Figure 4-6c** **Tertiary bore network - Stage 1 southern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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**NOT FOR CONSTRUCTION**

**ARROW ENERGY - BOWEN BASIN GAS PROJECT**

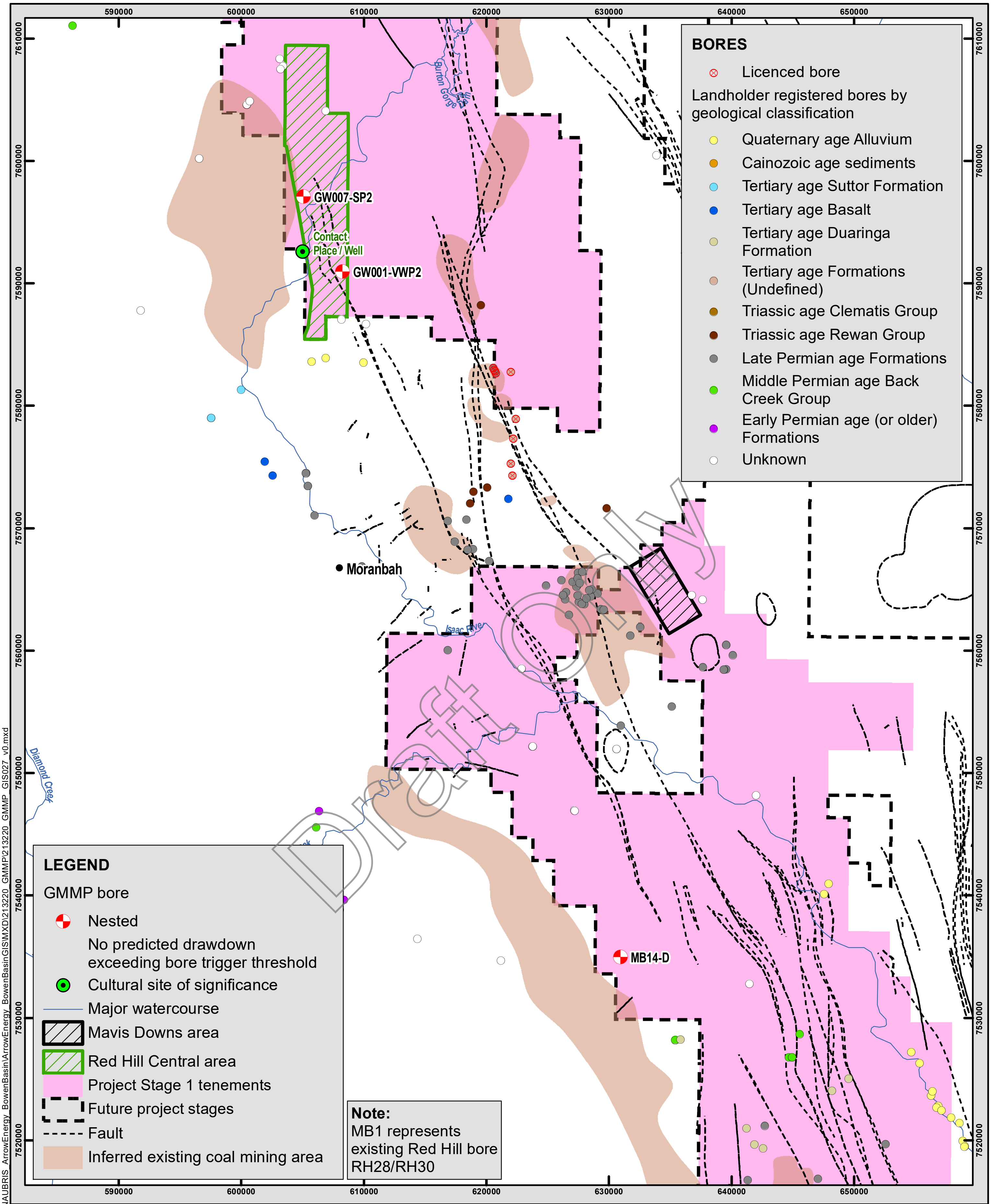


**Figure 4-7a** **FCCM monitoring bore network - Red Hill Central & Mavis Downs development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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**NOT FOR CONSTRUCTION**

ARROW ENERGY - BOWEN BASIN GAS PROJECT

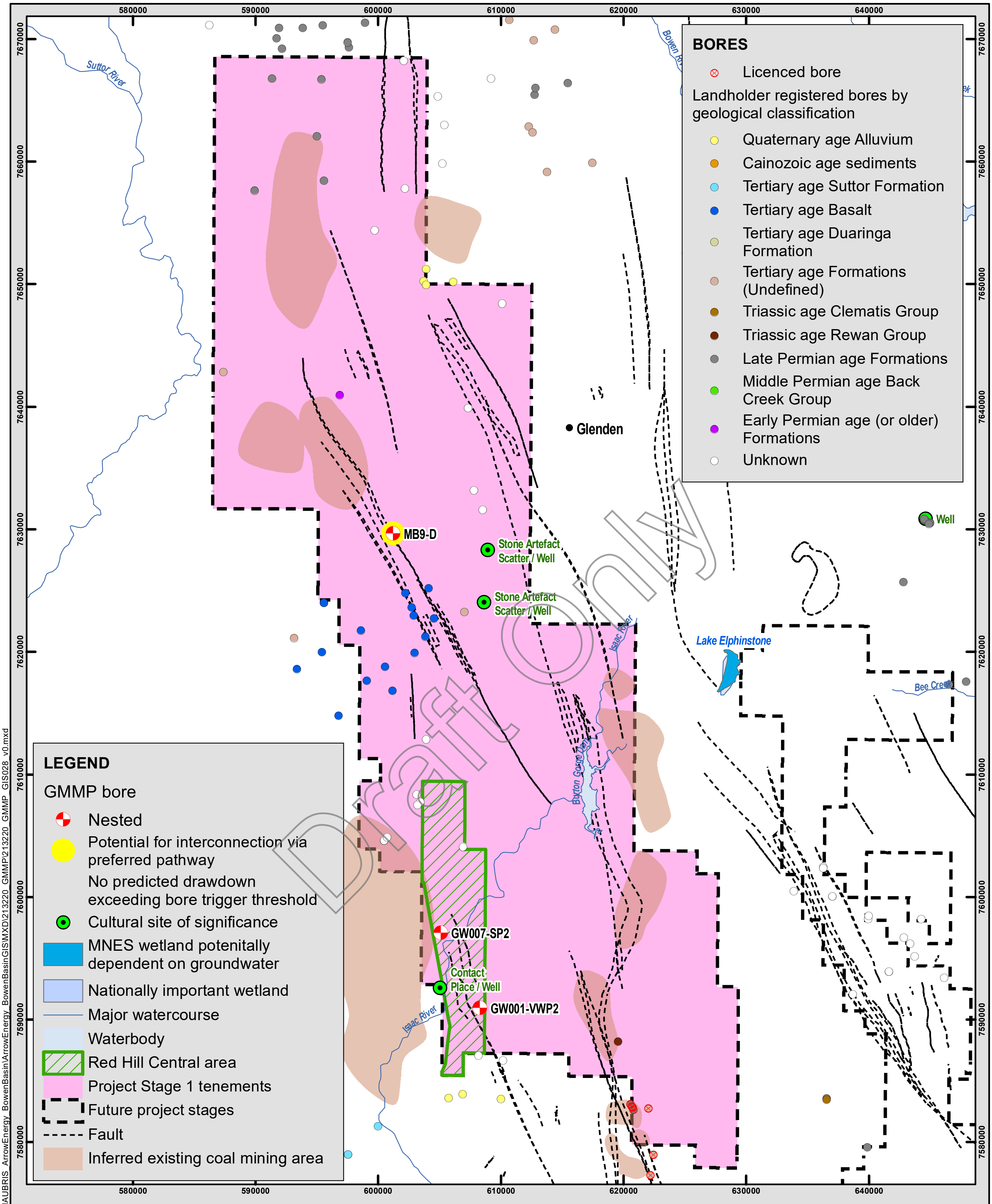


**Figure 4-7b** **FCCM bore network - Stage 1 northern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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NOT FOR CONSTRUCTION

**ARROW ENERGY - BOWEN BASIN GAS PROJECT**

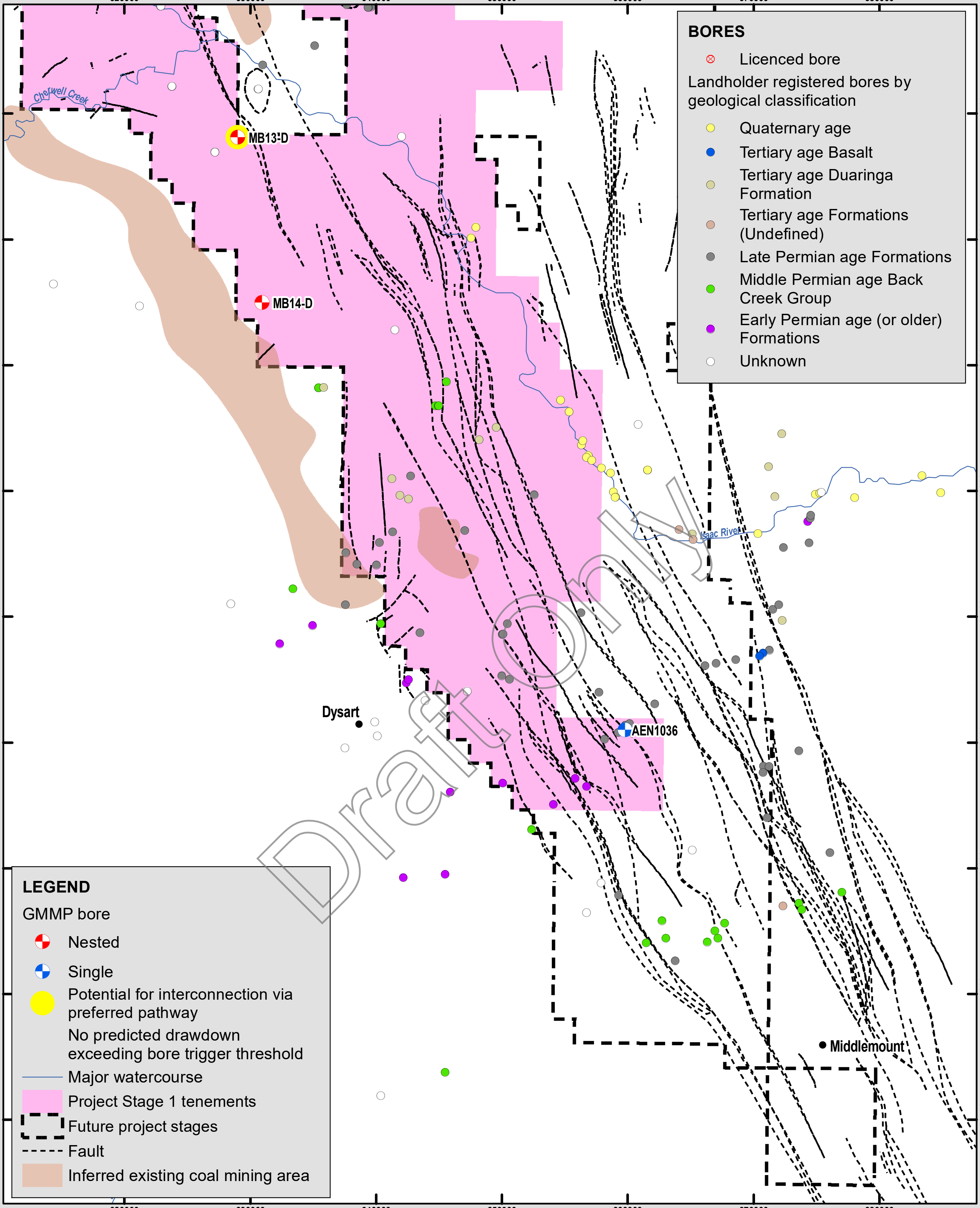


**Figure 4-7c** **FCCM monitoring bore network - Stage 1 southern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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**NOT FOR CONSTRUCTION**

**ARROW ENERGY - BOWEN BASIN GAS PROJECT**

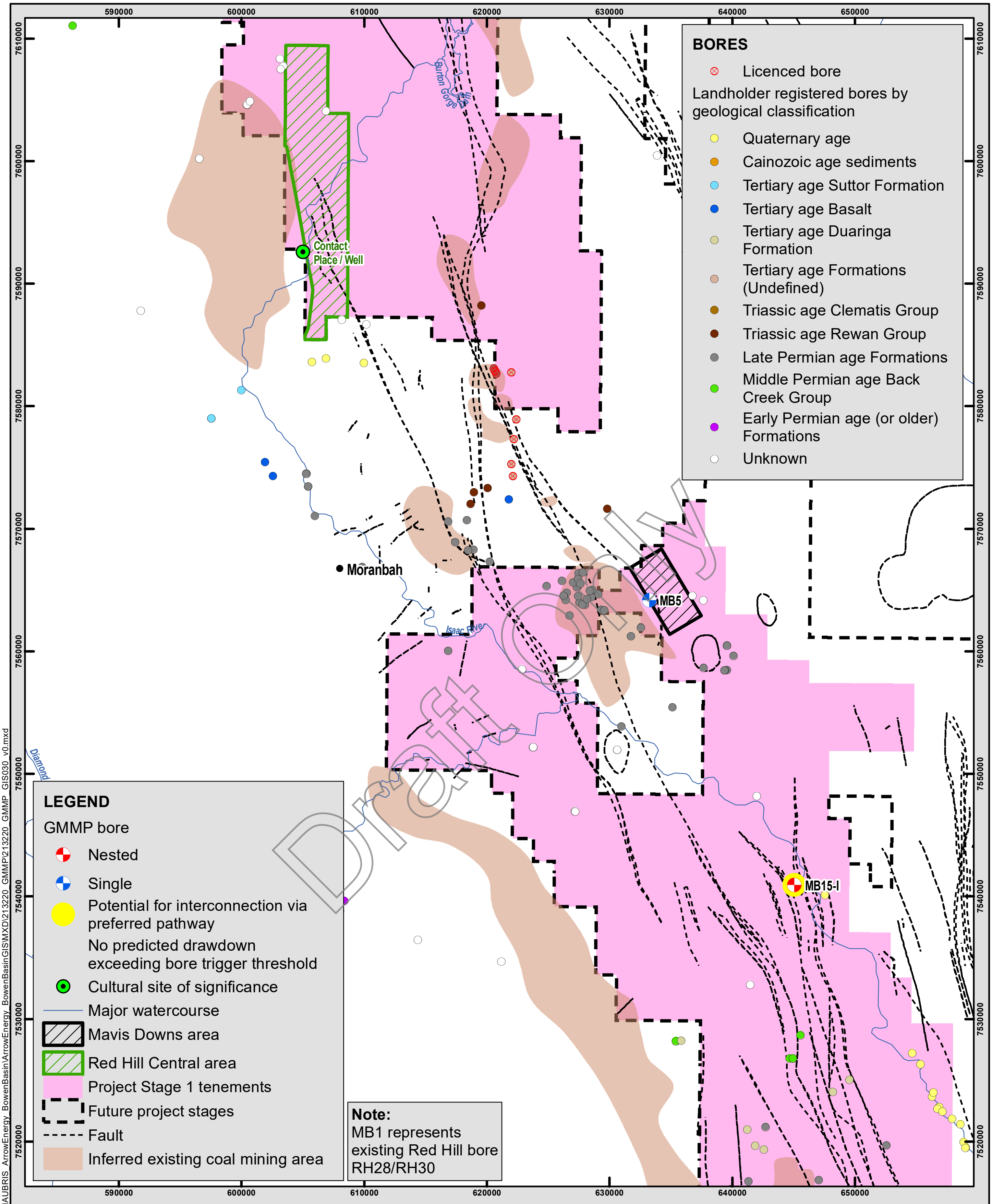


**Figure 4-8a Triassic monitoring bore network - Red Hill Central & Mavis Downs development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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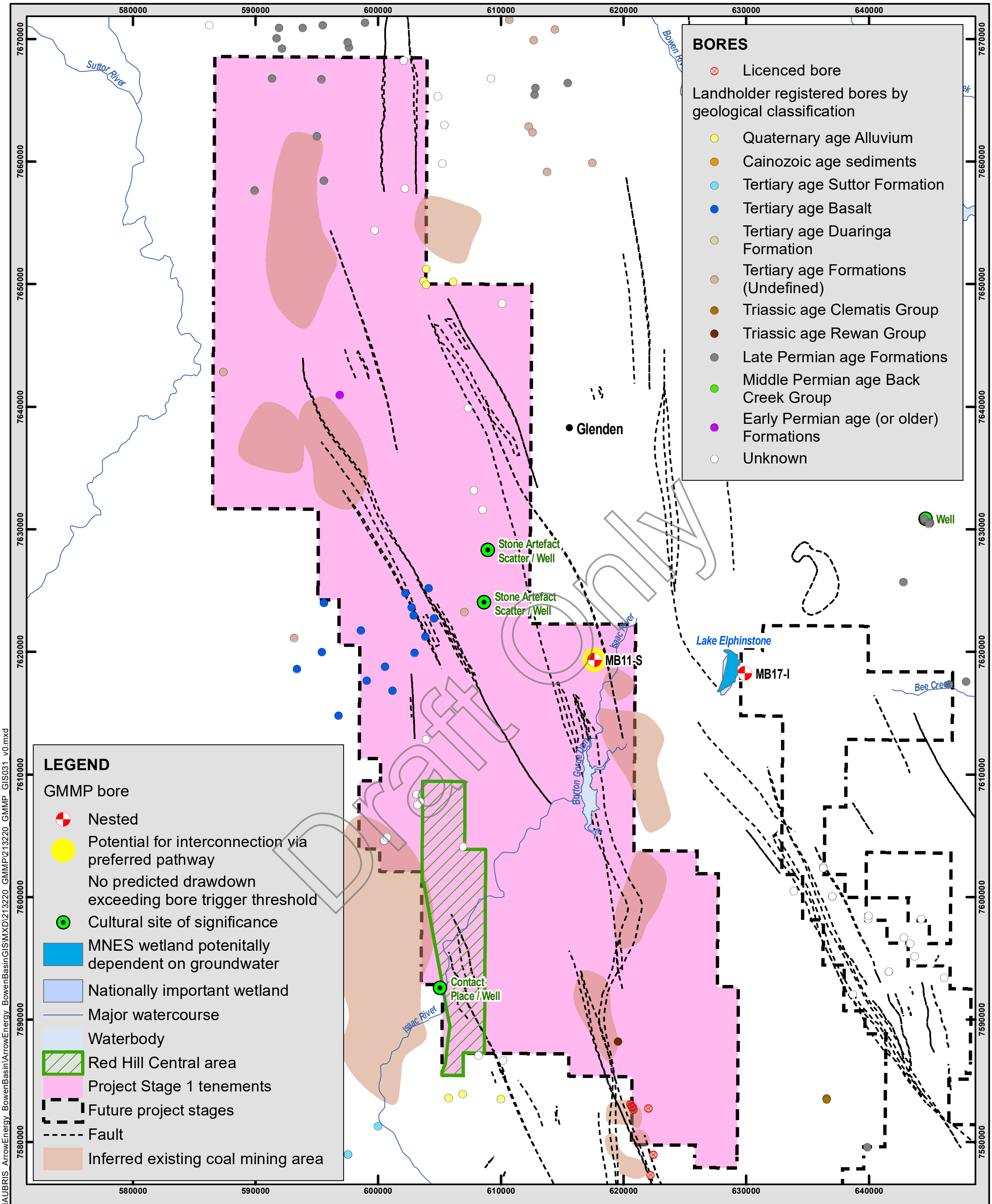
**NOT FOR CONSTRUCTION**

ARROW ENERGY - BOWEN BASIN GAS PROJECT




Document: \\Abtfarcv01\data$\GIS\7043_ENAUBRIS_ArrowEnergy_BowenBasin\ArrowEnergy_BowenBasinGIS\MXD\213220_GMMP\213220_GMMP_GIS031_v0.mxd

**Figure 4-8b** **Triassic bore network - Stage 1 northern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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NOT FOR CONSTRUCTION

# ARROW ENERGY - BOWEN BASIN GAS PROJECT

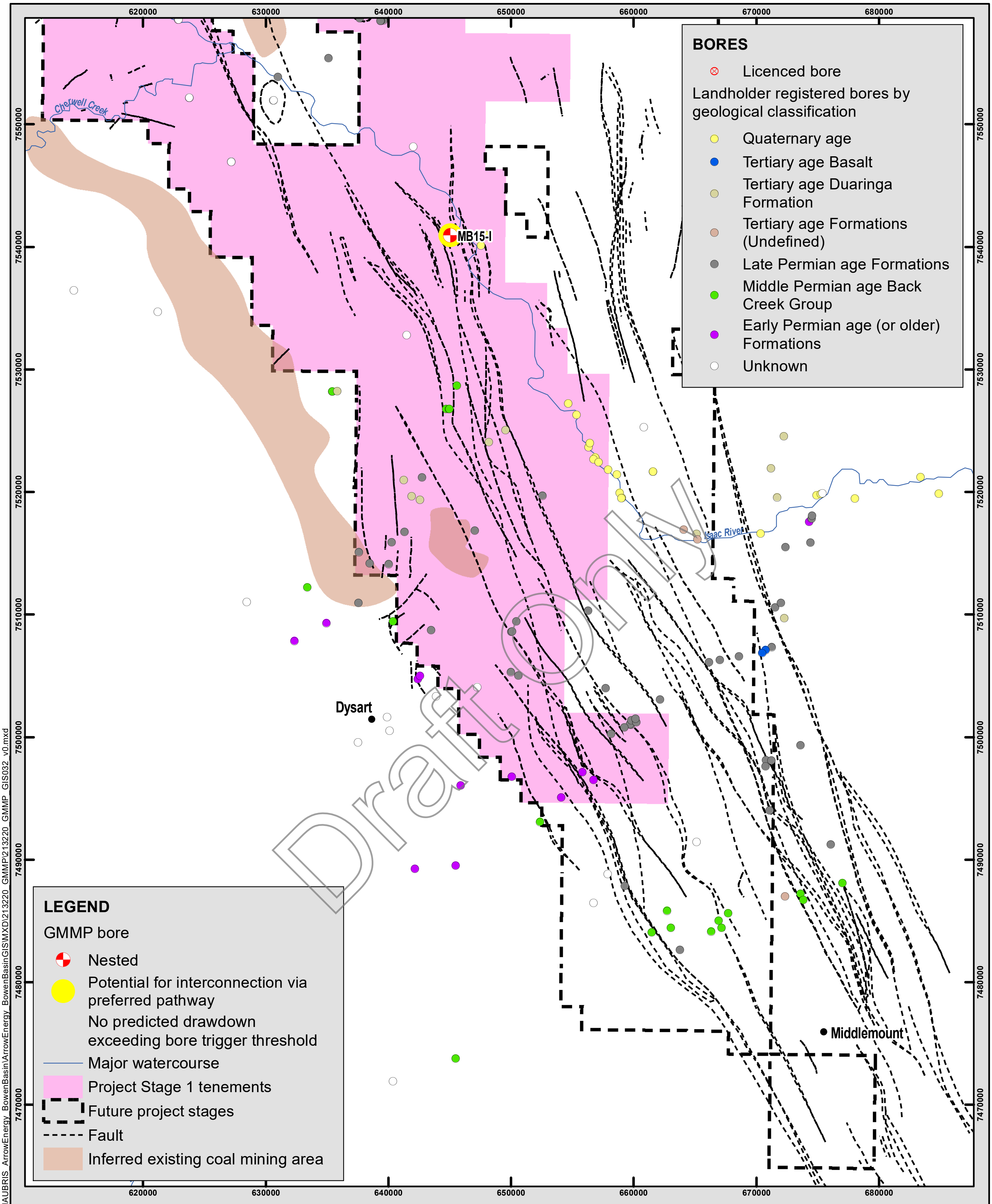


**Figure 4-8c** **Triassic bore network - Stage 1 southern development area**

**Source:**
Arrow Energy Pty Ltd
Coffey & Silwa (2016), Coffey (2018)
AGE (June 2018)

Date: 30/08/2019
Issued To: Arrow Energy
Author: Helen.Unkovich

0 2 4 8 12 16 20
Kilometres

Scale: 1:400,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.



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**NOT FOR CONSTRUCTION**

**ARROW ENERGY - BOWEN BASIN GAS PROJECT**

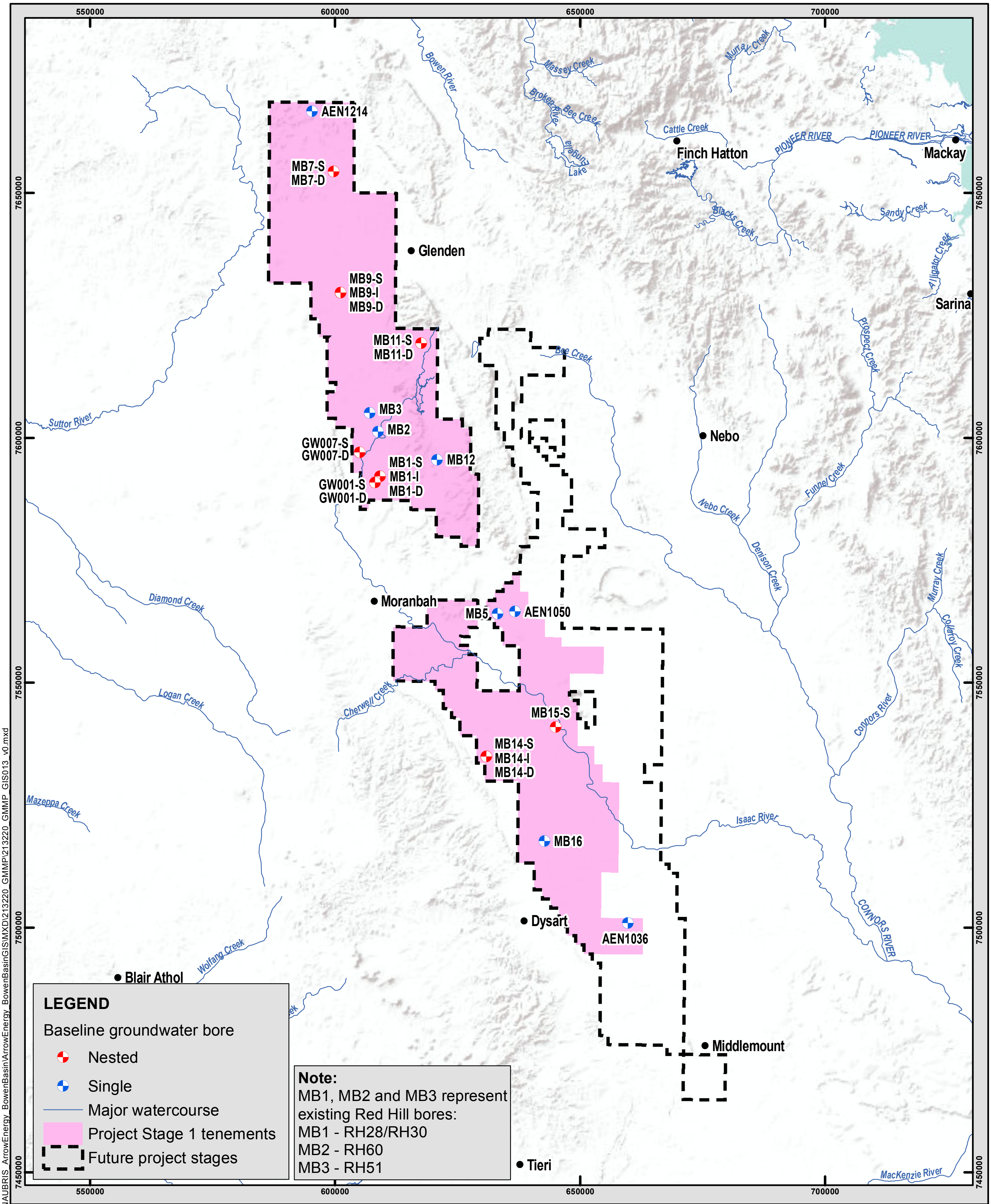


**Figure 4 -9** **BGP development area – Project Stage 1 - GMMP baseline monitoring bore network**

**Source:**
Arrow Energy Pty Ltd
Coffey
ESRI Online

Date: 15/08/2019
Issued To: Arrow Energy
Author: helen.unkovich

0 5 10 20 30 40 50
Kilometres

Scale: 1:1,000,000 @ A4
Coordinate System: GDA 1994 MGA Zone 55

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Document: \\Abtfarcv01\data$\GIS\7043_ENAUBRIS_ArrowEnergy_BowenBasin\ArrowEnergy_BowenBasinGIS\MXD\I213220_GMMP\I213220_GMMP_GIS013_v0.mxd

**NOT FOR CONSTRUCTION**

### 4.4.2 Supplementary monitoring bores

The monitoring network includes 5 supplementary monitoring locations, including 7 monitoring intervals. These monitoring locations comprise existing third-party monitoring bores and landholder bores and are included in the monitoring network specification (Table 4-2).

## 4.5 Monitoring program

The groundwater monitoring program is founded on the collection of sufficient groundwater level/pressure and groundwater quality data to fulfil the objectives of the monitoring network (Section 4.3) and to comply with Commonwealth Approval Conditions 21 to 25 and specified Arrow EIS/SREIS commitments. The groundwater monitoring program is described in the following section below.

### 4.5.1 Groundwater pressure and level

All functional Project Stage 1 GMMP monitoring points will be monitored for groundwater pressure/level. Table 4-4 presents the groundwater pressure and level monitoring program for monitoring sites with a primary purpose of baseline data collection (11 monitoring locations) and those with other primary purposes (3 monitoring locations), excluding 5 contingent locations.

Following the first 12 months of data collection at each baseline monitoring site, the data will be reviewed to characterise temporal and spatial variations in groundwater levels. Where there is confidence that the observed trends are adequately understood, the monitoring frequency will be reduced in accordance with the program specified in Table 4-4.

Consistent with the UWIR, the 12-month period is considered appropriate due to:

- The limited groundwater level variation from climate or seasonal fluctuations due to the depth of the confined formations (low recharge) and low permeability – for determining baseline levels.
- The length of time over which groundwater level impacts develop as a result of the CSG development.
- The stability of groundwater quality in these low permeability formations, and the delayed impact of CSG development on groundwater quality (if there is any impact on groundwater quality) relative to impact on groundwater levels (as change in groundwater quality is dependent on inducing flow).

In some instances, there may be a need to continue monitoring at the initial higher frequency to advance the conceptual understanding of the local and regional scale hydrogeological regime.

**Table 4-4 Groundwater level/pressure monitoring program**

| Monitoring location purpose | Monitoring location ID (1,3) | Minimum monitoring frequency (2) | |
|---|---|---|---|
| | | Initial 12 months following installation | Remainder of CSG production |
| **Baseline monitoring** | MB1-S, MB1-I, MB1-D<br>MB2<br>MB3<br>MB5<br>MB7-S, MB7-D<br>MB9-S, MB9-I, MB9-D<br>MB11-S, MB11-D<br>MB12<br>MB14-S, MB14-I, MB14-D<br>MB15-S, MB15-D<br>MB16 | Twice daily (via data logger) and 6-monthly manual readings | 6-monthly manual readings |
| **Other** | MB8<br>MB10<br>MB13-S | Twice daily (via data logger) and 6-monthly manual readings | 6-monthly manual readings |
| **Supplementary** | AEN1214<br>AEN1036<br>AEN1050<br>GW007 | Not applicable | 6-monthly manual(4) readings |
| | GW001 | Not applicable | Annual data download from VWP logger |

***Notes:***
*(1) S: shallow monitoring point, I: intermediate monitoring point, D: deep monitoring point (monitoring points and monitoring intervals have the same meaning).*
*(2) Timing for 6-monthly readings will be informed by the peaks and troughs identified during initial 12-month continuous (twice daily) data logger measurements.*
*(3) MB4, MB6, MB13-D, MB17-S and MB17-D are contingent locations (refer Section 4.4.1) and not included in the table above.*
*(4) Monitoring frequency may be revised at a future time, if data loggers are implemented.*

### 4.5.2 Groundwater quality

Groundwater quality monitoring will be undertaken at eleven groundwater monitoring locations. All monitoring intervals at nested monitoring site intervals will be sampled and analysed for groundwater quality. The exception is MB1 which will be re-purposed from RH28/RH30. Due to well completion constraints, it will not be possible to sample from the intermediate and shallow intervals at this site. Should pressure data indicate the potential for inter-connectivity between the MCM and overlying units at this site, a shallow groundwater quality monitoring point will be established:

- Red Hill Central: MB1-D
- Mavis Downs: MB5
- BGP FDP (northern development area): MB7-S/D, MB8, MB9-S/I/D, MB10, MB11-S/D
- BGP FDP (southern development area): MB13-S, MB14-S/I/D, MB15-S/I, MB16

Nested site bores MB13-D and MB17 (MB17-S and MB17-I) are contingent monitoring bores, the latter in proximity to Lake Elphinstone. Should these monitoring bores be installed, groundwater quality monitoring will be initiated in all the intervals.

During the initial twelve months following monitoring point installation, groundwater quality monitoring will be conducted on a 6-monthly basis and include the physical parameter and full analytical suites presented in Table 4-5. Following the initial monitoring, groundwater quality monitoring will be conducted annually. A reduced laboratory analytical suite may be selected for monitoring locations, if supported by a review of the initial monitoring data.

**Table 4-5 Groundwater quality monitoring program**

| Suite | Selected parameters / analytes | Comment |
|---|---|---|
| **Physical parameters** | Electrical conductivity (EC)<br>pH<br>Redox potential (Eh)<br>Dissolved oxygen (DO)<br>Temperature | The selected parameters will be measured in the field during every sampling event. |
| **Full laboratory analytical suite** | Total dissolved solids (TDS)<br>Major cations and anions (calcium, magnesium, potassium, sodium, chloride, sulphate, bicarbonate, carbonate and total alkalinity)<br>Speciated nitrogen (nitrite, nitrate, ammonia)<br>Fluoride<br>Strontium<br>Dissolved metals (arsenic, barium, boron, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, zinc)<br>Total and dissolved organic carbon (TOC/DOC)<br>Total phosphorus | The full analytical suite will be reviewed on a site-by-site basis following the first year of monitoring.<br>The analysis suite may subsequently be rationalised if supported by a review of the initial monitoring data. |

| Suite | Selected parameters / analytes | Comment |
|---|---|---|
| **Discretionary analyses** | Dissolved methane<br>Stable isotopes | Laboratory analysis where field observations indicate a requirement (e.g. groundwater sample is de-gassing or methane is detected at a wellhead). |

### 4.5.3 Data management and analysis

Implementation of the Project Stage 1 GMMP will generate considerable data including field records and observations, electronically logged water levels / pressure and laboratory water quality analysis. All data generated will be collated electronically and stored in a dedicated project database.

At a minimum, the database will contain details of:

- GMMP monitoring locations, construction details and monitored aquifer;
- Monitoring point drilling records, survey records, geophysical logs and interpreted stratigraphy;
- Any permanent monitoring location infrastructure or instrumentation;
- Groundwater level and pressure records; and
- Groundwater quality records (field records and observations, and laboratory analysis).

Following upload to the project database, data will be reviewed for transcription errors and consistency with historical data. Where anomalies are identified, or trends markedly deviate from model drawdowns, further data assessment and/or analysis will be triggered.

For each monitoring site, at the end of the first year of monitoring, groundwater level/pressure and quality data will be reviewed in detail to determine whether it is appropriate to reduce the monitoring frequency as described in Sections 4.5.1 and 4.5.2, respectively.

Should changes to monitoring frequencies be warranted (specifically reduced monitoring frequency), in accordance with Approval Condition 22, these changes would be implemented only following endorsement by suitably qualified water expert/s approved by the Minister in writing.

## 4.6 Groundwater balance

A water balance for the Bowen Basin was presented in the SREIS to quantify major inflows and outflows of the regional groundwater system for the duration of water production for the Project, and to predict changes in groundwater storage.

The water balance considered groundwater extraction (BGP and MGP, and other groundwater users). Data for the water balance was derived from the Arrow Bowen Basin EIS groundwater model (Ausenco-Norwest, 2012) and from DNRMs Water Management System Database (formerly the Water Entitlements Registration Database. It included gross recharge and evapotranspiration, and river baseflow.

The values provided in the SREIS were established through the model calibration process because many regional water balance parameters, such as recharge and evapotranspiration, cannot be measured directly.

### 4.6.1 Project Stage 1 GMMP water balance

**Project Stage 1 FDP water production**

As described in Section 1.2, water production for the Project Stage 1 FDP (82.25 GL) is substantially reduced from the SREIS FDP case (153 GL). This reduced water production will decrease the predicted reduction in aquifer storage, relative to the SREIS.

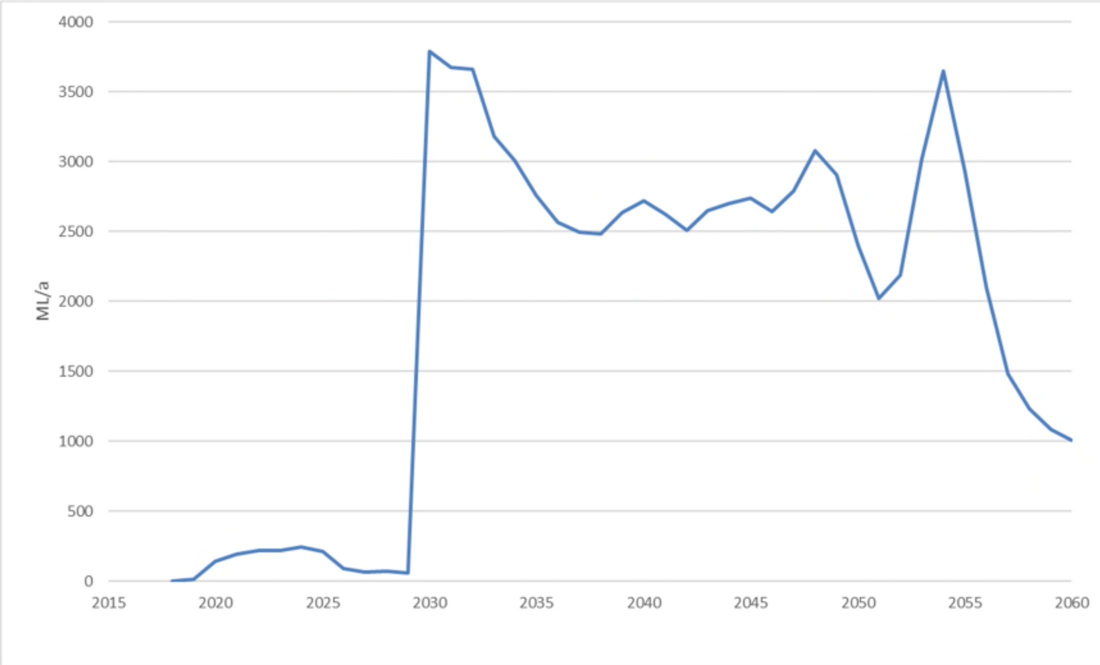
Project Stage 1 production volumes for Mavis Downs, PLa486, Red Hill Central, and the remainder of the Project Stage 1 area are provided in Table 4-6, and combined as shown on Figure 4-10 .

**Table 4-6 Project Stage 1 water production components**

| Component | Operational period | Total production (GL) |
|---|---|---|
| **Red Hill Central (Pl(a)486)** | 2019 to 2025 | 0.88 |
| **Mavis Downs** | 2021 to 2030 | 0.67 |
| **BGP (remainder of the Project Stage 1 area)** | 2030 to 2060 | 80.7 |
| **Total** | | **82.25** |

Approximately 90% of the GMMP FDP production is from the Moranbah Coal Measures, with the remainder form the Rangal Coal Measures.

**Figure 4-10 Project Stage 1 combined water production**




### Numerical model steady-state water balance

Values for model predicted inflows and outflows for the pre-development steady-state numerical model (AGE, 2018) underpinning the Project Stage 1 GMMP case are summarised in Table 4-7.

Under steady-state conditions, model inputs are balanced by model outputs resulting in no nett storage change under this no-abstraction scenario.

**Table 4-7 Pre-development model water balance**

| Parameter | In $m^3$/day | Out $m^3$/day | Nett $m^3$/day |
|---|---|---|---|
| **Rainfall recharge** | 313,100 | 0 | 313,100 |
| **River** | 0 | 32,208 | -32,208 |
| **Evapotranspiration** | 0 | 274,930 | -274,930 |
| **General head boundaries** | 1,171 | 7,133 | -5,962 |
| **Total** | **314,271** | **314,271** | **0** |

The steady-state model provides the initial starting basis for the predictive modelling, which incorporates groundwater abstraction for CSG and non-CSG uses.

### Predictive model water balance flux predictions

Table 4-8 presents the modelled formation fluxes for the duration of the predictive simulation (164 years – 2017 to 2181). These results represent the Project Stage 1 FDP case (refer Table 3-1) together with historical and future MGP production (historical abstraction from 2003 to 2017, future abstraction from 2017 to 2060).

**Table 4-8 Predictive simulation flux balance (GL)**

| Formation | Layers | Flux in | Flux out | Nett flux | GHB flux | Well flux |
|---|---|---|---|---|---|---|
| **Quaternary alluvium** | 1 | 3396.91 | 3609.22 | -212.32 | -150.94 | - |
| **Tertiary sediments, basalt & Moolayember Formation** | 2 | 313.77 | 3824.29 | -3510.51 | -11.33 | - |
| **Clematis Sandstone** | 3 | 409.10 | 293.17 | 115.93 | -155.91 | - |
| **Rangal Coal Measures** | 4 - 7 | 32.48 | 24.86 | 7.62 | -14.93 | -8.31 |
| **Fort Cooper Coal Measures** | 8 - 10 | 30.89 | 24.11 | 6.78 | -15.61 | - |
| **Moranbah Coal Measures** | 11 - 21 | 136.53 | 140.92 | -4.38 | -0.91 | -73.81 |
| **Collinsville Formation, Back Creek Group** | 22 | 80.59 | 92.94 | -12.34 | -8.13 | - |
| **Totals** | | **4400.3** | **8009.5** | **-3609.2** | **-357.77** | **-82.12** |

**Note:**
GHB = general head boundary flux. Well flux = CSG water extraction.

The decline in storage will be partly offset by enhanced recharge, which can occur in a basin setting due to the increased hydraulic gradients that result from groundwater extraction. An undeveloped groundwater basin exists in a state of approximate equilibrium that balances groundwater recharge and discharge processes, and the flows between formations are normally in approximate steady-state. Stresses such as groundwater development necessarily alter basin equilibrium, and recharge boundary conditions are changed as a result, in part due to vadose zone processes. This can lead to increased rates of groundwater recharge; however such effects are not fully accounted for in groundwater models, and therefore not represented in the water balance.

### 4.6.2 Assessing water balance changes

Changes to the water balance in a groundwater aquifer or basin are manifested as changes in groundwater potentiometric levels. Because the predicted drawdown is derived from the same model used to predict water balance changes, drawdown and changes in storage are directly correlated. Therefore, measurement of groundwater drawdown is a proxy for monitoring changes in basin storage.

The monitoring network is detailed in Table 4-2 and summarised in Table 4-3. Each monitoring bore represents a location for monitoring groundwater levels, and therefore contributes to monitoring changes to the project area groundwater balance.

Arrow will update the understanding of the project area groundwater with each annual review after a new UWIR is published, as described in Section 6.2.3. The reporting will include an assessment and interpretation of changes to the project area water balance, based on changes to the numerical groundwater model and FDP.

# 5. EARLY WARNING SYSTEM

This section presents the Early Warning System (EWS) for the BGP GMMP to address Approval Condition 21(d) which requires that proposed early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels, in accordance with the requirements of the UWIR, be described.

Section 5.1 provides an overview and rationale for the EWS, while Section 5.2 presents a description of the EWS, including specification of the limits, trigger thresholds and early warning indicators.

In response to Approval Condition 21(e), the exceedance response actions accompanying the EWS, including timeframes, are described in Section 5.3.

## 5.1 Overview

### 5.1.1 Target systems

**Consolidated and unconsolidated aquifers**

UWIRs must include, amongst other things, predictions of water level change in affected aquifers because of groundwater extraction undertaken as part of CSG production. The EWS therefore applies to aquifers that have the potential to be depressurised by CSG water extraction from the Late Permian age coal measures and include:

- Quaternary age alluvium;
- Tertiary age sediments and basalts; and
- Triassic age Clematis Sandstone.

These formations are treated as unconsolidated where they present as the watertable aquifer (Coffey 2019b). Geological formations that are formally recognised as aquitards or confining units are not recognised as target systems for the EWS.

**Coal measures**

The late Permian age coal measures being developed for CSG have been specifically excluded from the EWS because depressurisation of these coal seams is an essential and unavoidable component of the Action as described in the BGP SREIS (Coffey 2014).

**Groundwater Dependent Ecosystems**

The basis for assessing GDEs that may be impacted by the Action is presented in the BGP EIS/SREIS which identified a range of known and potential GDEs using existing information sources. This included known and potential GDEs as mapped in the Atlas of Groundwater Dependent Ecosystems (GDE Atlas), a publicly available data set developed under the National Water Commission’s Raising National Water Standards Program (BoM 2018).

In addition, field work was carried out in November 2015 to assess areas within the project area that were mapped in the GDE Atlas as having potential GDEs. This field work, conducted by specialist hydrogeologists and an ecologist, identified the limited likelihood for ecosystem groundwater dependence across most of the areas observed, including those mapped as being potential GDEs in the GDE Atlas.

The assessment and findings were updated with the current FDP and the 2018 BGP GMMP groundwater model (AGE 2018) in the monitoring network memorandum (Coffey 2019b). The assessment did not identify any potential spring GDEs or non-spring GDEs at risk of impact from the Action and accordingly, there are no current monitoring requirements for GDEs in the BGP GMMP.

Two watertable bores (MB4 (contingent) and MB15-S) have been sited to fulfil multiple monitoring purposes in proximity to the upper Isaac River which is associated with field verified riparian vegetation (Coffey 2019b).

The EWS described herein will be applied to spring and non-spring GDEs should such features be identified in the future that are assessed as being at risk of impact from the Action, or if monitoring indicates a potential for existing field verified riparian vegetation to be affected by groundwater drawdown in connected underlying aquifers, as additional information becomes available.

### 5.1.2 Investigation levels

Approval Condition 21(d) requires the proposal of early warning indicators, trigger thresholds, and limits for detecting impacts on groundwater levels. In addition to these requirements, periodic data review and analysis is a commitment under the BGP EIS/SREIS and an ongoing requirement under the Queensland Water Act (2000) obligations.

Table 5-1 provides a summary of the condition requirements for the EWS.

**Table 5-1 EWS requirements**

| System | Early warning indicator | Trigger threshold | Limit |
|---|---|---|---|
| **Consolidated aquifers** | ✓ | ✓ | ✓ |
| **Unconsolidated aquifers** | ✓ | ✓ | ✓ |

In accordance with Approval Condition 21(d), the EWS for the BGP includes tiered investigation levels with escalating responses:

1. **Early warning indicators**, for early identification of potential groundwater drawdown issues to enable additional baseline monitoring data to be collected.

2. **Trigger thresholds**, for identifying the potential for groundwater drawdown (as a consequence of the Action) to affect groundwater users and enable monitoring and management measures to be implemented to mitigate the potential for impact.

3. **Limits**, that define groundwater levels of drawdowns not to be exceeded.

Commensurate with Approval Condition 21(d), the proposed EWS for the BGP GMMP is aligned with the requirements for the preparation of UWIRs (DES 2018).

While the UWIR guideline (DES 2018) does not specify a requirement for an EWS, it does require groundwater level declines to be predicted for affected aquifers due to the Action and an accompanying water monitoring strategy to be developed. The predictions for affected aquifers are made for:

- Water level declines, by more than the applicable bore trigger threshold, within three years following the report consultation day (immediately affected area, or IAA); and
- Water level declines, by more than the applicable bore trigger threshold, at any time (long-term affected area, or LAA).

In the UWIR guideline (DES 2018), the bore trigger threshold has the following meaning under Section 362 of the Water Act (2000):

- A decline in water level in an aquifer prescribed by regulation, or otherwise 5 m for consolidated aquifers and 2 m for unconsolidated aquifers.

These principals are integrated into the proposed EWS for the BGP GMMP in the form of the adopted tiered investigation levels (Table 5-1) which are further elaborated on in Section 5.2, together with exceedance response actions (Section 5.3).

### 5.1.3 Approach and inputs

For consistency with the BGP UWIR, and as a conservative measure to serve as an early warning indicator, the $P_{95}$ groundwater level model drawdown predictions, sourced from the BGP Project Stage 1 GMMP numerical groundwater model (AGE 2018), will be utilised in identifying potential exceedances in the EWS.

Unlike the SGP Stage 1 and 2 WMMP, the BGP numerical groundwater model (AGE 2018) does not simulate cumulative drawdown (e.g. drawdown that is inclusive of the historical and current impact caused by coal mining) (Coffey 2019a). A direct comparison of observed groundwater level data and assigned EWS levels derived from predictive modelling, is therefore not a viable approach for identifying potential exceedances in the EWS.

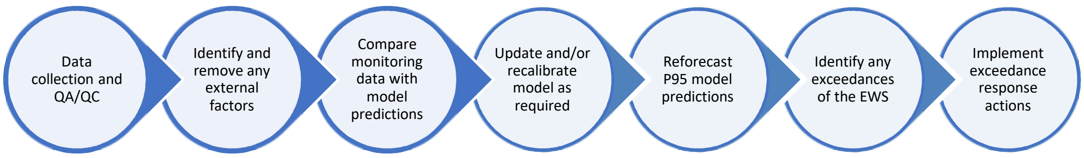
The first step in the EWS is the collection of groundwater monitoring data and the implementation of QA/QC procedures:

- Reviewing and checking data and field documents to identify transcription errors.
- Reviewing and checking the calibration of measurement equipment (e.g. pressure gauges, water quality meter).
- Correlation of logged data against manually gauged data.

Following data collection, any external physical factors that may affect the monitoring data will be identified and removed. Some of these influences relate to actual changes in storage, such as pumping from the aquifer, whilst other influences may cause apparent groundwater level changes, with no actual resource volumetric changes, for example, barometric pressure changes. Data may require the removal of confounding influences, such as barometric effects and earth tides, to provide corrected data that does not lead to misinterpretation of trends. Software available for this purpose includes proprietary software provided by data logger manufacturers.

Groundwater level and quality monitoring data collected from the Project Stage 1 GMMP monitoring network (defined in Coffey 2019b) will be used to help consolidate the understanding of groundwater systems across the BGP. Importantly, a comparison of monitoring data and model predictions, in consideration of cumulative scale effects on the groundwater resource, will guide any updates and/or requirements for model recalibration. In turn, potential $P_{95}$ groundwater drawdown and impacts will be re-forecast for ongoing implementation of the EWS.

The periodic approach to identifying potential exceedances in the EWS is illustrated below. The last two stages of the EWS are further explored in Sections 5.2 and 5.3, respectively.




## 5.2 Limits, trigger thresholds and early warning indicators

Approval Condition 21(d) requires that the BGP GMMP specify early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels as a consequence of the Action.

The EWS is based on comparing modelled groundwater drawdowns derived from the BGP GMMP groundwater model (AGE 2018) with staged early warning indicator levels, trigger threshold levels, and drawdown limits, to inform escalating response actions.

As reported in the Review Schedule Memorandum (Coffey 2018), the revised GMMP will be prepared and delivered concurrently with 3-yearly updates to the UWIR for the purposes of aligning and achieving consistency between the two documents, to the extent practicable.

Events triggering an EWS level initiate prescribed investigation and actions to mitigate potential impacts, as described in Section 5.3.

Figure 5-1 illustrates operation of the EWS.

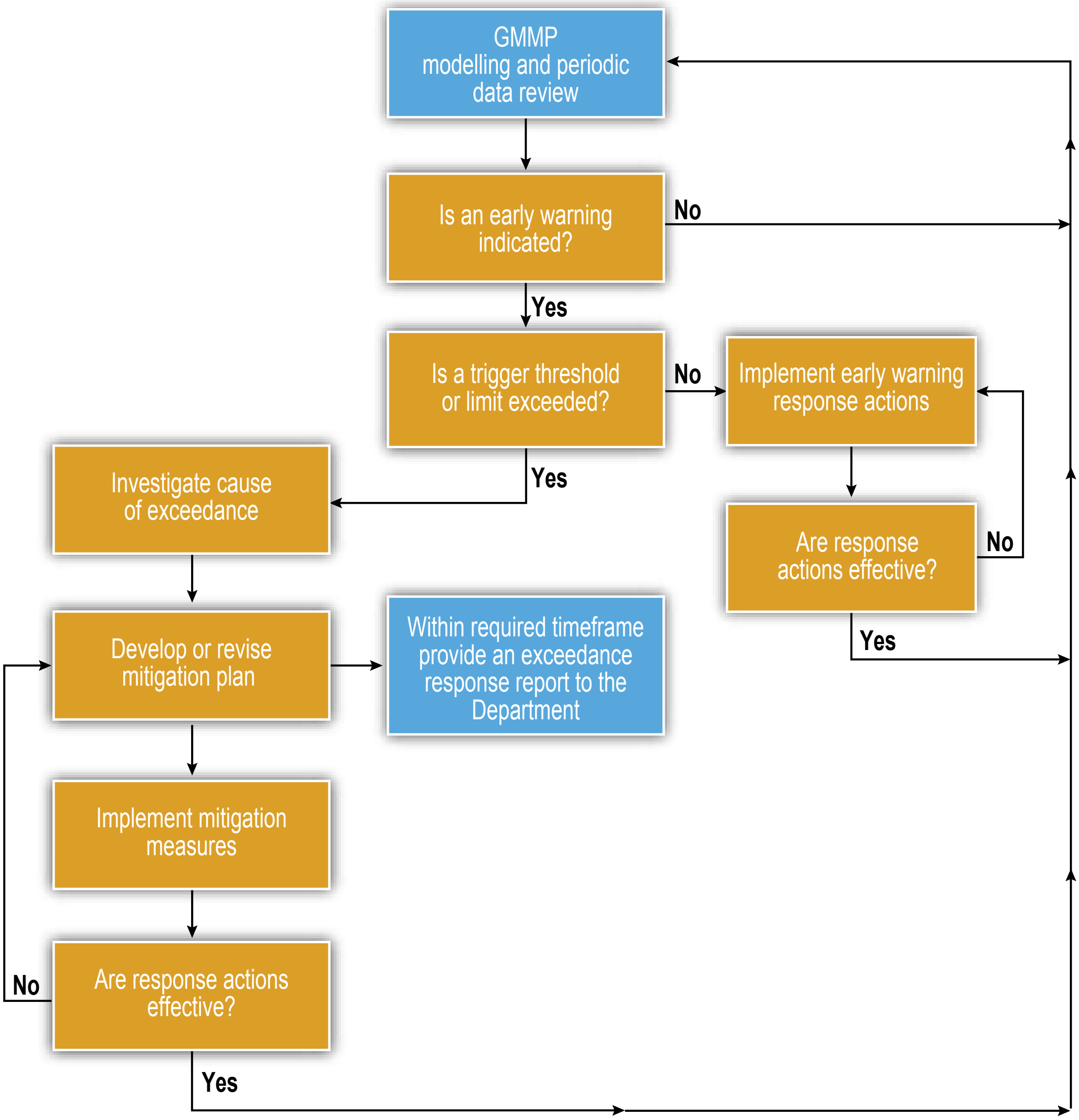



**Figure 5-1** **EWS process and actions**

**Source:**
Coffey

Date: 20/12/2018
Issued To: Arrow Energy
Author: Helen.Unkovich



**NOT FOR CONSTRUCTION**

### 5.2.1 Early warning indicators

An early warning indicator is considered exceeded if an existing water supply bore is identified within a predicted $P_{95}$ LAA for the BGP in any of the target systems. [11] Identification of LAAs for affected aquifers is a requirement of the UWIR (DES 2018).

The $P_{95}$ model predictions conducted as part of the Project Stage 1 GMMP (Coffey 2019a) did not identify any predicted LAAs in the consolidated or unconsolidated aquifers, outside of the coal measures targeted for CSG development.

### 5.2.2 Trigger thresholds

A trigger threshold is considered exceeded if an existing water supply bore is identified within a predicted $P_{95}$ IAA for the BGP in any of the target systems.[11] Identification of IAAs for affected aquifers is a requirement of the UWIR (DES 2018).

The $P_{95}$ model predictions conducted as part of the Project Stage 1 GMMP (Coffey 2019a) did not identify any predicted IAAs in the consolidated or unconsolidated aquifers, outside of the coal measures targeted for CSG development.

### 5.2.3 Limits

A limit is considered exceeded if an existing water supply bore is identified within a predicted $P_{95}$ IAA for the BGP, with predicted drawdown of more than double the UWIR guideline (DES 2018) of the bore trigger threshold (10 m for consolidated aquifers and 4 m for unconsolidated aquifers), at an existing water supply bore.

As per Section 5.1.1, the coal measures targeted for CSG development are excluded from the target systems.

## 5.3 Exceedance response actions

Approval Condition 21(e) requires the BGP GMMP to include a risk based exceedance response plan that details the actions to be taken and timeframes if early warning indicators or trigger threshold values are exceeded. According to the Approval Conditions, while a risk based exceedance response plan is not required to consider responses for exceeding limits, the Project Stage 1 GMMP has been prepared to include such measures.

EWS response actions are risk-based in that escalating actions apply to exceedances due to the Action, depending on the level of the exceedance. The response actions (identified in Table 5-2) have been developed with the aim of achieving consistency with the requirements of the UWIR (DES 2018).

The levels of exceedance are described in Sections 5.2.1 and 5.2.3 above.

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[11] As identified in a future UWIR for the tenures in the project area.

An evaluation of potential exceedances of the EWS will be undertaken, on a 3-yearly basis, as part of the review and update of the BGP GMMP and BGP UWIR.

The next version of the BGP UWIR is scheduled for submission on 4 April 2019. The document will report on the revised IAAs and LAAs for the BGP and any implications or exceedances of the EWS, together with any corresponding revisions to the Bore Assessment Plan (BAP) and obligations concerning bore assessments. The BGP GMMP will be reviewed on the basis of the outcomes of the next version of the BGP UWIR.

**Table 5-2 Risk-based exceedance response actions**

| Risk-based exceedance level | Response action |
|---|---|
| **Early warning indicator** | Within 12 months of exceeding an early warning indicator, conduct a baseline assessment of water bores potentially affected by the Action.<br><br>Baseline assessments will be undertaken in accordance with the updated (if necessary) Baseline Assessment Plans (BAPs) for tenures in the Project Area. (1) The information collected in baseline assessments establishes benchmark data prior to the bore experiencing any impact from the resource tenure holder exercising their underground water rights. The results of baseline assessments will be summarised in each annual review.<br><br>Within 30 days of completing the revised baseline assessments, submit these to the relevant Queensland state agencies (OGIA or their successor) and the bore owner.<br><br>Within 15 months of exceeding an early warning indicator, prepare and submit to the Department an Early Warning Indicator Exceedance Report which includes:<br><br>a) The results of an evaluation of the reasons for the predicted EWI exceedance, and the likelihood of a future exceedance of a trigger threshold or limit.<br><br>b) The outcomes of the baseline assessment program. |
| **Trigger threshold** | Arrow will comply with the requirements of the Queensland Water Act (2000) including by using best endeavours to enter into a make good agreements with the bore owner (after a bore assessment has been undertaken) and comply with the agreement.<br><br>Within 1 month of exceeding a trigger threshold, advise the Department of the exceedance, and of the obligation to conduct bore assessments of those water bores within the new IAA.<br><br>Within 60 business days of exceeding a trigger threshold (or a later if the chief executive of DES agrees), conduct bore assessment(s) for those water bores within the new IAA. (2)<br><br>The bore assessment aims to establish whether a bore has, or is likely to have, an impaired capacity as a result of CSG groundwater extraction, and in turn, to determine whether make good measures are required as part of a make good agreement between the tenure holder and the bore owner. Make good agreements ensure that the bore owner is not disadvantaged if their bore is, or is likely to be, impaired as a result of resource activities.<br><br>Within 15 months of exceeding a trigger threshold, prepare and submit to the Department a Trigger Threshold Exceedance Report which includes: |

| Risk-based exceedance level | Response action |
|---|---|
| | a) The results of an evaluation of the reasons for the predicted trigger threshold exceedance, and the likelihood of a future exceedance of a limit.<br>b) Details of compliance with any make good obligations arising because of the trigger threshold exceedance including the outcomes of the bore assessment program.<br>c) The outcomes of the bore assessment program and any make good obligations. |
| **Limit** | Within 120 days, prepare and submit to the Department a limit exceedance report that includes:<br>a) The results of an evaluation of the reasons for the limit exceedance, and an evaluation of any impacts that may arise due to the exceedance.<br>b) An evaluation of the risk to groundwater environmental values.<br>c) Corrective actions to mitigate against any impacts, including demonstration that make good obligations of impacted water supply bores have been entered in to. |

***Notes:***

*(1) The underground water impact management framework under Chapter 3 of the Water Act (2000), requires resource tenure holders to undertake Baseline Assessments on all authorised water bores potentially affected by the Action. A baseline assessment (defined in section 394 of the Water Act 2000) is an assessment of a water bore, undertaken by a resource tenure holder, to obtain information about the bore, including: level and quality of water, construction and pumping infrastructure.*

*(2) Undertaking a bore assessment is a key element of a resource tenure holder's make good obligations under Chapter 3 of the Water Act (2000). The 2016 UWIR also sets out Arrow's commitment to bore assessments for any landholder bore intersected by the IAA.*

# 6. REPORTING, REVIEW AND PERIODIC PLAN UPDATES

Approval Conditions 21(f), 21(g) and 21(h), relate to administrative commitments including defining a timeframe for regular review and updates of the GMMP, public dissemination of the monitoring results and provision of monitoring data to Federal and State Government authorities, if requested. These non-technical requirements and Arrow's response are described below and further detailed in Appendix G.

In addition, Approval Conditions 29, 30, 31, 32 and 37 require record keeping, reporting and non-compliance notification. Arrow will meet the requirements of these conditions, with respect to the BGP GMMP, as set out in this Chapter, and in conjunction with Arrow's EIS/SREIS reporting, updating and review commitments.

## 6.1 Record keeping and data management

Arrow will maintain records of relevant activities carried out in accordance with the Project Stage 1 GMMP. These records will be made available to the Department upon request.

Implementation of the GMMP will generate significant data including field records and observations, electronically-logged water pressure data, and laboratory water-quality analytical data.

The data generated (Section 4.5.3) will be stored electronically in a database and be subject to a quality control review program or system to identify data or transcription errors.

## 6.2 Reporting

Reporting for the GMMP is detailed below, and includes:

- Non-compliance reporting (including potential non-compliances)
- Exceedance reporting for the EWS
- Updates of the GMMP
- Annual reporting

### 6.2.1 Potential non-compliance reporting

In accordance with Approval Condition 32, the Department will be notified in writing no later than ten business days after becoming aware of any potential non-compliance with any Approval Condition.

Potential non-compliance notification will occur if:

1. Arrow fail to meet any of the requirements of Approval Condition 21 (i.e. Arrow do not develop or carry out any of the activities required under approval conditions 21(a) to 21(h)).

The notification will include:

- The condition which the approval holder has potentially breached;
- The nature of the potential non-compliance;
- When and how the approval holder became aware of the non-compliance;
- How the non-compliance will affect the anticipated impacts of the approved action;
- How the potential non-compliance may affect the anticipated impacts of the approved action, in particular any impacts on MNES, and the measures to be taken to address the impacts of the potential non-compliance on MNES and to rectify the potential non-compliance; and
- The time by when the approval holder will rectify the non-compliance.

### 6.2.2 Early warning indicator, trigger threshold and limit exceedance reports

Consistent with the EWS described in Section 5, exceedance response reports will be prepared for any confirmed early warning indicator, trigger threshold or limit exceedance.

The Department will be provided with copies of any EWS exceedance response reports.

### 6.2.3 GMMP updates

**Triennial review of GMMP**

Consistent with and following the release of a new UWIR, the Project Stage 1 GMMP will be reviewed to determine its ongoing suitability, adequacy and effectiveness. The results of this review will be reported in the Annual Report (refer Section 6.2.4).

If one or more of the following criteria are triggered as part of the review, a revised GMMP will be produced:

- Revised modelling indicates potential impacts to a terrestrial GDE (i.e. modelled 1 m LAA in the water table aquifer or greater drawdown is predicted coincident with a potential or known terrestrial GDE).
- Revised modelling indicates potential impacts to a surface water feature.
- Revised modelling indicates a material change to forecast impacts (i.e. a predicted IAA or LAA in an aquifer that is not forecast in the current GMMP).
- CSG development is proposed for areas outside the Project Stage 1 area.
- CSG development is proposed to utilise greater than 1,408 production wells.

Where the above criteria are not triggered (and a GMMP update is not required) the results of the three-yearly review will be documented in an annual report (refer Section 6.2.4).

As part of the GMMP review following the release of a new UWIR every three years, the risk assessment will be reviewed to identify if any surface water features or terrestrial GDEs are at risk based on the outcomes of the UWIR.

If the revised risk assessment indicates that surface water features may be at risk due to changes in groundwater –surface water connectivity resulting from the Action:

- Arrow will include in the updated GMMP a monitoring system that will be developed to provide for the early detection of changes in groundwater-surface water connectivity.

If the revised risk assessment or the UWIR (1m LAA in a water table aquifer) indicate that terrestrial GDEs may be at risk from the Action:

- Arrow commits to include in the updated GMMP an early warning system (EWS) for terrestrial GDEs that will include:
    - Details of a monitoring system to be implemented for the identified at-risk terrestrial GDEs, and the timing of the implementation of the system.
    - A detailed EWS for terrestrial GDEs.
    - Mitigation measures for managing any impacts that might arise.

Where the findings of the above risk assessment indicated that a GMMP update is not required, then the findings will be documented in an annual report (refer Section 6.2.4). Where findings from a revised risk assessment determine that additional monitoring is not required, this will be adequately documented.

Where the review process triggers a requirement for an updated GMMP, an updated GMMP will be prepared and submitted within six months of the annual report submission, and take into consideration:

- Any revisions to the numerical groundwater model and water balance calculations (e.g. in response to significant operational changes, new knowledge and data, or upon review and consideration of monitoring outcomes).
- Any implications to assigned early warning indicators, trigger thresholds and limits, and revision of such if necessary.
- The outcomes of the most recent UWIR.
- An updated groundwater monitoring network if required.
- The conditions of approval relating to the GMMP (in particular condition 21 a to h)

**Peer review of updated GMMP**

In accordance with Approval Condition 22, an updated GMMP will be peer reviewed by a suitably qualified water resources expert/s approved by the Minister, and issued directly to the Department within 6 months following each third anniversary day of when the updated UWIR takes effect.[12] Relevant electronic data will be provided to the Department upon request. The revised GMMP will be published on Arrow's website once approved by the Department.

### 6.2.4 Annual report

An annual report on the Project Stage 1 GMMP will be prepared for the preceding 12 month period (Approval Condition 30).

Annual reports will be submitted to the Department and published on Arrow's website within three months of every 12-month anniversary of the commencement of the BGP.

Each annual report will present a summary of progress towards Arrow's commitments and document Arrow's compliance against the approval conditions. A summary will be included of whether there has been a material change in the information or predictions used to inform the impacted areas.

To the extent practicable, and dependent on timing of approvals and anniversary dates, the annual reports for the GMMP and UWIR will be prepared concurrently to facilitate alignment and consistency. There is no requirement under the BGP EPBC Approval Conditions for the annual reports to be peer reviewed.

Annual reports will be factual, and will:

- Report on any relevant ongoing studies and research projects and include any supporting technical studies as appendices to the annual report.
- Document the number of coal seam gas wells, including:
  - Total number of wells installed, the number of operational wells, the number of non-operational wells, and the number of decommissioned or failed wells.
  - Confirmation that production is not from more than 1,408 operational wells.
- Provide an update on the implementation of the groundwater monitoring network and baseline monitoring, and summarise relevant monitoring results, including:
  - Groundwater levels and trends.
  - Groundwater chemistry results and trends.
  - Analysis and interpretation of data and identification whether drawdown predictions made have changed materially.

[12] This will apply to all UWIRs approved greater than 12 months after the GMMP is approved.

  - o An assessment of factors contributing to observed groundwater level changes (e.g. non-CSG versus CSG influences).

- Provide any updates to the groundwater monitoring network if required.
- Detailing any confirmed non-compliances along with details of any remedial actions (Approval Condition 29).
- Document compliance against the approval conditions over the preceding 12 months, including monitoring obligations and implementation of the EWS (Approval Condition 30).
- Document corrective actions implemented to address any exceedances of trigger thresholds, limits, or non-compliance with approval conditions (Approval Condition 30).
- Report against the performance measure criteria.
- Identify if an out of cycle UWIR was submitted (due to a material change or error in the information or predictions) and if practical consider a review of the GMMP outside of the 3-yearly review schedule.

## 6.3 Performance measure criteria

Performance measure criteria have been established which enable assessment of project performance in the context of protection of MNES. These ensure that the project operational and management aspects that limit, protect or mitigate against impacts to MNES potentially affected by the project, are achieving the required outcome, and that impacts to MNES are either not occurring, or are effectively corrected. The performance measures are predicated on the assumption that a fundamental purpose of the Approval Conditions is the management of impacts to MNES. Therefore, compliance with these conditions will achieve this outcome.

The performance measure criteria for assessment of the protection of MNES are:

- Compliance with the Approval Conditions.
- Impacts to MNES are predicted and monitored.
- Where an exceedance under the EWS has occurred, the corrective actions for ameliorating impacts from exceedance of the limits are implemented, and effective.

## 6.4 Publication and release of data and reports

Commensurate with Approval Condition 21(g), Arrow will make public the results of data obtained from the water-related aspects of their monitoring network for the life of the project via three mechanisms:

- Publication of annual reports on Arrow’s website;

- Publication of the Project Stage 1 GMMP and UWIR (and subsequent revisions) on Arrow's website; and
- Publication of monitoring results, including those collected from associated investigations, undertaken as a requirement of the GMMP.

Supply of data collected by Arrow, including bore and baseline data, will be reported to the Office of Groundwater Impact Assessment (OGIA), associated with obligations under the UWIR, and baseline and bore assessment obligations.

In accordance with Approval Condition 21(h), Arrow will make monitoring data available to the Department and Queensland Government authorities, as requested, for inclusion in cumulative impact assessments, regional water balance modelling, bioregional assessments or other relevant research. Arrow will store monitoring data in an internal database which can be exported and provided as part of any such information requests. This approach is consistent with groundwater monitoring results currently being provided to the OGIA.

## 6.5 Peer review

The BGP GMMP required formal peer review by a suitably qualified water resources expert in accordance with Approval Condition 22 of the Australian Government approval. The peer reviewer was approved by the Minister for the Environment and was engaged in a progressive review process of the GMMP.

A statement from the suitably qualified water resources expert endorsing the findings and the content of the GMMP are provided in Appendix G.

# 7. REFERENCES


Arrow Energy 2016, *Underground Water Impact Report for Petroleum Leases 191, 196, 223, 224 and Authority to Prospect 1103, 742, 831 and 1031*, August 2016.

Arrow Energy 2018, *Annual Review of Underground Water Impact Report for Petroleum Leases 191, 196, 223, 224 and Authority to Prospect 1103, 742, 831 and 1031*, April 2018.

Arrow Energy 2019, *Underground Water Impact Report for Petroleum Leases 191, 196, 223, 224 and Authority to Prospect 1103, 742 and 1031*, (For consultation) January 2019.

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) 2018, *Arrow Project, Bowen Groundwater Management and Monitoring Plan Uncertainty Analysis*.

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Coffey 2014, *Supplementary Groundwater Assessment - Arrow Energy Bowen Gas Project. Supplementary Report to the EIS*, Document ENAUBRIS107043AC. April 2014.

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Coffey 2018a, *Bowen Gas Project (BGP) Groundwater Management and Monitoring Plan (GMMP) - Review schedule memorandum*, 20 June 2018.

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Coffey 2019c, *Bowen Gas Project (BGP) Groundwater Management and Monitoring Plan (GMMP) - Groundwater monitoring program and EWS*, 13 March 2019.

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Queensland Government 2018, *Water Act 2000*, reprint current from 2 July 2018.

SKM 2009, *Isaac Connors Groundwater Project. Part A: Conceptual Model for Groundwater*. Technical report for the Fitzroy Basin Water Resource Plan Amendment, Final Report, 13 May 2009.

URS 2012, *Groundwater Impact Assessment Bowen Gas Project*, Appendix L Groundwater and Geology Technical Report, November 2012, Prepared for Arrow Energy Pty Ltd.

# 8. ABBREVIATIONS

**Table 8-1 Abbreviations**

| | |
|---|---|
| **AHD** | Australian Height Datum |
| **ATP** | Authority to Prospect |
| **BGP** | Bowen Gas Project |
| **BOM** | Bureau of Meteorology |
| **CSG** | Coal seam gas |
| **DEHP** | Department of Environment and Heritage Protection |
| **DO** | Dissolved oxygen |
| **DNRME** | Department of Natural Resources, Mines and Energy |
| **EA** | Environmental Authority |
| **EHP** | Environment and Heritage Protection |
| **EIS** | Environmental impact statement |
| **EPBC** | Environment Protection and Biodiversity Conservation |
| **EWS** | Early warning system |
| **FDP** | Field development plan |
| **GAB** | Great Artesian Basin |
| **GDE** | Groundwater dependent ecosystem |
| **GL** | Gigalitre |
| **GMMP** | Groundwater management and monitoring plan |
| **ML** | Megalitre |
| **MNES** | Matters of national environmental significance |
| **OGIA** | Office of Groundwater Impact Assessment |
| **PL** | Petroleum lease |
| **QWC** | Queensland Water Commission |
| **SREIS** | Supplementary report to the EIS |
| **TDS** | Total dissolved solids |
| **TKN** | Total Kjeldahl nitrogen |
| **TSS** | Total suspended solids |
| **UWIR** | Underground water impact report |
| **VWP** | Vibrating wire piezometer |
| **WMS** | Water management strategy |
| **UWIR** | Underground water impact report |

# APPENDIX A APPROVAL CONDITIONS AND COMPLIANCE

To demonstrate where the GMMP achieves compliance with the requirements of the approval conditions, Table A.1 presents a summary of the approval conditions, cross-referenced to the relevant sections of the GMMP where the conditions are addressed.

**Table A.1 Approval condition compliance reference summary**

| Approval Condition | Condition description | Relevant GMMP section |
|---|---|---|
| **21a** | Details of a groundwater monitoring network for the measurement of impacts on water resources associated directly or indirectly with the action, including the ability to:<br><br>(i) provide for the early detection of any changes in the groundwater regime in terms of amplitude and frequency of fluctuations in water pressure, water level and water quality in groundwater systems and changes in connectivity with surface water;<br><br>(ii) monitor relevant formations to determine hydraulic connectivity and provide for early detection of impacts prior to reaching migration pathways to other formations (e.g. faults and areas of unconformities known to connect two or more formations);<br><br>(iii) monitor potential impacts on groundwater dependent ecosystems, including spring based and non-spring based ecosystems, and provide for the early detection of impacts;<br><br>(iv) monitor changes to the project area groundwater balance; and<br><br>(v) monitor changes to water availability for water users and the environment. | Sections 3 and 4<br><br>Appendix C and Appendix D |
| **21b** | Details of a baseline monitoring data acquisition program for the approved action. | Section 4.5<br><br>Appendix F |
| **21c** | A rationale for the design of the monitoring network with respect to the nature of potential impacts and the location and occurrence of matters of national environmental significance. | Section 4<br><br>Appendix D |
| **21d** | Details of proposed early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels and a description of how and when these measures will be finalised and subsequently reviewed in accordance with the requirements of an Underground Water Impact Report. | Sections 5.1 and 5.2<br><br>Appendix F |
| **21e** | Details of a risk based exceedance response for the actions the approval holder will take, and the timeframes in which these | Section 5.3<br><br>Appendix F |

| Approval Condition | Condition description | Relevant GMMP section |
|---|---|---|
| | actions will be undertaken, if early warning indicators and trigger threshold values are exceeded. | |
| **21f** | Details of the timeframe for a regular review of the GMMP in accordance with the requirements of the Underground Water Impact Report and subsequent updates of the GMMP, including to incorporate the outcomes of updates to the numerical groundwater model and water balance calculations. | Section 6.2<br>Appendix G |
| **21g** | Provisions to make monitoring results publicly available on the approval holder's website for the life of the project. | Section 6.4<br>Appendix G |
| **21h** | Provisions to make monitoring data available to the Department and Queensland Government authorities (if requested) for inclusion in any cumulative impact assessment, regional water balance model, bioregional assessment or relevant research. | Section 6.4<br>Appendix G |
| **22** | The GMMP, including any revised plans, must be peer reviewed by a suitably qualified water resources expert approved by the Minister in writing. A peer review must be submitted to the Minister together with the GMMP and a statement from the suitably qualified water resources experts stating that they carried out the peer review and endorse the findings and the content of the GMMP. | Section 6.5<br>Appendix G<br>Appendix H |
| **29, 30, 21, 32** | Approval Condition 29 requires that the annual report (Approval Condition 30) must state all confirmed cases of non-compliance along with details of any remedial actions.<br><br>Approval Condition 30 requires that the approval holder must publish an annual report on its website outlining how they have been compliant with the conditions of the approval over the previous 12 months, including the implementation of any management plans, strategies or programs as specified in the conditions.<br><br>Approval Condition 31 requires that the approval holder must provide documentary evidence to the Department (at the same time as the compliance report, Approval Condition 30, is published) with proof of the date of publication of any non-compliance with any of the conditions of the approval.<br><br>Approval Condition 32 requires that the approval holder must notify the Department 2 in writing of potential non-compliance with any condition of this approval as soon as practical and within no later than ten business days of becoming aware of the potential | Section 6<br>Appendix F |

| Approval Condition | Condition description | Relevant GMMP section |
|---|---|---|
| | non-compliance. Under Approval Condition 32, the notice provided to the Department must specify:<br><br>a) The condition which the approval holder has potentially breached;<br><br>b) The nature of the potential non-compliance;<br><br>c) When and how the approval holder became aware of the non-compliance;<br><br>d) How the non-compliance will affect the anticipated impacts of the approved action, in particular how the non-compliance will affect the impacts on the matters of national environmental significance (MNES);<br><br>e) The measures the approval holder will take to address the impacts of the non-compliance on the MNES and rectify the non-compliance; and<br><br>f) The time by when the approval holder will rectify the non-compliance. | |

# APPENDIX B BGP EIS/SREIS COMMITMENTS

As part of the SREIS, six new and four updated management measures (commitments) relevant to groundwater were identified as a result of revisions to the project description (where further clarity was provided for the assessment of impacts on deep aquifers), to incorporate the findings of information made available since publication of the EIS and to make reference to the latest codes, standards and legislative requirements.

These are presented below in Table B.1, cross-referencing where each commitment is addressed in the GMMP. The full list of commitments, including those that remain unchanged from the EIS and details on those that have changed, are included in Commitments Update (Appendix O) of the SREIS.

**Table B.1 EIS/SREIS commitments cross-reference**

| Number | Description of commitment | Relevant GMMP Section |
|---|---|---|
| B644 | If the need to hydraulically stimulate any wells arises, prior to the commencement of hydraulic stimulation activities Arrow will develop and implement a procedure that satisfies the relevant regulatory requirements relating to hydraulic stimulation, for each hydraulic stimulation campaign. | EIS/SREIS |
| B249 | Construct, decommission or repair all CSG production wells in accordance with the Code of Practice for Constructing and Abandoning CSG Wells in Queensland (DEEDI, 2011b), or relevant code at the time of construction, which details mandatory requirements for well installations, monitoring, management and eventual decommissioning. Should production wells be converted into monitoring bores, do so in accordance with relevant regulations. | EIS/SREIS |
| B250 | Construct, decommission or repair all water bores (including monitoring bores) in accordance with the pertinent legislation; either the relevant minimum requirements; the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC, 2012) or the *Minimum Standards for the Construction and Reconditioning of Water Bores that Intersect the Sediments of Artesian Basins in Queensland* (DERM, 2004); or the *Code of Practice for Constructing and Abandoning CSG Wells in Queensland* (DEEDI, 2011b). | EIS/SREIS |

| Number | Description of commitment | Relevant GMMP Section |
|---|---|---|
| B281 | Connect wastewater and sewerage systems to sewers where locally present. Alternatively, install wastewater treatment or reuse systems in accordance with AS / NZS 1547: 2000 On-site Domestic Wastewater Management (Standards Australia, 2012); DERM guideline for managing sewerage infrastructure to reduce overflows and environmental impacts (DERM, 2010); and Queensland water recycling guidelines (DERM, 2005). | EIS/SREIS |
| B398 | Liquid waste generated (other than CSG water and sewage) will be stored and periodically removed for disposal or recycling. All waste drilling fluids resulting from drilling activities will be contained in dams or storage tanks, lined as appropriate, prior to re-use, recycling, treatment or disposal. Putrescible solid waste will be stored in covered containers to prevent odours, public health hazards and access by fauna. | EIS/SREIS |
| B655 | Arrow will continue to provide information to the Office of Groundwater Impact Assessment (OGIA), as required by the Underground Water Impact Report, to enable continual development and updates to the regional cumulative model administered by OGIA. | Section 6<br>Appendix G |
| B656 | Design all hydraulic stimulation wells and events in accordance with relevant requirements of the Petroleum and Gas (Production and Safety) Regulation 2004 and the Environmental Protection Act 1994 (EP Act 1994). | EIS/SREIS |
| B657 | Manage non-spring groundwater-dependent ecosystems (GDE) according to the following framework:<br>• Identify potential GDE landscapes;<br>• Use modelling to predict impacts;<br>• Identify GDEs at risk of impact through a risk assessment. Where identified as being at risk of impact, conduct further assessment including field studies and monitoring to ascertain connectivity of GDE to underlying aquifers; and<br>• Monitor and manage impacts as required. | Section 4<br>Appendix D |

| Number | Description of commitment | Relevant GMMP Section |
|---|---|---|
| B658 | Investigate potentially impacted sites of Indigenous cultural and spiritual importance that may have dependence on groundwater to determine the status of the feature, confirm groundwater-dependence and develop mitigation measures where required. | Section 4<br><br>Appendix D |
| B659 | Where sites of cultural and spiritual significance within the Project area that may have dependence on groundwater will be potentially impacted by Project activities:<br><br>• Liaise with traditional owners of the land in accordance with any endorsed Cultural Heritage Management Plan to located potentially impacted features and further understand their significance;<br><br>• Undertake field surveys to confirm the status of potentially impacted features (i.e. whether feature still exists and/or is actively used) associated with groundwater; and<br><br>• Develop monitoring, management and mitigation measures to assess, manage, avoid or minimise impact to the feature(s). | Section 4<br><br>Appendix D |

# APPENDIX C GROUNDWATER MODELLING MEMORANDUM

## Memorandum

| | |
|---|---|
| **Recipient** | Arrow Energy Pty Ltd |
| **Memo date** | 14/03/2019 |
| **Author** | Coffey Services Australia Pty Ltd |
| **Project number** | 754-MELEN213220 |
| **Memo Subject** | BGP CSG Groundwater Management and Monitoring Plan (GMMP)<br>Groundwater modelling memorandum |

## 1. Introduction

This memorandum presents updates to groundwater modelling undertaken for the Bowen Gas Project (BGP), including a revised Field Development Plan (FDP).

The memo outlines the groundwater modelling that provides an underlying basis supporting a range of aspects of Approval Condition 21. These aspects include monitoring network design and rationale, groundwater limits and indicators, and early detection of aquifer pressure changes.

## 2. Approval conditions and related documents

In addition to the BGP Environmental Impact Statement (EIS) and Supplementary Report to the EIS (SREIS), further supporting assessment for approval conditions is presented in separate memoranda, as summarised in Table 2.1.

These documents provide the basis for development of the GMMP.

**Table 2.1: Summary of BGP GMMP supporting assessments**

| Memoranda | Approval Conditions addressed | Document ID |
|---|---|---|
| Review schedule memorandum | 21(f, g, h) | 754-MELEN213220-M02 |
| Groundwater modelling memorandum | 21(a, b, c) (part) | 754-MELEN213220-M03 (this document) |
| Groundwater monitoring network memorandum | 21(a)(i),(ii),(iii),(iv),(v), 21(c) | 754-MELEN213220-M04 |
| Groundwater monitoring program and Early Warning System memorandum | 21(b, d, e) | 754-MELEN213220-M05 |

# 3. Updated FDP

The BGP involves a phased expansion of Arrow's CSG production in the Bowen Basin (Figure 1). It comprises development in the same areas (i.e. within tenements ATP742, ATP1103, and ATP1031) as presented in the SREIS with the addition of development in Mavis Downs (also located within ATP1103). The project area also encompasses Arrow's existing Moranbah Gas Project (MGP) operations (PL191, PL196, PL223, PL224).

The SREIS presented development in 3 phases (1, 2 and 3) between 2019 and 2049, based on 4,000 wells and total water production of 153 GL. This production has been revised and the GMMP is based on an updated FDP as follows:

- Red Hill Central (PL486 within ATP 1103) commencing 2019
- Mavis Downs (PCa152 within ATP1103) commencing 2021
- The remainder of the field development case area presented in the SREIS (ATP1103, ATP742 and ATP1031) commencing 2030

Red Hill Central lies within the footprint of BGP development case presented in the SREIS. It is located approximately 30 km north of the township of Moranbah, and borders the MGP area to the south. Water production from Red Hill Central is currently forecast to occur from 2019 to 2025, with a total of 0.88 GL of water to be produced.

The Mavis Downs development is located to the south of PL223 on PCa152, a comparatively mature area in ATP 1103, approximately 24 km east of the township of Moranbah. This development borders the MGP to the east. Mavis Downs production is currently forecast to occur from 2021 to 2030, with a total of 0.67 GL of water to be produced.

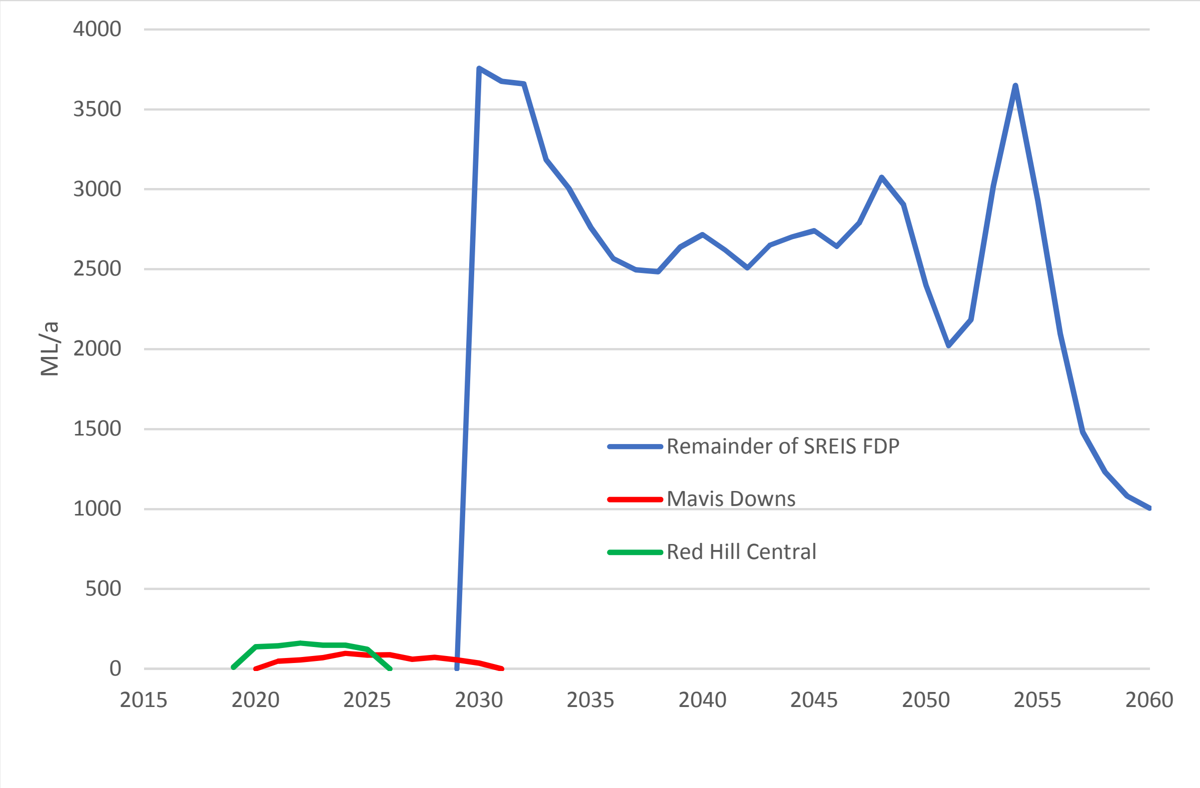
Production from the remainder of the SREIS FDP area, tentatively planned from 2030 to 2060, will comprise 1,360 wells and total water production of 80.7 GL.

Table 3.1 provides a summary comparison between the SREIS development and the revised FDP used in preparing the GMMP. Figure 2 shows forecast water production for the GMMP FDP.

**Table 3.1 FDP comparison**

| FDP | | Number of wells | Water production | | Timing | |
|---|---|---|---|---|---|---|
| | | | Total (GL) | Peak (GL/a) | Start | End |
| SREIS BGP FDP | | 4000 | 153 | 10.4 | 2019 | 2049 |
| GMMP BGP FDP | Red Hill Central | 31 | 0.88 | 0.16 | 2019 | 2025 |
| | Mavis Downs | 17 | 0.67 | 0.097 | 2021 | 2030 |
| | Remainder of the SREIS FDP | 1360 | 80.7 | 3.8 | 2030 | 2060 |
| | GMMP Total | 1408 | 82.25 | 4.057 | 2019 | 2060 |

**Figure 2 GMMP FDP water production**




The project description for the GMMP BGP FDP also includes other infrastructure such as gas and water gathering systems. This has been previously described in the SREIS which covers gathering lines at Red Hill (as well as the 13 km Ironbark gathering line), Mavis Downs and the remainder of the SREIS FDP.

In addition to the development detailed above, Arrow operates the MGP which has produced gas for the domestic market since 2004, and is forecast to remain operational until 2030.

## 4. Groundwater modelling

Previous groundwater modelling for the BGP supported both the SREIS and the 2016 Underground Water Impact Report (UWIR). Table 4.1 provides a summary of the modelling over time that has been undertaken for the evolving FDP versions. These models are discussed in Section 4.1 below.

**Table 4.1 Evolution of BGP modelling**

| FDP | Total water production (GL) | Numerical model | Comments |
|---|---|---|---|
| EIS | 274 | 2012 NBB model (Ausenco-Norwest) | Modflow-Surfact numerical model |
| SREIS | 153 | 2012 NBB model (Ausenco-Norwest) | Modflow-Surfact numerical model |
| UWIR | 116 | 2016 Bowen UWIR model | Modflow-Surfact numerical model |
| GMMP | 82* | 2018 GMMP model | Modflow-USG numerical model |

* Includes the remainder of the SREIS FDP, Mavis Downs and PL486 development

## 4.1. SREIS groundwater modelling

Numerical modelling for the SREIS BGP FDP was previously undertaken by Ausenco-Norwest in 2012. This model (the 2012 Northern Bowen Basin (NBB) Model) was a Class-1 confidence level model, for predicting long-term impacts of the BGP on the generally low-value aquifers of the Northern Bowen Basin (Ausenco-Norwest, 2012). The simulations undertaken allowed for the BGP production until 2072 with an additional 50 years post-production recovery time.

The 2012 NBB Model was implemented using Modflow-Surfact code, with a rectilinear-orthogonal grid and variable elevation layers. The underlying geological model was developed by Arrow geologists using Petrel software and implemented into the numerical model by Ausenco-Norwest.

The numerical groundwater model developed included 18 layers and 1.5 km square cells, within a domain of 402 km length by 165 km width. The model included all target coal seam gas (CSG) formations above the Back Creek Group. Fault representation was also included.

CSG activity was simulated in this model by using the Modflow WEL package to represent associated water extraction.

The 2012 NBB Model was separately peer reviewed by CDM-Smith (CDM-Smith, 2013). The peer review found that the model conforms to best industry practice, was fit for purpose, and fulfilled the appropriate portions of the Australian Groundwater Modelling Guidelines (CDM-Smith, 2013).

**Boundary conditions and parameters**

Boundary conditions for the 2012 NBB Model were assigned based on conceptualisation and presence of hydrological features, and included river boundaries, general head boundaries (GHB), and horizontal flow barrier boundaries (HFB).

River boundaries were used to represent the Bowen and Isaac-Connors River systems, and GHBs were used to represent the southern boundary of the Bowen Basin (where it dips under the Surat Basin, a location where groundwater data were limited). HFBs were used to represent major faults as barriers to flow, under the assumption that flow should be restricted across these features within the model.

Hydraulic parameters were established from previously compiled literature-review data sets for Arrow.

**Recharge and evapotranspiration**

Recharge was applied based on rainfall and geology, and imported using the same geologic zones used to assign hydraulic conductivity. In general, higher rates are applied along river drainage areas, and lower rates in Triassic/Permian outcrops (lower permeability rocks) (Ausenco-Norwest, 2012).

Evapotranspiration was handled using the Modflow EVT package. Data inputs were derived from BOM grid files of potential evapotranspiration (PET) and actual evapotranspiration (AET). Within the model, the difference between PET and AET is inferred to represent evapotranspiration (ET) demand that could be provided by groundwater above the extinction depth (i.e. not met by rainfall) (Ausenco-Norwest, 2012).

**Calibration and predictions**

Steady state and transient calibration was undertaken, and included data for the depressurisation of the MGP. Calibrated parameters included hydraulic conductivity, specific storage, recharge and evapotranspiration.

Predictive simulation included the calibrated base case that incorporated only BGP production. This was simulated both with and without discrete fault representation. A cumulative case was also simulated that included the BGP, MGP and third party (bore) users. In addition to the calibrated model, Monte Carlo analysis was also undertaken to understand model uncertainty (Ausenco-Norwest, 2013).

The base case scenario modelled indicated that under the SREIS BGP FDP areas of drawdown exceeding 2 m would primarily remain within Arrow tenements, would be closely associated with CSG well distribution, and would occur mainly within the target CSG formation. Except for a single cell in the Blackwater ATP, no modelled drawdown exceeding 2 m occurred in Layer 1 of the model following the 50-year post-production recovery period (Ausenco-Norwest, 2012).

## 4.2. 2016 UWIR groundwater modelling

Pursuant to section 370 of the Water Act 2000, the Department of the Environment and Heritage Protection (DEHP) directed Arrow to submit a single UWIR for its relevant Bowen Basin Petroleum Leases, to provide information on the potential decline in water levels in aquifers due to the taking of water during CSG production and testing[1].

To support the 2016 UWIR, the 2012 NBB Model was updated with a revised FDP (refer Table 4.1).

The set up and calibration of the 2016 Bowen UWIR Model was unchanged from the SREIS Model, however updates were made to the wells simulated in the model to reflect historical and forecast production (UWIR FDP) and historical production testing.

The 2016 Bowen UWIR Model predicted groundwater level changes, due to CSG extraction and production testing in the MGP Area as well as the BGP, but simulated no other groundwater extraction. Production included:

- Historical production and production testing in PLs 191, 196, 223, 224, and ATPs 1103, 1031, and 742
- Forecast production wells in PLs 191, 196, 223, 224, and production wells for the BGP

The model simulated forecast production within the MGP Area from 2016 to 2025, and the BGP UWIR FDP from 2019 to 2049.

## 4.3. 2018 GMMP groundwater modelling

AGE was engaged by Arrow to undertake revised numerical groundwater modelling to assess the regional scale groundwater impacts of the MGP, and the updated GMMP FDP (refer Section 3). The revised model incorporated recent developments in model code and processing.

## 4.4. NBB model update

The 2018 update largely represents a repeat of previous modelling undertaken by Ausenco-Norwest and Arrow, but incorporated a revised unstructured grid mesh (Figure 3) under MODFLOW-USG code and updated calibration. The flexibility of the revised mesh under MODFLOW-USG enabled a significant improvement in resolution of model features in the MGP area. The resulting model comprised 188,516 cells, down significantly from the 530,640 cells of the previous model, thereby enabling faster simulation times with better resolution in specific areas (AGE, 2018).

Model layer elevations were based on the Ausenco-Norwest regional geological model (Ausenco-Norwest, 2012) however an increased layer count resulted from splitting the original layer 18 (lumped Collinsville Formation-Back Creek Group) into 5 layers (2 coal seams, 2 interburden layers, and a basal Permian layer).

Groundwater layer types were prescribed as convertible layers, with unsaturated flow represented using the ‘upstream weighting’ function (AGE, 2018).

The model domain was identical to the previous Norwest model: approximately 157 km wide and 395 km long.

The approximate following cell dimensions were adopted:

- MGP area: 200 m hexagonal cells aligned to in-seam wells;
- BGP area: 1500 m rectangle cells (centred on CSG wells);

[1] This contrasts with the Surat Basin UWIR, where the Office of Groundwater Impact Assessment (OGIA) are directed to prepare a UWIR that encompasses multiple CSG developers.

- Faults: 1000 m x 1000 m centred on either side of fault trace;
- Surficial aquifers: 1000 m x 1000 m centred either side of aquifer extents; and
- Major drainage systems: 500m x 500 m centred along river lines near to the MGP.

**Boundary conditions and parameters**

Boundary conditions were adopted from the previous calibrated 2012 NBB Model.

Aquifer parameters from the calibrated 2012 NBB Model were translated into the new mesh as closely as possible, with the exception of coal seam hydraulic conductivity.

To better represent the depth-decline relationships for the coal seams, an approximated average depth-decline equation was applied to the groundwater model, on a cell-by-cell basis for the coal seams in the Moranbah and Rangal Coal Measures. Figure 4 presents the depth-decline equations for the Moranbah Coal Measures (as derived from the BGP area production tests) compared with the 2012 NBB Model representation, and the 2018 model representation.

**Water production cases**

Three water production cases were considered, and these provided the basis for the simulations run under the updated model. All three production scenarios included the existing MGP and comprised the following cases:

- Scenario 0: Historical MGP production only (2003 to Dec 2017)
- Scenario 1: Historical MGP + forecast MGP production to 2030
- Scenario 2: Historical MGP + forecast MGP production and PL486 + Mavis Downs + BGP

In addition to the above production scenarios, a simulation with no Arrow production was run (referred to as the 'NC' scenario) and a scenario with CSG production matching the 2016 UWIR FDP (referred to as the 'UWIR' scenario) (AGE, 2018).

Figure 5 presents a comparison of water production for these cases. Figure 6 presents the model wells on the updated mesh, and shows the starting time for each production area in Scenario 2.

**Model calibration**

Initial calibration included a pre-development steady-state simulation using available groundwater level data, comprising a total of 482 monitoring points (AGE, 2018).

The transient calibration utilised time-series data for the period 2000 to 2017, from 47 Arrow time-series monitoring locations (AGE, 2018). Within the calibration dataset, frequency of observations varies between bores and therefore the number of available records for each bore also varies. To overcome this observation data was weighted to normalise the error on a bore by bore basis (AGE, 2018). In addition, bores potentially impacted by mining in the region had a reduced weighting, to minimise bias, both in the calibration and in the uncertainty analysis.

Aquifer parameters were adjusted during calibration using an inverse automated method whereby hydraulic conductivity and storage were adjusted using pilot point multiplying fields to match groundwater observation levels with time, using PEST automated calibration software (AGE, 2018).

Pilot points were also used to help calibrate the model, and to explore uncertainty for the predictive analysis. Pilot points multipliers allowed +/- 2 orders of magnitude variation from starting values (AGE, 2018). Horizontal and vertical hydraulic conductivity were adjusted, and the absolute values were capped to ensure maximum and minimum values did not exceed literature ranges for their respective units. A scaled RMS error of 3.8% was reported for the calibrated model (AGE, 2018).

**Predictions**

Predictions of groundwater impact (i.e. drawdown) underpinning the monitoring network are based on the calibrated model case. This model version is parameter adjusted to provide a close model fit to the available calibration data set, and therefore represents a plausible estimate of the 'real world' parameter distribution in the BGP area. Adoption of the calibrated model realisation, as opposed to the 95th percentile (P95) model version, also helps to ensure that monitoring locations are not positioned at unreasonable distances from production areas[2].

Drawdown is presented for four scenarios in AGE (2018):

- Scenario UWIR - CSG production as per 2016 UWIR FDP (cumulative only);
- Scenario 0 - historical MGP production (2003 to Dec 2017) (cumulative only);
- Scenario 1 - historical + Future MGP production (cumulative and incremental); and
- Scenario 2 - historical MGP + Future MGP + PL486 + Mavis Downs + BGP (cumulative and incremental).

Cumulative drawdown is calculated by subtracting the heads from the 'no CSG production' scenario from the heads at the respective scenarios, and incremental drawdown is calculated by subtracting cumulative drawdown from the Scenario 0 drawdown (historical production) and represents additional drawdown post 2018 (AGE, 2018). All drawdown represents composite maximum drawdown[3].

The UWIR scenario enables a comparison to help understand how the updated model predictions vary from the 2016 UWIR results.

To represent maximum drawdown within the Moranbah and Rangal Coal Measures, drawdown from each seam within the associated coal measure was combined and presented as a spatial composite of the maximum drawdown (AGE, 2018). Outputs are derived from this to establish the Long-term Affected Area (LAA), defined by groundwater drawdown greater than 5 m, and presented in Figures 24 and 25 of the UWIR.

Figures 7 and 8 present the maximum drawdown (Scenario 2) for the Moranbah and Rangal Coal Measures. The results show that in general, the extent of drawdown has contracted from the 2016 UWIR predictions, primarily due to a more refined CSG production field (AGE, 2018).

Figure 9 presents the time to maximum drawdown (Scenario 2) for the Moranbah Coal Measures and indicates the year when maximum drawdown under the cumulative case is likely to occur.

Figures 10 and 11 present the cumulative maximum drawdown (Scenario 2) in the alluvium and regolith (layers 1 and 2). It shows that the drawdowns in layer 1 are very limited and generally lower than 0.2 m. With respect to layer 2, there is an isolated patch of saturated drawdown in the surficial systems, east of the BGP near Glenden of up to 10 m. Given the extent and patchy nature of the drawdown, the apparent impacts are considered a local model artefact mainly due to layering and lack of lateral connection with discontinuous sections of layer 2.

## 4.5. Uncertainty analysis

The null-space Monte Carlo (NSMC) analysis method was used to quantify uncertainty in predicted impacts, through multiple model simulations with differing parameter realisations, and accepting only results from the realisations that could be adequately calibrated.

The valid range for model parameters was determined, and 350 model realisations were created, each with differing values of the non-unique pilot point parameters. Model realisations were constrained using calibration datasets, and these constrained realisations were tested. Those that failed to converge or could not achieve adequate calibration were rejected. The process achieved 208 successful models, the output from which was analysed to provide a statistical distribution of the regional model predictions (AGE, 2018).

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[2] Wells located at greater distance from the production areas would have limited ability to provide early warning data, due to responses arriving at a late stage following commencement of production.

[3] Drawdown is queried across the entire simulation period and the maximum drawdown recorded for each model cell. Hence the drawdown represents a composite result from the entire simulation

The uncertainty analysis will assist in understanding, over time, whether the model provides a reasonable representation of the northern Bowen Basin groundwater system, and how the calibrated realisation fits, within the context of parameter uncertainty.

Figure 12 presents composite drawdown (Scenario 2) from all realisations assessed in the uncertainty analysis, expressed as the 5$^{th}$, 50$^{th}$ and 95$^{th}$ percentile for the Moranbah Coal Measures (cumulative case). Figure 13 presents the same for the Rangal Coal Measures.

The results show expected non-linear behaviour of the system at the extremities of the datasets, with extensive 95$^{th}$ percentile contours due to realisations with particularly higher permeability and lower storage (AGE, 2018).

## 5. Basis for supporting Approval Conditions

This section identifies how the specific approval conditions are addressed by the updated numerical groundwater modelling predictions.

### 5.1. Condition 21

Approval Condition 21 requires: *The approval holder must submit a Groundwater Management and Monitoring Plan (GMMP) for the written approval of the Minister who may seek the advice of an expert panel*. Specific details and particulars of the condition are provided in 21(a) to 21(h).

This memorandum addresses those aspects of Condition 21 that require the output and predictions from groundwater modelling, including for example, the development of a monitoring network, provision for the early detection of impacts, monitoring of impacts, and a rationale for the design of the monitoring network. Accordingly, the condition is only partially addressed in this memorandum.

Table 5.1 relates the specific approval conditions with the modelling outputs required, and comments on the approach.

**Table 5.1 Summary of approval conditions requirements and outputs**

| Approval Condition[1] | Relevant requirement | Model outputs required[2] | Comments on approach |
|---|---|---|---|
| **21(a)** | The GMMP must contain details of a groundwater monitoring network for the measurement of impacts on water resources associated directly or indirectly with the action, including the ability to:<br>(i) provide for the early detection of any changes in the groundwater regime in terms of amplitude and frequency of fluctuations in water pressure, water level and water quality in groundwater systems and changes in connectivity with surface water;<br>(ii) monitor relevant formations to determine hydraulic connectivity and provide for early detection of impacts prior to reaching migration pathways to other formations (e.g. faults and areas of unconformities known to connect two or more formations);<br>(iii) monitor potential impacts on groundwater dependent ecosystems, including spring based and non-spring based ecosystems, and provide for the early detection of impacts;<br>(iv) monitor changes to the project area groundwater balance; and<br>(v) monitor changes to water availability for water users and the environment. | Model predicted drawdown[3] contours (calibrated case):<br>• 5 m drawdown (all consolidated aquifers)<br>• 2 m drawdown (unconsolidated watertable aquifers)<br>• 0.2 and 1.0 m drawdown for GDEs (unconsolidated watertable aquifers)<br>• Time to maximum drawdown (consolidated aquifers)<br>• Time to maximum drawdown (unconsolidated aquifers) | Key aspects of the GMMP will be developed by understanding the spatial relationship and timing of depressurisation, and the physical location of surface water features, third party users and GDEs. This will rely on predictions from the 2018 GMMP Model.<br>This will also help ensure that the monitoring network is sufficiently robust and meets the conditions and intent underpinning the GMMP. |
| **21(b)** | The GMMP must contain details of a baseline monitoring data acquisition program for the approved action. | Baseline monitoring locations will be established with reference to the model outputs listed for Condition 21(a) above, and the predictions of groundwater drawdown. | The baseline data acquisition program will take into account existing baseline data collection, and the environmental monitoring |

| Approval Condition[1] | Relevant requirement | Model outputs required[2] | Comments on approach |
|---|---|---|---|
| | | | required in accordance with EIS/SREIS commitments. |
| **21(c)** | The GMMP must contain a rationale for the design of the monitoring network with respect to the nature of potential impacts and the location and occurrence of matters of national environmental significance (MNES). | Maps of model predicted groundwater drawdown and/or monitoring point hydrographs (drawdown vs time) may assist in establishing the indicative timing of drawdown in areas where MNES are identified. | Based on previous work, Lake Elphinstone is understood to be the primary occurrence of a water/groundwater related MNES for consideration in the region potentially at risk by BGP depressurisation. |
| **21(d)** | The GMMP must contain details of proposed early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels and a description of how and when these measures will be finalised and subsequently reviewed in accordance with the requirements of the UWIR | Numerical model predictions of groundwater drawdown across Arrow tenure under the P95 cumulative case will be used to establish both the early warning indicators, trigger thresholds and the groundwater drawdown limits. | The early warning monitoring system (EWMS) is described in the *Groundwater limits, indicators and response* actions technical memorandum.<br>EWMS levels will be established based on the latest model version and will incorporate (where available) updated production data for other (non-Arrow) extractors. |

**1** Conditions applicable to the BGP GMMP made on 27th October 2014 under sections 130(1) and 133 of the Environment Protection and Biodiversity Conservation Act 1999.
**2** Identified model outputs are indicative and typical. Timing of predictions to be considered in detail in the groundwater monitoring network technical memoranda.
**3** Composite maximum drawdown for each model cell.

## 6. References

Arrow Energy (2016). Bowen Basin Underground Water Impact Report. August 2016.p

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2018). Arrow Project – Bowen Groundwater Monitoring and Management Plan Uncertainty Analysis.

Ausenco-Norwest (2012). Groundwater model, Northern Bowen Basin regional model impact predictions. Queensland, Australia. Report for Arrow Energy, October 2012.

Ausenco-Norwest (2013). Parameter and predictive uncertainty assessment, Northern Bowen Basin regional groundwater model. Queensland, Australia. Report for Arrow Energy, May 2013.

CDM-Smith (2013). Bowen Basin EIS Groundwater Model Review. Report PGW130025, 11 September 2013.

# Figures

Figure 1 Project area

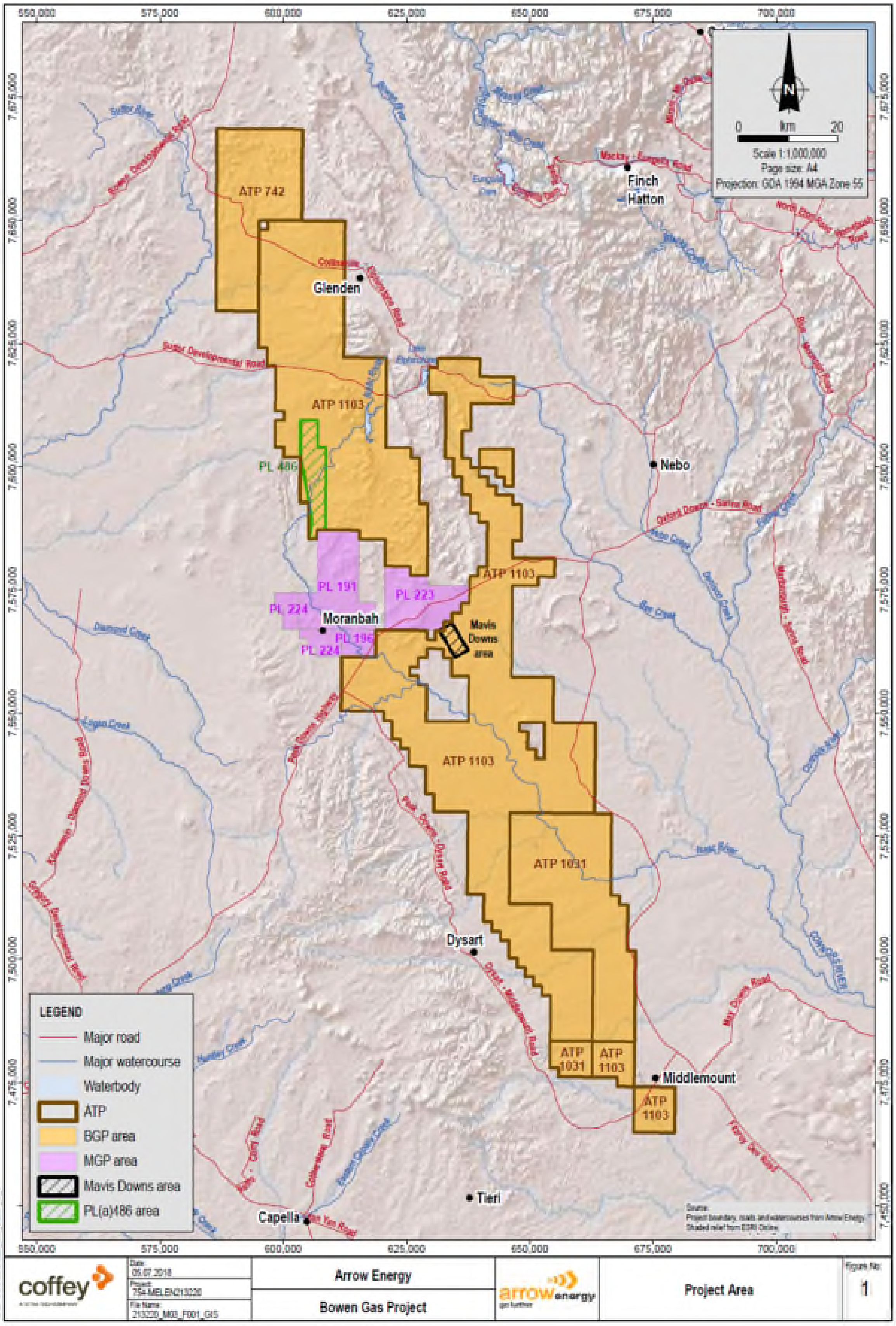


Figure 3 Bowen Basin 2018 model mesh

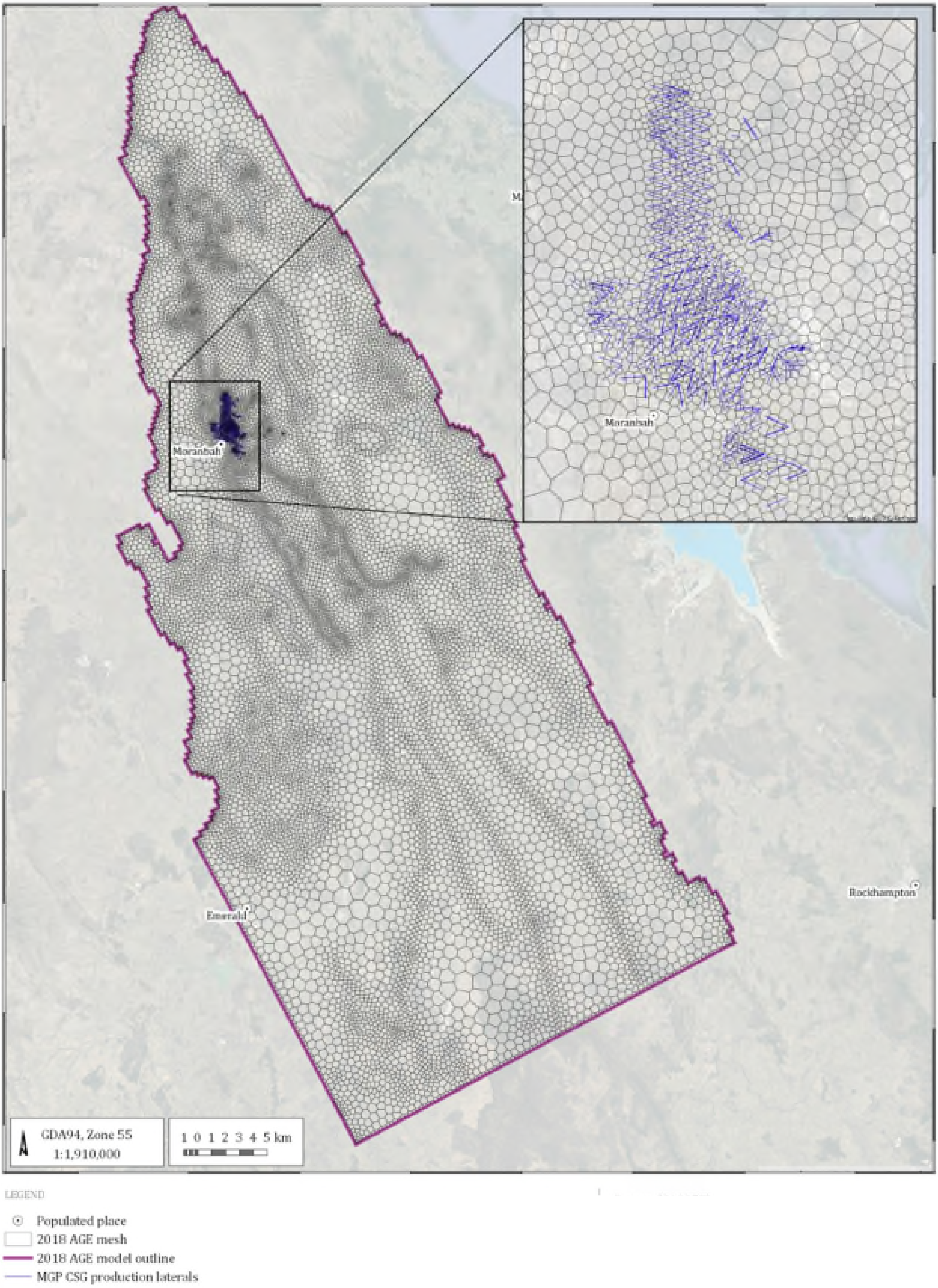


Figure 4 Depth decline relationship – Moranbah Coal Measures

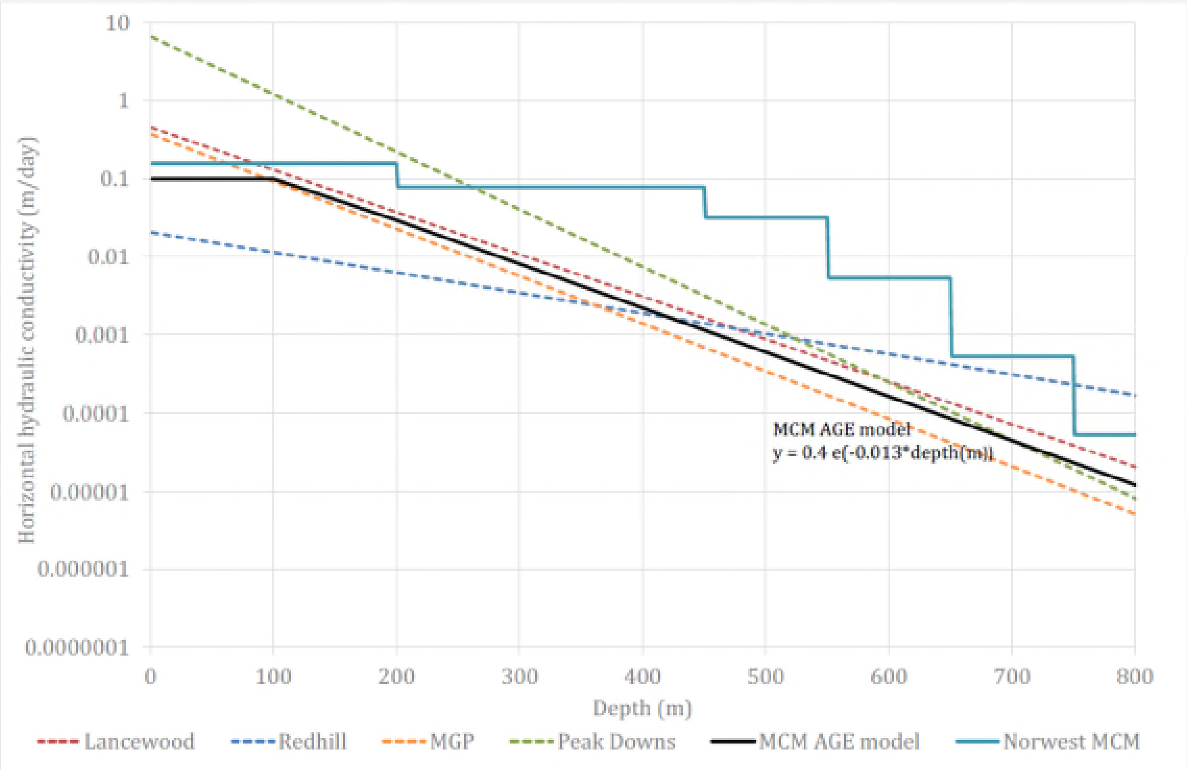



Figure 5 Water production summary

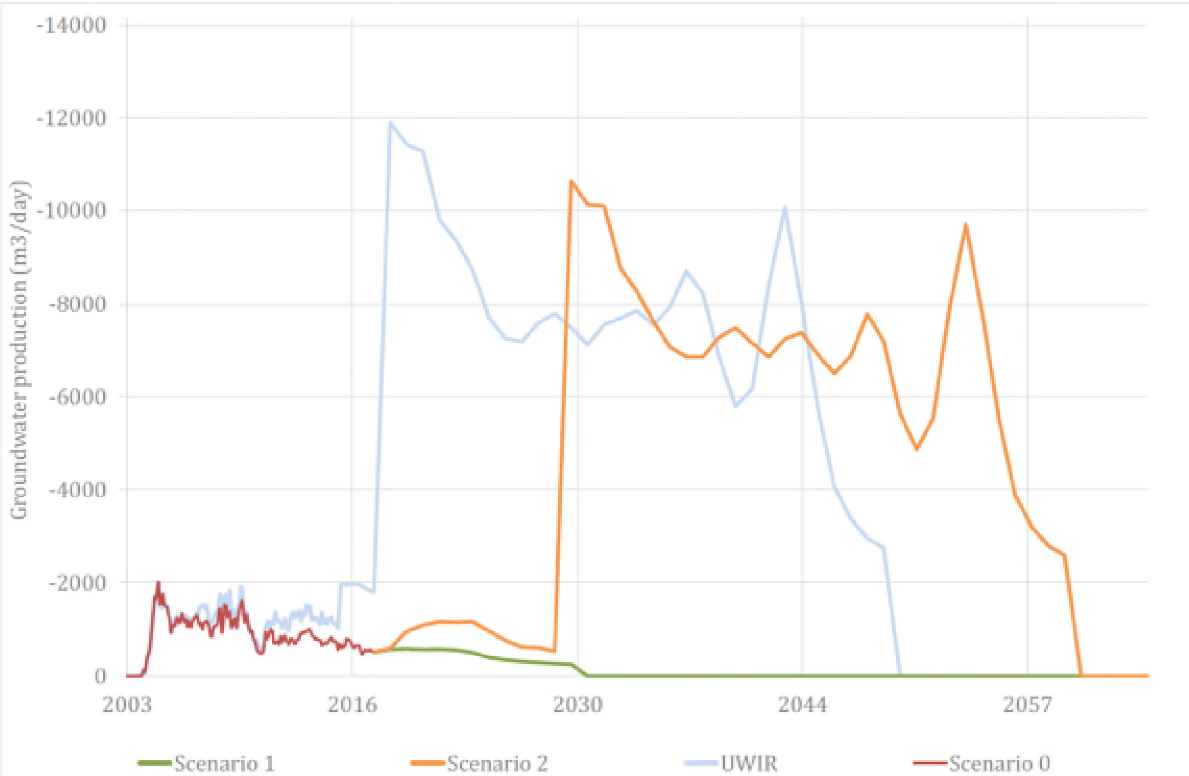


Figure 6 Scenario 2 well production start year

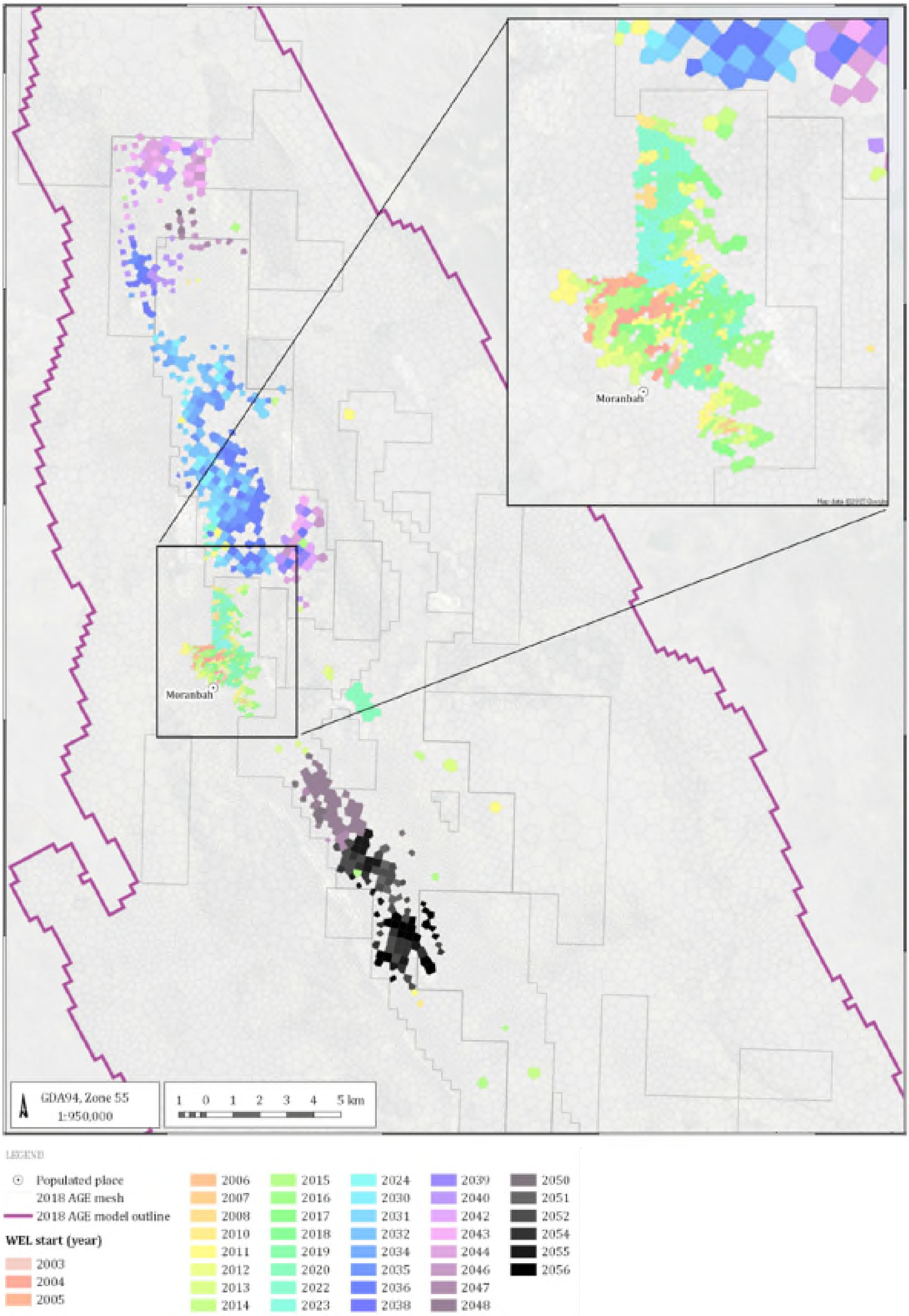


Figure 7 Scenario 2 maximum drawdown for Moranbah Coal Measures

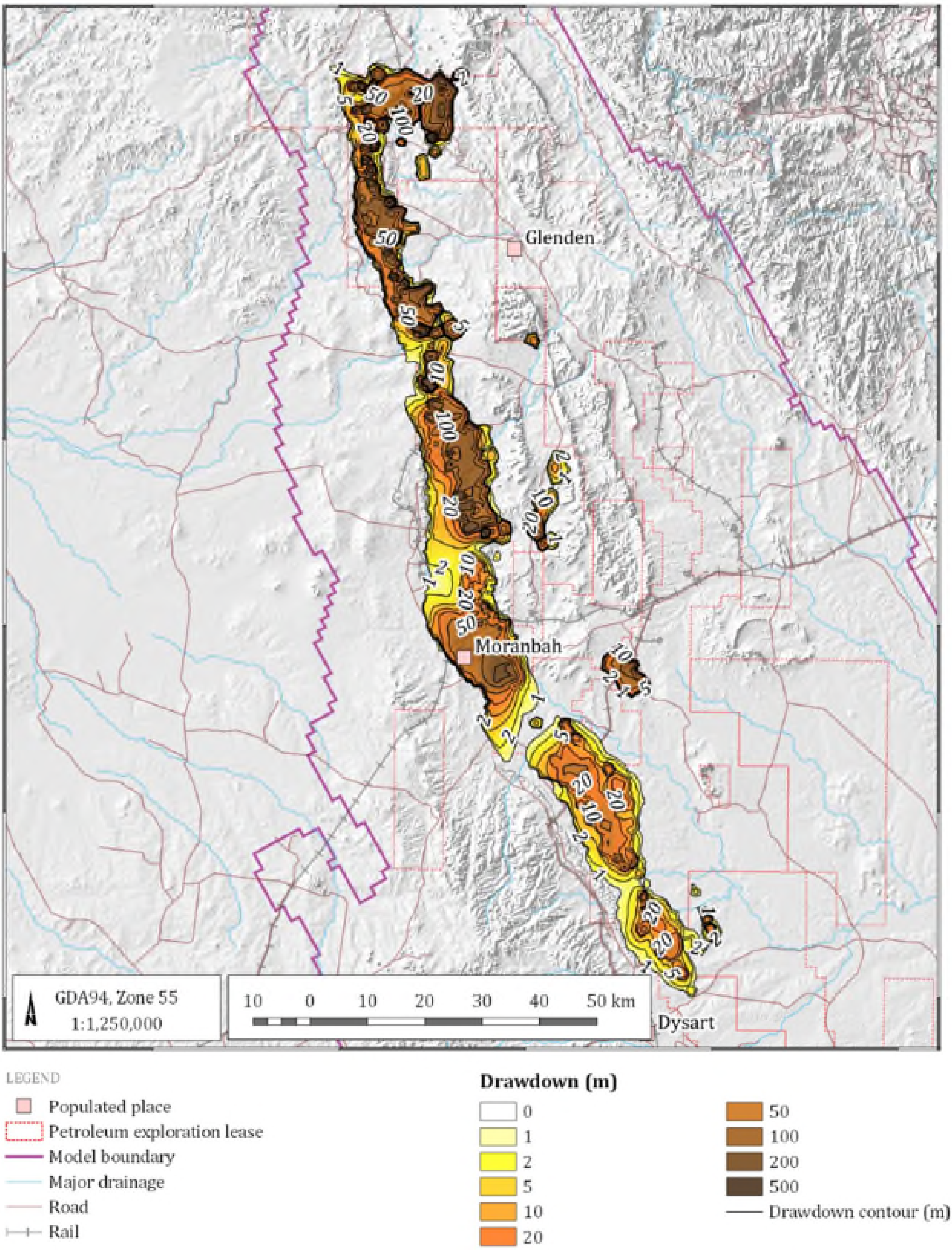


Figure 8 Scenario 2 maximum drawdown for Rangal Coal Measures

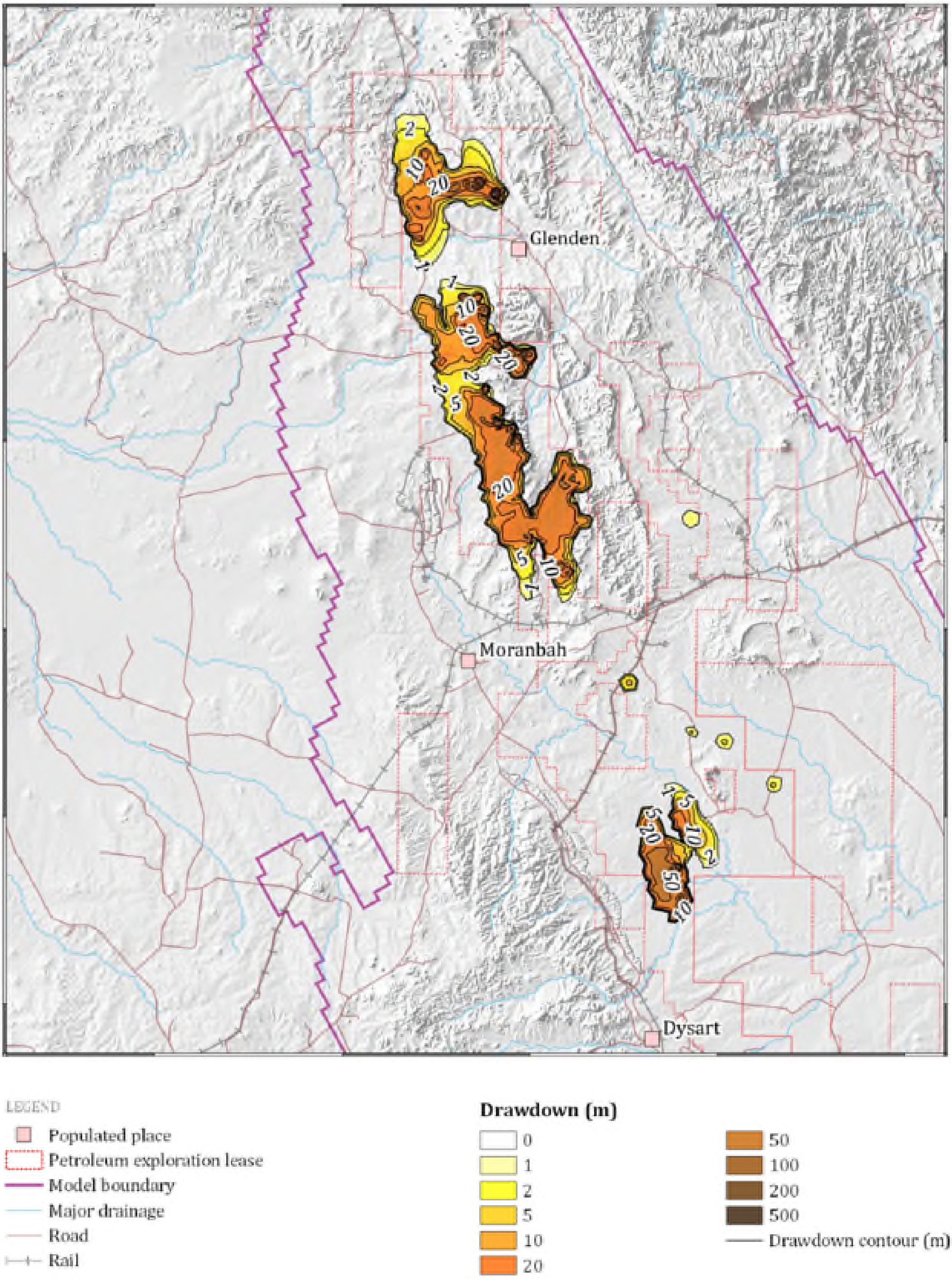


Figure 9 Time to max cumulative drawdown – Moranbah Coal Measures

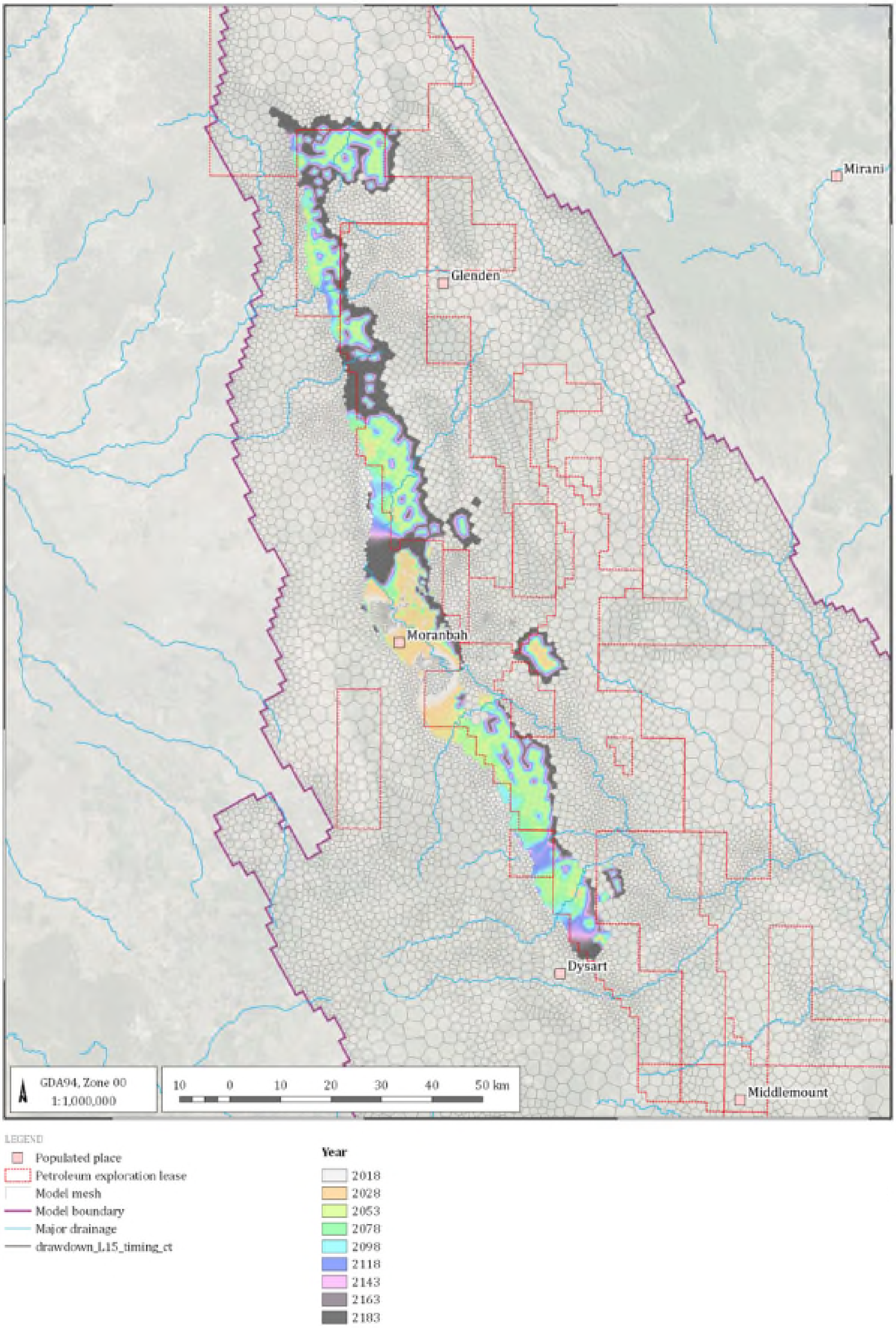


Figure 10 Maximum cumulative drawdown in Layer 1

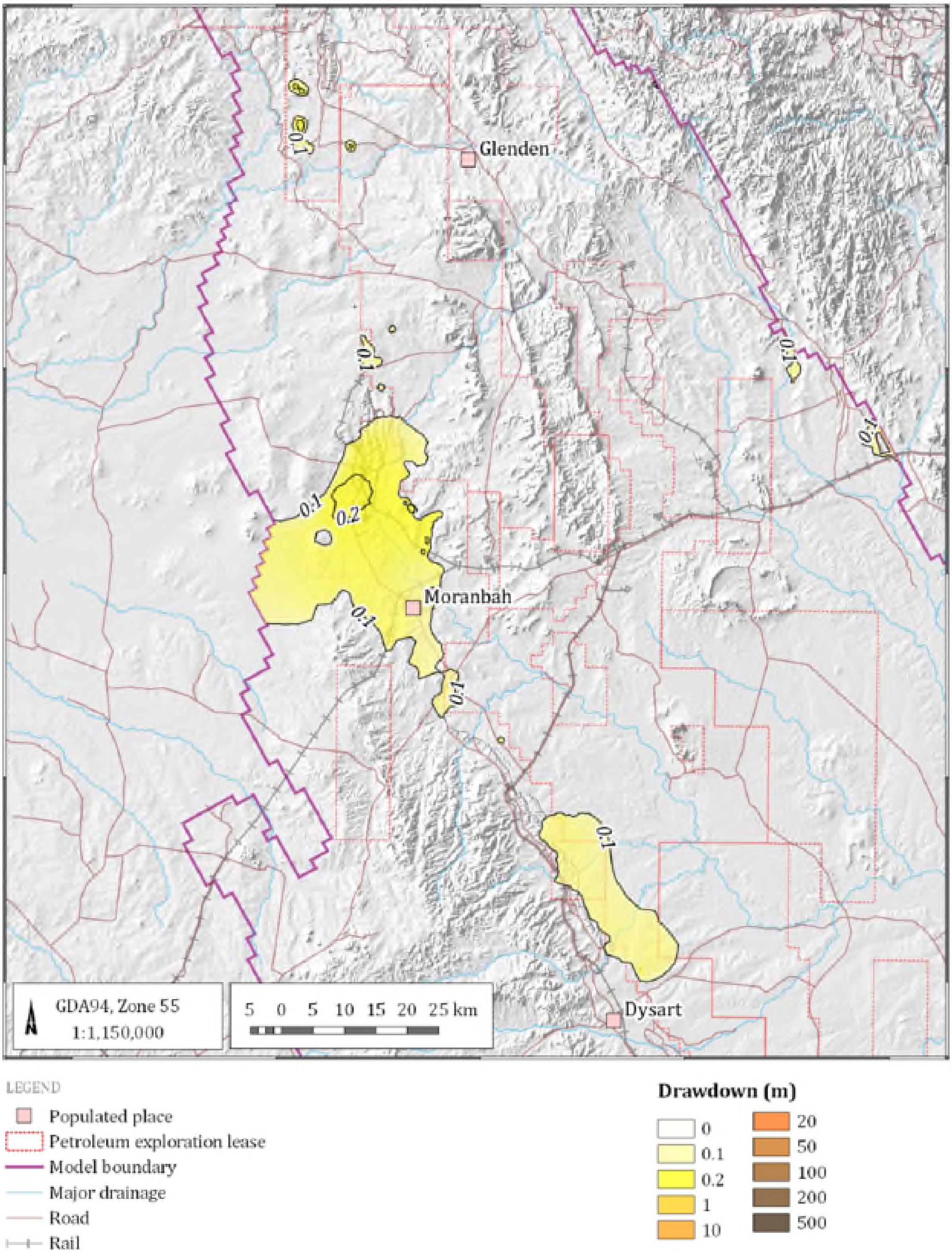


Figure 11 Maximum cumulative drawdown in Layer 2

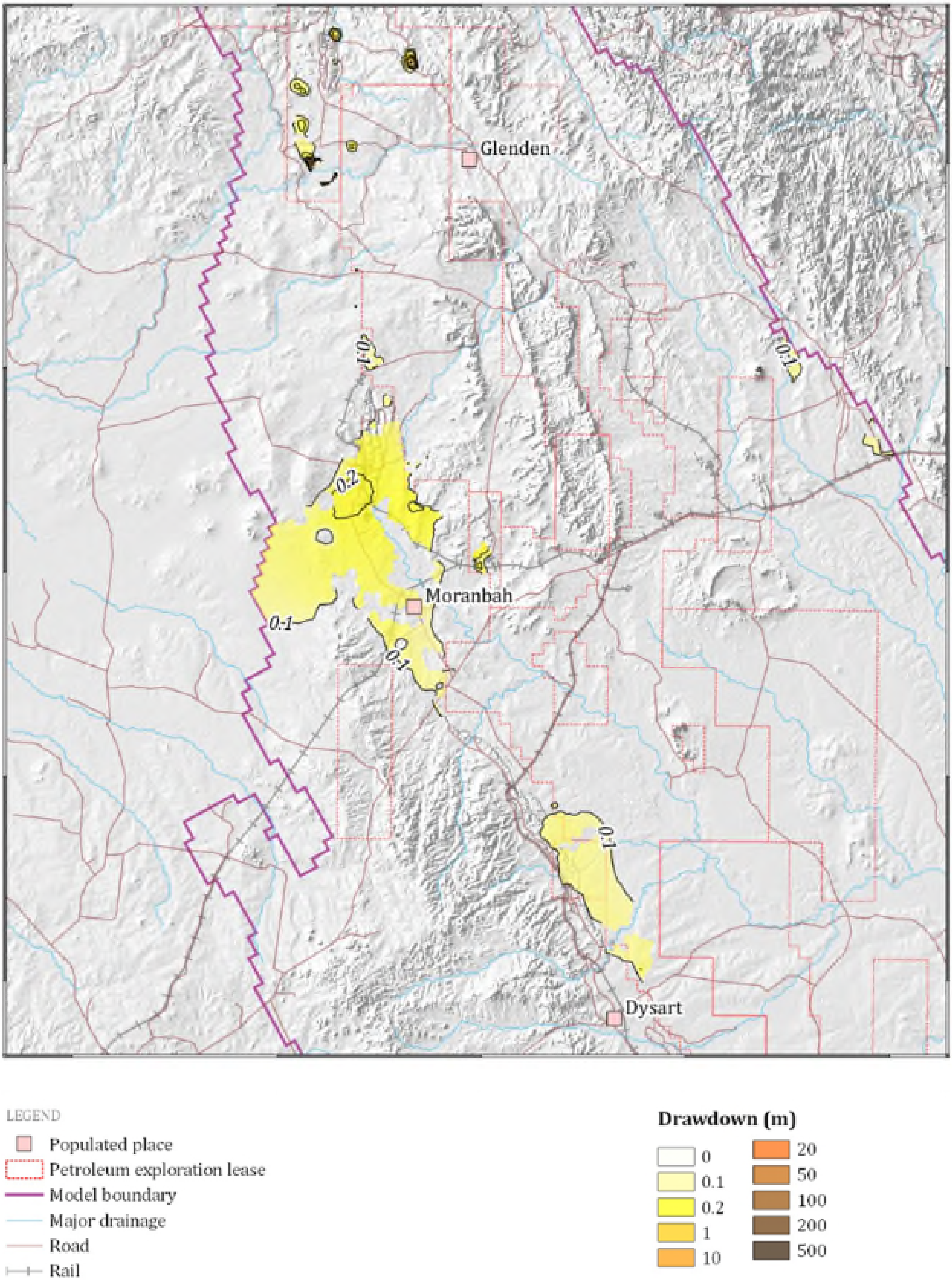


Figure 12 LAA drawdown percentile contours – Moranbah Coal Measures

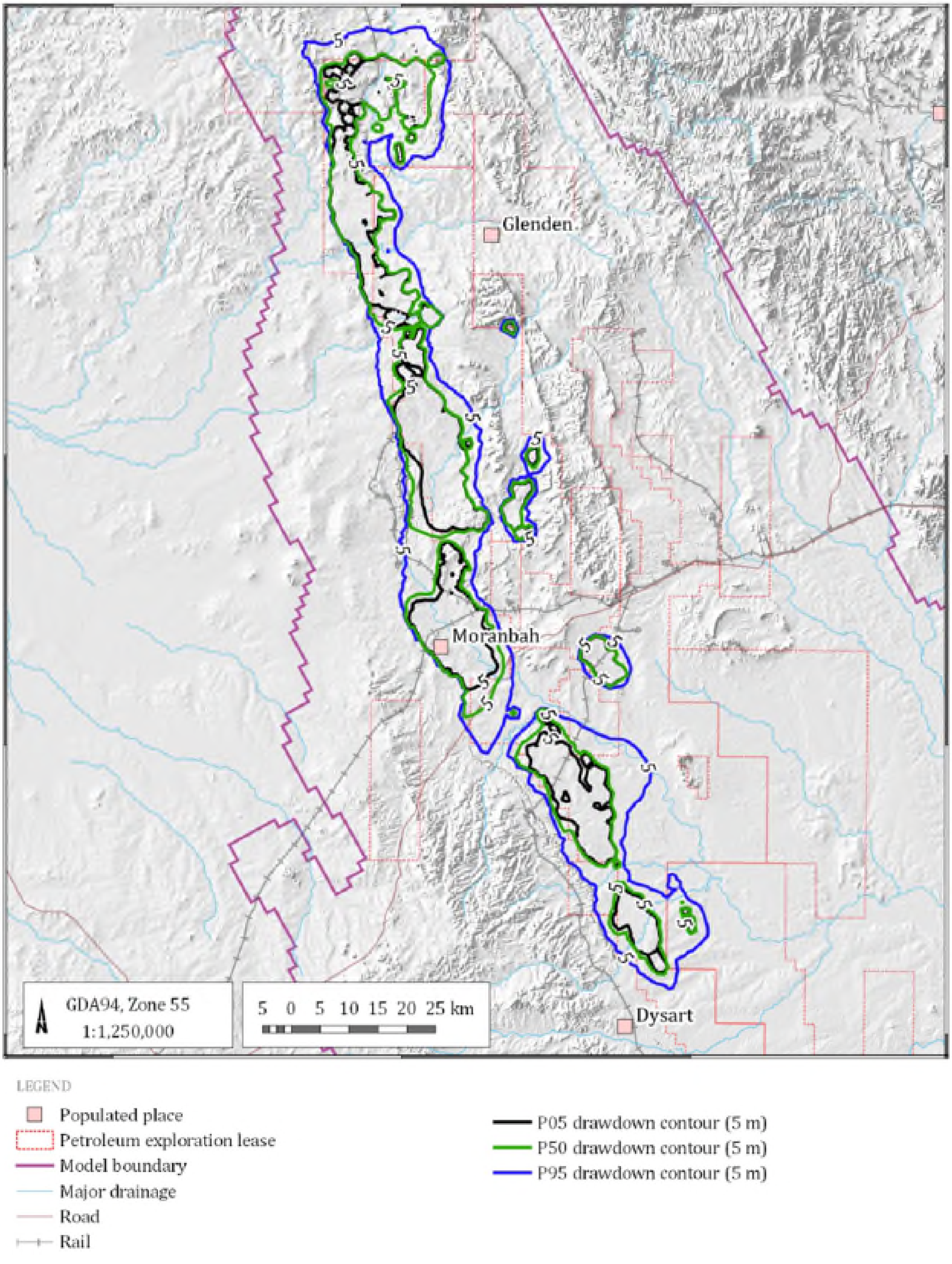
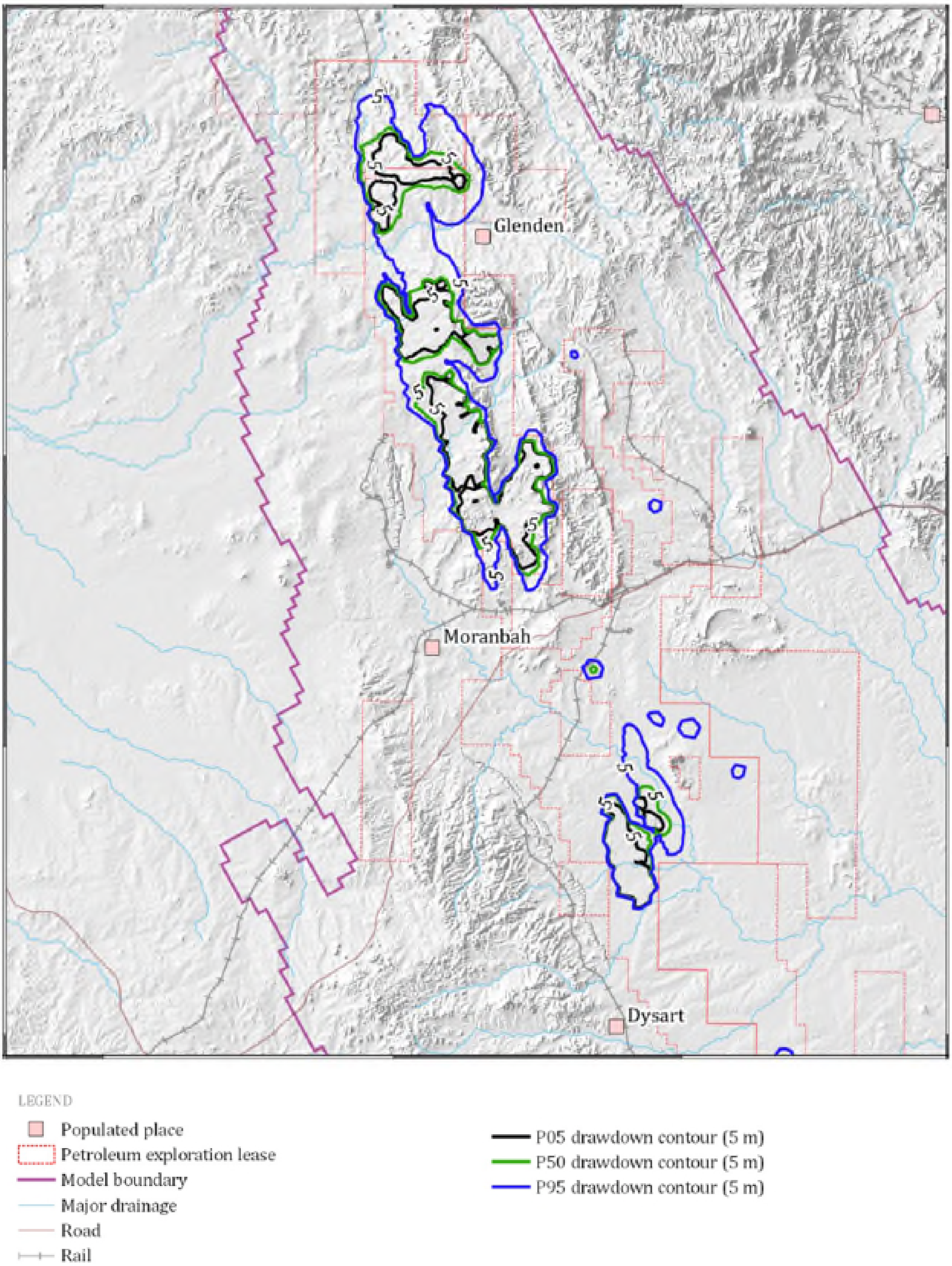


Figure 13 LAA drawdown percentile contours – Rangal Coal Measures



# APPENDIX D GROUNDWATER MONITORING NETWORK MEMORANDUM

## Memorandum

| | |
|---|---|
| **Recipient** | Arrow Energy Pty Ltd |
| **Memo date** | 13/03/2019 |
| **Author** | Coffey Services Australia Pty Ltd |
| **Project number** | 754-MELEN213220 |
| **Memo Subject** | BGP Groundwater Management and Monitoring Plan<br>Groundwater monitoring network memorandum |

# 1. Introduction

The Arrow Bowen Gas Project (BGP) EPBC Approval Conditions (EPBC 2012/6377) require the development of a Groundwater Management and Monitoring Plan (GMMP). The requirements of the GMMP are set out in Conditions 21 to 23.

The Conditions addressed in this memorandum concern the development of a groundwater monitoring network, specifically:

**Approval Condition 21**

*The approval holder must submit a Groundwater Management and Monitoring Plan (GMMP) for the written approval of the Minister who may seek the advice of an expert panel. The GMMP must contain:*

> **Approval Condition 21(a):** *details of a groundwater monitoring network for the measurement of impacts on water resources associated directly or indirectly with the action, including the ability to:*
>
> *(i) provide for the early detection of any changes in the groundwater regime in terms of amplitude and frequency of fluctuations in water pressure, water level and water quality in groundwater systems and changes in connectivity with surface water;*
>
> *(ii) monitor relevant formations to determine hydraulic connectivity and provide for early detection of impacts prior to reaching migration pathways to other formations (e.g. faults and areas of unconformities known to connect two or more formations);*
>
> *(iii) monitor potential impacts on groundwater dependent ecosystems, including spring based and non-spring based ecosystems, and provide for the early detection of impacts;*
>
> *(iv) monitor changes to the project area groundwater balance; and*
>
> *(v) monitor changes to water availability for water users and the environment.*
>
> **Approval Condition 21(c):** *a rationale for the design of the monitoring network with respect to the nature of potential impacts and the location and occurrence of matters of national environmental significance.*

This memorandum will also be used to underpin other Approval Conditions, including Approval Conditions 21(d), (e), which will be addressed in separate documents.

Following endorsement of the groundwater monitoring network, a corresponding groundwater monitoring program will be developed consistent with: (i) the requirements of Commonwealth Approval Condition 21(b) - details of a baseline monitoring data acquisition program for the approved actions and (ii) an Underground Water Impact Report (UWIR) and Water Management Strategy (WMS).

# 2. Assessment framework

The assessment framework adopted for the identification of the groundwater monitoring targets that will form the monitoring network, is based on a source-pathway-receptor model. Under this model, a source of potential impact must be linked by a complete exposure pathway to a sensitive groundwater receptor for an impact to be realised, necessitating the requirement for monitoring and/or management.

The source-pathway-receptor model, as it relates to the BGP GMMP, is described in the following sections.

## 2.1. Source of potential impact

The source of potential impact considered for the development of this GMMP is primarily groundwater drawdown associated with the depressurisation of target coal seams for the BGP. As described in the Environmental Impact Statement (EIS) (URS 2012) and Supplementary Report to the EIS (SREIS) (Coffey 2014), this may result in both direct and indirect impacts.

The current field development plan (FDP) associated with the BGP is described in Section 2.1.1 while the adopted criteria for the assessment framework are documented in Section 2.1.2. Predicted model drawdowns associated with Arrow's current and future production are presented in Section 2.1.3, while other potential sources of impact such as existing coal mining operations, are explored in Sections 2.1.4. Potential subsidence impacts were assessed in the EIS and SREIS. No conditions associated with subsidence were issued by the (then) Commonwealth Department of the Environment for the BGP and accordingly subsidence is not considered further in the development of the GMMP.

Broadly, whilst the extent of depressurisation to the end of production has been considered in the assessment of project impact, it is recognised that uncertainty in modelling predictions increases the further predictions are made into the future. Changes to gas and water production scenarios as the project evolves, also contributes to uncertainty in the model predictions. Consequently, the predicted extent of impact is expected to change as the project advances. Commonwealth Approval Condition 21(f) requires periodic review and update of the modelling predictions and the GMMP. Therefore, future iterations of the GMMP will incorporate revisions to the numerical model and outputs that may occur in association with revised development scenarios, or upon recalibration of the numerical model (following interrogation of baseline and/or ongoing monitoring data).

Other potential sources of impact to groundwater values associated with coal seam gas (CSG) development (i.e. field development and operations, hydraulic stimulation and management of produced water) will be monitored and managed under the relevant Environmental Authority conditions for the project.

### 2.1.1. Current field development program

The BGP involves a phased expansion of Arrow's CSG production in the Bowen Basin (Figure 1). It comprises development in the same areas (i.e. within tenements ATP742, ATP1103, and ATP1031) as presented in the SREIS with the addition of development in Mavis Downs (also located within ATP1103). The project area also encompasses Arrow's existing Moranbah Gas Project (MGP) operations (PL191, PL196, PL223, PL224).

The SREIS presented development in 3 phases (1, 2 and 3) between 2019 and 2049, based on 4,000 wells and total water production of 153 GL. This production has been revised and the GMMP is based on an updated FDP as follows:

- Red Hill Central (PL486 within ATP 1103) commencing 2019.
- Mavis Downs (PCa152 within ATP1103) commencing 2021.

- The remainder of the FDP area presented in the SREIS (ATP1103, ATP742 and ATP1031) commencing 2030.

Red Hill Central lies within the footprint of the BGP FDP that was presented in the SREIS. It is located approximately 30 km north of the township of Moranbah and borders the MGP area to the south. Water production from Red Hill Central is currently forecast to occur from 2019 to 2025, with a total of 0.88 GL of water to be produced.

The Mavis Downs development is located to the south of PL223 on PCa152, a comparatively mature area in ATP 1103, approximately 24 km east of the township of Moranbah. This development borders the MGP to the east. Mavis Downs production is currently forecast to occur from 2021 to 2030, with a total of 0.67 GL of water to be produced.

Production from the remainder of the BGP FDP area, tentatively planned from 2030 to 2060, will comprise 1,360 wells and total water production of 80.7 GL.

Table 2-1 provides a summary comparison between the SREIS FDP proposed for the BGP, and the revised FDP used in preparing the GMMP.

Table 2-1 Adopted drawdown assessment criteria

| **FDP** | | **Approximate number of production wells** | **Water production** | | **Timing** | |
|---|---|---|---|---|---|---|
| | | | **Total (GL)** | **Peak (GL/a)** | **Start** | **End** |
| SREIS BGP FDP | | 4,000 | 153 | 10.4 | 2019 | 2049 |
| GMMP BGP FDP | Red Hill Central | 31 | 0.88 | 0.16 | 2019 | 2025 |
| | Mavis Downs | 17 | 0.67 | 0.097 | 2021 | 2030 |
| | Remainder of the BGP FDP | 1,360 | 80.7 | 3.8 | 2030 | 2060 |
| | GMMP Total | 1,408 | 82.25 | 4.057 | 2019 | 2060 |

A comprehensive description of the BGP FDP is provided in the Coffey (2018) groundwater modelling memorandum together with a review of the numerical groundwater modelling conducted for the GMMP by AGE (2018).

Groundwater depressurisation (the source of potential impact) was simulated by AGE (2018) using an updated Modflow-USG numerical groundwater model, derived from the structure of the 2012 Northern Bowen Basin Modflow-Surfact groundwater model (Ausenco-Norwest 2012). This model was developed for the BGP SREIS and simulated a range of scenarios.

The Scenario 2 calibrated case simulates cumulative drawdown across Arrow's Bowen Basin tenures and provides a development basis for the groundwater monitoring network presented herein (note: Scenario 1 represents groundwater development associated with the MGP only, and does not include groundwater development associated with the BGP).

The modelled drawdown adopted to inform the monitoring network design was taken from the calibrated case, rather than the 95th percentile uncertainty analysis ($P_{95}$) case. This model version is parameter adjusted to provide a close model fit to the available calibration data set, and therefore provides a prediction with the minimum error to observed data.

The monitoring network is designed to provide for the early detection of any changes and impacts in the groundwater regime in accordance with Approval Condition 21(a)(i), (ii) and (iii). The approach adopted for the BGP is consistent with the approach taken for the SGP CSG WMMP, which used the calibrated model case as the basis for monitoring network design.

Monitoring bores sited according to a more conservative $P_{95}$ model drawdown case, would risk not detecting groundwater drawdown until propagation was well advanced both spatially and temporally, and such an approach would be counter to the principles of early impact detection stipulated in the Approval Conditions. In addition to early impact detection, monitoring bores sited in closer proximity to CSG development activities will provide useful water level data for the checking of model outputs and for future model calibrations, in contrast to more distal monitoring bores which may only detect minor drawdown responses, or none at all.

### 2.1.2. Predicted model impacts and adopted assessment criteria

Model outputs selected for the assessment represent the long-term affected area (LAA); the area of an aquifer within which groundwater levels are predicted to decline by more than the bore trigger thresholds at any time in the future (as specified in the Queensland Water Act (2000) and as per the requirements of a UWIR). The bore trigger thresholds adopted, in accordance with the Act and requirements of a UWIR, are:

- 5 m for consolidated aquifers; and
- 2 m for unconsolidated aquifers (assumed to represent the watertable).

These LAA's have been adopted to define the spatial extent of potential impact to existing landholder bores within the source aquifer, to assist with development of the groundwater monitoring network. As there is no temporal element to designing the monitoring network, IAAs are not used in this assessment, but are intrinsically captured in the LAA.

For surface expression groundwater dependent ecosystems (GDEs) (i.e. springs, groundwater-fed wetlands and baseflow contribution to watercourses spring) and sites of potential cultural or spiritual significance, the spatial extent of potential impact has been defined according to the 0.2 m predicted drawdown contour of the inferred source aquifer, as specified in the Queensland Water Act (2000).

For non-spring GDEs (i.e. terrestrial ecosystems), the spatial extent of potential impact has been defined according to a 1 m predicted drawdown contour in the watertable. A 1 m watertable drawdown (consistent with that applied in the Surat Gas Project (SGP) Stage 1 and 2 WMMP to assess potential areas of terrestrial GDE at risk of impact from CSG activities) is considered appropriate for the study area on the basis of:

- Arrow's watertable monitoring network in and around the MGP, constituting 8 monitoring bores, indicates groundwater levels (between 2012 and 2017) are characterised by annual variations, on average, greater than 1 m.
- Model predictions (AGE 2018) indicate the rate of drawdown in the watertable is considerably less than 1 m in a single year. Accordingly, the rate of predicted drawdown is less than the expected natural variability in the watertable.
- The scale of existing variability (due to natural fluctuation and other anthropogenic influences) in the watertable indicates existing terrestrial vegetation that currently use groundwater and which remains in good condition has the ability to adapt to, or is tolerant of, this scale of watertable variability.
- The concept of ecological resilience is one of natural systems being in a state of change, rather than equilibrium (Sommer and Froend 2011) meaning that terrestrial GDEs are necessarily adapted to some degree of groundwater level fluctuation and the terrestrial vegetation community composition will progressively respond to the prevailing conditions. It is

reasonable to assume that vegetation would adapt to the very gradual changes that may eventuate over a long period of time in the areas beyond the 1 m watertable drawdown contour interval, as evidenced by adaptation to the historical change in levels and seasonal fluctuation.

- Zolfagher (2013) indicates Eucalyptus species, which have a significant presence in the BGP study area, have an ability to adapt to decreased groundwater availability and are adept at utilising both groundwater, surface water and soil moisture, depending on availability. It is therefore reasonable to assume vegetation will be able to adapt to the relatively low magnitude of watertable drawdowns predicted in the Project area.
- Many riparian trees have dimorphic root systems which include shallow roots to improve stability, nutrient uptake, and rapid uptake of surface soil water after rainfall events, with deeper sinker roots that can access the capillary fringe of groundwater (Eamus et al. 2006; Pinto et al. 2014). Therefore, small fluctuations in the availability of soil moisture from one source (e.g. groundwater) is unlikely to impart any significant ecological response.

It is noted that terrestrial GDEs differ significantly in their ecohydrological function and response from spring GDEs, where a 0.2 m drawdown limit in the source aquifer is adopted as the impact threshold. The adoption of the 0.2 m drawdown trigger for spring GDEs is defined in the Queensland Water Act (2000) based on this being the smallest quantifiable drawdown that essentially is reflective of no impact. For some springs, even small reductions in groundwater pressure may have a bearing on the flow rates and the ecosystems supported by this groundwater.

Terrestrial GDEs, however, are fundamentally adapted to some variability in groundwater levels and they also play a part in controlling groundwater levels, as described above. Adoption of a 1 m drawdown contour is therefore considered to be an appropriate and pragmatic position for the ongoing assessment of potential impacts to terrestrial GDEs.

Further definition of the GDEs mapped and field verified in the study area is provided in Section 2.3.2.

In summary, the drawdown assessment criteria adopted are listed in Table 2-2 according to each receptor considered.

Table 2-2 Adopted drawdown assessment criteria

| Receptor | Drawdown assessment criteria |
|---|---|
| Existing groundwater bores (consolidated aquifers) | 5 m |
| Existing groundwater bores (unconsolidated aquifers) | 2 m |
| Surface expression GDEs and sites of cultural or spiritual significance | 0.2 m |
| Non-spring (terrestrial) GDEs | 1.0 m |

### 2.1.3. Predicted drawdown associated with the Project area

**Consolidated and unconsolidated aquifer**

The predicted extents of the cumulative LAAs (Scenario 2) in consideration of the assessment criteria adopted for the consolidated and unconsolidated aquifers to assess the potential impact to existing groundwater bores are illustrated in Figure 2 and are described as follows:

- Consolidated aquifers: the predicted LAA 5 m drawdown contours for the Late Permian age target coal seams represented by the amalgamated layers of the Rangal Coal Measures (RCM) and Moranbah Coal Measures (MCM) demonstrate the bore trigger threshold drawdowns are largely contained within or in the immediate vicinity of the development area. The predicted LAA 5 m drawdown contours for other geological units were also prepared and depicted in Figure 2, including:

  - Tertiary age sediments and basalts and the Triassic age Moolayember Formation (Model layer 2);
  - Triassic age Clematis Sandstone (Model layer 3);
  - Triassic age Rewan Formation (Model layer 4); and
  - Middle Permian age Formation (i.e. Back Creek Group; Model layer 22).

  Two occurrences of predicted LAA drawdown equivalent to or greater than 5 m in Model layer 2 and Model layer 4 were identified in highly localised areas, spanning less than 1 km in diameter in both instances. Specifically, in the southern part of ATP 742 for Model layer 2 and in ATP 1103 immediately to the north of Red Hill Central for Model layer 4 (Figure 2). These isolated predicted drawdowns are considered to be a local scale model artefact.

- Unconsolidated aquifers: no occurrences of drawdown in the watertable at or above the bore trigger threshold of 2 m is predicted by the model as a result of Arrow's current and future developments.

**Surface expression GDEs and non-spring GDEs assessment criteria**

The predicted watertable drawdowns of 0.2 m and 1.0 m (adopted to assess potential risks to surface expression GDEs and sites of potential cultural or spiritual significance and non-spring GDEs, respectively) are presented in Figure 3.

In summary, there are no predicted occurrences of 1.0 m drawdown in the watertable associated with Arrow's current and future developments. Localised areas of predicted 0.2 m watertable drawdown are identified in and adjacent to ATP 742, in proximity and to the west of the MGP and to the northeast of Dysart in ATP 1103 (BGP southern development area). These occurrences of modelled drawdown generally correlate with outcropping or sub-cropping Permian age coal measures in close proximity to or in overlap with the development.

#### 2.1.4. Existing coal mining operations

Significant open cut and underground longwall mining has resulted in an altered landscape across the northern Bowen Basin, changing the hydrogeological regime of the region.

There is potential for cumulative groundwater impacts to occur, where depressurisation of target coal seams during CSG extraction propagates to existing surface and underground mining operations. These impacts may relate to both water quality and quantity. The quantification of the impact (i.e. existing groundwater drawdown) that has already occurred is not possible due to the limited availability of data.

For the risk assessment, the footprint of coal mining operations has been approximated using aerial imagery and other publicly available information. Figure 2 presents the approximate locations of existing surface and underground coal mines in relation to the predicted LAAs for the consolidated and unconsolidated aquifers. The figure demonstrates there is a potential for overlap between existing coal mining operations and predicted LAAs for the Project area, and accordingly for the potential for cumulative drawdown impacts to occur, consistent with the assessment of cumulative impacts in the EIS/SREIS.

In addition to coal mining operations, the MGP is located central to the Project area, immediately south of the Red Hill Central development area (Figure 1). The MGP has produced gas for domestic supply since 2004. While the annual review of the UWIR (April 2018) for the MGP indicates that the predicted Immediately Affected Area (IAA) is largely contained within the MGP petroleum lease tenements, the predicted drawdowns presented in the current memorandum are for the LAA of Scenario 2 which represents cumulative drawdown across all of Arrow's current and future developments, including the MGP.

The GMMP will include monitoring locations considered necessary for the identification of multiple impact sources to differentiate impacts generated by the BGP and impacts caused by existing coal mining operations.

## 2.2. Exposure pathways

Exposure pathways are the mechanisms that have the potential to propagate the effects of groundwater depressurisation and lead to environmental or other impacts. Two types of pathways of groundwater depressurisation are considered below in the context of CSG production associated with the BGP: (i) formation hydraulic interconnectivity and (ii) interconnection via preferred pathways.

<u>Formation hydraulic interconnectivity</u>

The pathway for propagation of groundwater depressurisation impacts in a layered aquifer system is through leakage across confining layers that separate permeable formations. This leakage occurs due to the inherent, but typically low permeability of the confining layer and the difference in hydraulic head across the layer. The rate of leakage will also be dependent on the thickness (or absence) of the confining layer.

The numerical model simulates both direct and indirect impacts to the coal seam aquifers and connected aquifers. For example, the Rewan Formation is considered a regional aquitard and is present across the majority of the study area. Its spatial extent is represented as Layer 4 in the numerical groundwater model (AGE 2018) and therefore the drawdown predictions reflect the control the Rewan Formation has on aquifer connectivity between the target coal seams and overlying Quaternary, Tertiary and Triassic age formations. Therefore, the numerical model captures both the direct and indirect impacts associated with the Action.

The vertical hydraulic conductivity of confining layers is challenging to directly measure in the field or laboratory. This parameter is typically established by estimation based on lithology, or through the calibration process and uncertainty analysis in groundwater modelling. Refinement and reduction in the uncertainty for this key modelling parameter can be established over time with targeted monitoring, as the coal seam aquifer systems are stressed due to production depressurisation. Monitoring data for the producing and adjacent formations enables the re-calibration adjustment of groundwater models. In turn, this leads to more accurate modelled drawdown predictions due to the more reliable parameterisation.

<u>Interconnection via preferred pathway</u>

The presence of geological structures, primarily faults and its attendant fracture zone, as well as permeable conduits such as weathered dykes, may provide preferred pathways that could facilitate the vertical propagation of CSG drawdown impacts from the coal measures to adjacent aquifers.

Since preparation of the EIS, further assessment of the nature of faulting within the Project area was undertaken, including consideration of a review of published and mapped faulting and other structures within the Bowen Basin. In addition, a study of the hydraulic properties of faults, including models for predicting the permeability of faults, was undertaken and documented in Appendix A of the Supplementary Groundwater Assessment to the EIS (Coffey, 2014).

Based on these assessments, compelling evidence was identified that faults in the Bowen Basin are generally of low permeability both parallel to and normal to the fault planes. This finding is consistent with and supported by other important lines of evidence and is presented in detail in Section 5.1 of the Supplementary Groundwater Assessment to the EIS (Coffey, 2014). In brief, this evidence includes:

- Arrow operational field evidence;

- expected fault sealing, limited re-activation, and the geological age of faulting in the Bowen Basin;
- the lack of neotectonic activity in the Bowen Basin;
- the compressive Bowen Basin stress regime; and
- the expected low permeability of fault core rock.

A numerical groundwater modelling study was also undertaken, referred to in Section 6.5.2 of the Coffey (2014) report, to consider the effect of permeable faults as pathways to groundwater flow, should such features occur.

The modelling results demonstrated that faults in the Bowen Basin behave as barriers to groundwater flow along and across fault planes near CSG wells. It was concluded that in the event that a fault zone or weathered dyke represents an existing preferential pathway for flow, these features would only represent a minor contributor to propagation of drawdown impacts across formations.

Faulting information (referenced from the SREIS) is supplied in the figures representing the identified BGP GMMP monitoring network (Figure 8, Figure 9 and Figure 10).

## 2.3. Sensitive groundwater receptors

Groundwater receptors that may be affected by the depressurisation of the target coal seams were classified in the EIS under the following categories:

- Existing groundwater users
- GDEs
- Cultural and spiritual sites of significance

These features are explored further in the sections below.

### 2.3.1. Existing groundwater users

Groundwater is used for extractive purposes across the Bowen Basin. Within the study area, there are a relatively small number of licensed groundwater entitlements, which relate to use for industrial purposes to the north-east of Moranbah.

The Queensland Department of Natural Resources, Mines and Energy (DNRME) maintains a database of registered and licensed groundwater users, and registered monitoring bores. Arrow also maintains a database of landowner bores. Figure 4 presents the locations of registered and licensed landholder bores across the study area. Where information concerning the screened lithology of the bore was available, a geological unit has been assigned to the bore.

### 2.3.2. Groundwater dependent ecosystems

Types of GDEs that have been considered during the development of this GMMP include:

- Surface expression GDEs: springs, baseflow contribution to watercourses and groundwater dependent wetlands (including wetlands classified as a matter of national environmental significance (MNES) under the Commonwealth’s Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)); and
- Non-spring GDEs: vegetation dependent on the subsurface presence of groundwater (i.e. deep-rooted vegetation), referred to in this document as terrestrial GDEs.

As concluded in the EIS (URS, 2012), there are no known or anticipated fault controlled springs in the BGP area. GDEs in the project area, where present, will be dependent on the watertable aquifer. Thus, the adopted assessment criteria for surface expression GDEs is assigned to the watertable aquifer, as described in Section 2.1.2.

The SREIS (Coffey, 2014) did identify a range of actual and potential GDEs across the project area. To further refine these locations, a site visit was conducted in November 2015 to inspect locations identified as having the potential to support GDEs. Following the site visit, a detailed analysis of the potential for GDEs to be present across the project area was completed (Coffey, 2015). The findings of the study are presented in Appendix 1. The memorandum has been reviewed and endorsed by the appointed independent peer reviewer for the BGP GMMP (a copy of which is provided at the close of Appendix 1). The study concluded the following:

- Depth to groundwater data and mapped vegetation communities indicate riparian vegetation along major watercourses may be supported by groundwater on a facultative basis (i.e. use groundwater but capable of functioning without it). Within the Project area this includes the following watercourses:
    - Upper Isaac River.
    - Suttor Creek.
    - Cherwell Creek.
    - Phillips Creek.
- Terrestrial vegetation away from immediate riparian environments is not considered supported by regional groundwater systems. This conclusion is based on:
    - Available depth to groundwater information and known rooting depth characteristics of the vegetation in these areas.
    - Site observation which includes rapidly diminished vegetation stature with distance from watercourse channels and/or as depth of the alluvial soil profile over basement rock diminishes.
- Groundwater baseflow contribution to stream reaches does not occur. This is supported by the ephemeral nature of all streams in the project area, rainfall correlated flow duration and depth to groundwater exceeding channel incision depth. Release of bank storage, which will occur following recession of surface flows, is not considered to represent groundwater baseflow contribution.

It is acknowledged that the riparian environments (i.e. terrestrial GDEs) described above as being potentially dependent on groundwater do not necessarily represent all groundwater dependent riparian environments across the Project area. Rather, they represent what has been identified to date. Where impact to the watertable aquifer in the vicinity of a watercourse is predicted by numerical modelling, the riparian environment should be adequately assessed to identify whether similar characteristics exist that indicate the potential for groundwater dependence.

The locations of the identified or likely GDEs considered for this GMMP, based on Coffey (2015) field reconnaissance and desk study are presented in Figure 5. The known and potential GDEs (attributed as having high or moderate potential for groundwater dependency), as mapped in the Atlas of Groundwater Dependent Ecosystems are a publicly available data set developed under the National Water Commission’s Raising National Water Standards Program (BoM 2018). These GDEs are also illustrated in Figure 5.

#### 2.3.3. Cultural and spiritual sites of significance

Cultural heritage studies were carried out to support the BGP EIS. Four significant sites with potential association with groundwater were identified based on their description as 'wells'. Three of these sites are located within the study area.

The sites of cultural significance are presented in Figure 5.

### 2.4. Groundwater receptors potentially at risk

The predicted LAA for Scenario 2 (Section 2.1) was assessed in consideration of the location of potential groundwater receptors (Section 2.3) to identify where these may be at risk from coal seam gas depressurisation activities associated with all of Arrow's current and future developments (the Project area). Potential risks to each type of receptor in the Project area are discussed further in the sections below.

#### 2.4.1. Existing groundwater users

Figure 6 presents the location of water supply bores across the Project area in relation to the predicted 5 m LAA drawdowns for consolidated aquifers. It is noted that no occurrences of predicted 2 m LAA drawdowns for unconsolidated aquifers (the watertable aquifer) are present in the Project area.

**MGP**

Drawdown associated with the MGP is represented by the predicted 5 m LAA drawdown for the MCM which intercepts four bores inferred as screening the Late Permian age formations. However, based on an interrogation of bore card information on the Queensland Government Groundwater Database, these bores have been either re-classified in shallower formations or identified to be mine monitoring bores. Therefore, the four bores are not predicted to be at potential risk of impact from the development.

Predicted 5 m LAA drawdowns for other consolidated aquifers and the predicted 2 m LAA drawdown for unconsoldiated aquifers do not occur in the MGP. Accordingly, water bores associated with these aquifers are not considered at potential risk of impact from the development.

**Red Hill Central**

The predicted 5 m LAA drawdown for the MCM captures the entire extent of the Red Hill Central development area. The predicted 5 m LAA drawdown for the RCM partly overlaps the eastern section of the development area.

Two bores of unknown geological classification are intercepted by the 5 m LAA drawdown for the MCM within the development area. Based on an interrogation of bore card information on the Queensland Government Groundwater Database, one of the bores has been identified to be a mine monitoring bore. No other registered water supply bores occur in proximity to Red Hill Central.

**Mavis Downs**

Potential drawdown associated with the Mavis Downs development is represented by the predicted 5 m LAA drawdown for the MCM.

The 5 m LAA drawdown for the MCM intercepts two registered landholder bores of unknown geological classification.

Predicted 5 m LAA drawdown for other consolidated aquifers and the 2 m LAA drawdown for the unconsolidated aquifers do not occur as a result of the Mavis Downs development. Accordingly, water bores associated with these aquifers are not considered at potential risk of impact from the development.

**Remainder of BGP FDP**

The other predicted modelled drawdowns in the consolidated aquifers across the Project area are considered in relation to the remainder of the BGP FDP. These are depicted by the predicted 5 m LAA drawdown for the MCM and RCM (Figure 6).

For the consolidated aquifers, the predicted 5 m LAA drawdown in the MCM and RCM intercepts eleven water supply bores screening the Late Permian age Formations which may potentially be at risk of impact from the development. The 5 m LAA drawdown for the MCM and RCM also intercepts seventeen water supply bores of unknown geological classification.

The 5 m LAA drawdown for the remaining consolidated aquifers (Tertiary age units, Triassic age Rewan Formation, Early Permian to Mid Permian age Formations), where present, do not intercept any water supply bores screened in the corresponding formations. These water supply bores are therefore not considered to be at potential risk of impact from the development.

The 2 m LAA drawdown for the unconsolidated aquifers is not predicted by the model to occur in the remainder of the BGP FDP and accordingly, any water supply bores screening the watertable aquifer are not expected to be affected by the development.

### 2.4.2. Groundwater dependent ecosystems

The predicted drawdowns of 0.2 m and 1.0 m (adopted as bore trigger thresholds for the watertable aquifer to assess potential risks to surface expression GDEs and non-spring GDEs, respectively), are presented in Figure 7.

There are no predicted occurrences of 1.0 m drawdown in the watertable aquifer associated with Arrow's current and future developments. Potential non-spring GDEs (terrestrial GDEs) in the Project area (Figure 5) are therefore not considered at risk from the development.

Localised areas of predicted 0.2 m drawdowns in the watertable aquifer are identified in and adjacent to ATP 742, in proximity and to the west of the MGP and to the northeast of Dystart in ATP 1103 (southern remainder of the BGP FDP) (Figure 7). As there are no known or anticipated fault controlled springs in the BGP area, nor does groundwater baseflow contribution to stream reaches occur, such features are not considered at risk of impact from Arrow's current or future development.

### 2.4.3. Cultural and spiritual sites of significance

The predicted 0.2 m watertable drawdown contour occurs in highly localised zones in the Project area (Figure 7). The predicted 0.2 m watertable drawdown contour does not intersect any locations identified as potential sites of cultural and spiritual sites of significance. These sites are therefore not considered at potential risk of impact from Arrow's current and future developments.

# 3. Groundwater monitoring network

This section outlines the rationale for the design of a groundwater monitoring network (Section 3.2) to address the Approval Conditions and details the monitoring network locations and specifications (Section 3.3). An accompanying monitoring bore installation schedule is presented in Section 3.4.

The requirement for baseline assessments and bore assessments, as specified in the Queensland Water Act (2000), is described below in Section 3.1.

## 3.1. Baseline and Bore Assessments

The underground water impact management framework under Chapter 3 of the Queensland Water Act (2000), requires resource tenure holders to undertake baseline assessments on all authorised water bores potentially affected by the Action. A baseline assessment (defined in section 394 of the Queensland Water Act 2000) is an assessment of a water bore, undertaken by a resource tenure holder, to obtain information about the bore, including: level and quality of water, construction and pumping infrastructure. Data collected during baseline assessments provides a baseline for future water level changes to be assessed against and forms a central piece of data around which the monitoring network has been designed. The information collected also establishes benchmark data for the water bore prior to it experiencing any impact from the resource tenure holder exercising their underground water rights.

Undertaking a bore assessment is a key element of a resource tenure holder's make good obligations under Chapter 3 of the Queensland Water Act (2000). Bore assessments are required to establish whether a bore has, or is likely to have, an impaired capacity as a result of resource activities. The bore assessment also determines whether make good measures are required as part of a make good agreement between the tenure holder and the bore owner. Make good agreements ensure that the bore owner is not disadvantaged if their bore is, or is likely to be, impaired as a result of resource activities.

Baseline assessments will be undertaken in accordance with the Baseline Assessment Plan (BAP) for the project, as reported in the current UWIR (2016). The 2016 UWIR also sets out Arrow's commitment to bore assessments for any landholder bore intersected by the IAA. The next revision to the UWIR in 2019 will revise the IAAs and LAAs for the BGP and any corresponding revisions to the BAP and obligations concerning bore assessments.

## 3.2. Monitoring network design

A groundwater monitoring network has been developed to comply with Commonwealth Approval Conditions 21 to 25 and specified Arrow EIS/SREIS commitments. A structured analysis was undertaken to identify where predicted groundwater drawdowns may correspond to potential risks, and to rationalise the monitoring locations.[1] In addition, the selection of monitoring locations takes into consideration the requirement to provide baseline data before development impacts occur, and to enable early impact detection through analysis of groundwater hydrograph trends and the checking and possible re-calibration of the numerical groundwater model, as monitoring data is acquired over time.

Design of the groundwater monitoring network is underpinned by numerical groundwater modelling that simulates BGP groundwater abstraction and predicts the degree and extent of aquifer depressurisation in a spatial and temporal context. In turn, geospatial analysis has been used to enable the magnitude, extent and timing of depressurisation to be related to the location of connected environmental features and existing water users, thereby providing an informed basis for establishing monitoring locations (Section 2.4).

[1] The terms 'monitoring locations' and 'monitoring sites' are used interchangeably throughout this GMMP, and are used to describe a location where one or more groundwater monitoring bores are installed.

In summary, in designing the monitoring network consideration has been afforded to the following:

- acquisition of baseline data and on-going data for review and possible re-calibration of the numerical groundwater model;
- spatial extent and timing of predicted aquifer depressurisation;
- geological formations that require monitoring and potential migration pathways;
- potential changes to the groundwater balance;
- environmental features that require monitoring; and
- groundwater level or pressure impacts that are anticipated to occur in the context of connected receptors.

The design approach and rationale for the monitoring network, as it relates to Approval Condition 21(a), (b) and (c) for monitoring of impacts on water resources associated directly or indirectly with the BGP, is presented in Table 3-1.

It is noted that BGP GMMP monitoring network will be supported by the UWIR WMS groundwater monitoring network located in the MGP area, consisting of 8 shallow and 8 deep monitoring bores (Arrow Energy 2016 & 2018). Groundwater level and quality monitoring of this network is ongoing with up to 6 years of historical data collected to date.

Table 3-1 Groundwater monitoring network requirements and approach to design and assessment

| Monitoring requirement | Monitoring network design and rationale | Monitoring assessment approach |
|---|---|---|
| ***Approval Condition 21(a)(i):*** *To provide for the early detection of any changes in the groundwater regime in terms of amplitude and frequency of fluctuations in water pressure, water level and water quality in groundwater systems* | A network of monitoring sites will be established in target formations to enable groundwater levels and quality (both field and laboratory based) to be monitored on an ongoing basis. The risk assessment undertaken (Section 2.4) will assist in establishing and phasing appropriate monitoring sites. | Analysis of baseline and ongoing groundwater level and quality data sourced from the monitoring network will be assessed to inform the early detection of changes to the groundwater regime. |
| ***Approval Condition 21(a)(i):*** *To provide for the early detection of changes in connectivity with surface water* | In circumstances where potential baseflow occurs in proximity to predicted project related watertable drawdowns, changes to groundwater-surface water connectivity will be assessed by targeted groundwater level and stream flow monitoring. The current assessment (Section 2.4.2) has not identified any surface water features at risk of changes to connectivity from Project related CSG drawdowns. Accordingly, monitoring infrastructure with the intention of monitoring changes to groundwater-surface water connectivity is not warranted, at present. In accordance with Approval Condition 21(c) dedicated monitoring infrastructure will be installed to serve as an early detection of potential impacts to Lake Elphinstone; the sole MNES identified in the study. Further details of the response to this approval condition is provided below. | Should the assessment of risk to connectivity with surface waters change in the future, a commitment is made to develop a targeted monitoring network and accompanying early warning system (EWS) capable of providing for and responding to the early detection of changes to groundwater-surface water interconnection. |
| ***Approval Condition 21(a)(ii):*** *To monitor relevant formations to determine hydraulic connectivity and provide for early detection of impacts prior to reaching migration* | Nested monitoring bores will be employed to evaluate hydraulic gradients across relevant formations, and in locations with mapped geological features such as faults and unconformities that could function as preferential migration pathways. | Baseline and ongoing groundwater level monitoring at these nested site locations will enable the early detection of changes to hydraulic connectivity prior to potential impacts being received. |

| Monitoring requirement | Monitoring network design and rationale | Monitoring assessment approach |
|---|---|---|
| *pathways to other formations (e.g. faults and areas of unconformities known to connect two or more formations)* | Monitoring locations will be selected by correlating predicted modelled drawdowns and mapped geology and geological features to identify risk areas for inter-formation connectivity. | |
| ***Approval Condition 21(a)(iii):*** *To monitor potential impacts on GDEs, including spring based and non-spring based ecosystems, and provide for the early detection of impacts* | Monitoring sites will be established at appropriate locations to enable ongoing monitoring of groundwater levels and quality in relevant aquifer formations identified as being associated with GDEs and/or sites of cultural or spiritual significance at risk of impact from project related drawdowns. The current assessment (Section 2.4.2) has not identified any surface expression or non-spring GDEs at risk of impact from Project related CSG drawdowns. While monitoring infrastructure with the intention of monitoring potential impacts to GDEs is not warranted, at present, two watertable bores (MB4 (contingent) and MB14-S) have been sited to fulfil multiple monitoring purposes in proximity to the upper Isaac River which is associated with field verified riparian vegetation. It is acknowledged that EIS Commitment B649 refers to the monitoring of sites with cultural and spiritual significance. Although such sites have been identified in the Project area, watertable drawdown in their proximity is not predicted at or beyond the adopted assessment criteria of 0.2 m (Section 2.4.3). | To demonstrate Arrow's commitment to the monitoring and management of potential GDEs in the Project area, watertable monitoring in proximity to the upper Isaac River, at sites associated with this feature, is proposed and described in further detail in Section 3.3. Should this risk assessment change in the future, a commitment is made to develop a targeted monitoring network and accompanying EWS capable of providing for and responding to the early detection of impacts to GDEs and/or sites of cultural or spiritual significance. |
| ***Approval Condition 21(a)(iv):*** *To monitor changes to the project area groundwater balance* | CSG development leads to changes in groundwater balance, primarily due to net groundwater extraction. This will be reflected in changes in aquifer storage. | Updates or revisions to the groundwater balance / aquifer storage in the Project area will be reported upon in the three yearly GMMP updates. |

| Monitoring requirement | Monitoring network design and rationale | Monitoring assessment approach |
|---|---|---|
| | The monitoring network is designed to enable the monitoring of spatial and temporal variations in groundwater pressure / level within the Project area, which in turn will permit changes to aquifer storage to be approximated. | |
| ***Approval Condition 21(a)(v):***<br>*To monitor changes to water availability for water users and the environment* | Monitoring sites will be established at appropriate locations to enable ongoing monitoring of groundwater levels and quality in relevant aquifer formations identified as being associated with groundwater users and GDEs at potential risk from project related drawdowns.<br>For GDEs refer to response provided to Approval Condition 21(a)(iii).<br>Monitoring locations to assess potential impacts to existing groundwater users will be selected in target formations by correlating predicted LAA modelled drawdowns and locations of existing landowner bores (Section 2.4.1). | For GDEs refer to response provided to Approval Condition 21(a)(iii).<br>For existing groundwater users, collection of baseline and ongoing groundwater level and quality monitoring data sourced from the monitoring network will be assessed to inform the early detection of changes to the groundwater regime.<br>The monitoring, assessment and management approach and reporting obligations will comply with the requirements of the Queensland Water Act (2000). The requirement for baseline assessments and bore assessments of water bores potentially affected by the Action will be addressed in the 3 yearly revisions to the UWIR. |
| ***Approval Condition 21(b):***<br>*Details of a baseline monitoring data acquisition program* | The monitoring network will be designed and phased to ensure a suitable level of baseline groundwater level and quality data is acquired prior to development occurring in the area. | The acquisition of baseline groundwater level and quality monitoring data will provide a benchmark against which risk and impacts to connected receptors can be assessed and managed. |
| ***Approval Condition 21(c):***<br>*For the monitoring network design to consider the nature of potential impacts and the location and occurrence of matters of national environmental significance (MNES)* | Lake Elphinstone is identified in the EIS/SREIS as a matter of national environmental significance (MNES). No other MNES with a known or potential groundwater-dependence are identified within the study area, or beyond the Project area where indirect impacts are predicted to occur. | Baseline and ongoing groundwater level monitoring at a nested site location west of Lake Elphinstone will enable the early detection of potential shallow groundwater level and connectivity changes prior to any potential impacts being received at the lake. A contingent nested monitoring site |

| Monitoring requirement | Monitoring network design and rationale | Monitoring assessment approach |
|---|---|---|
| | While Lake Elphinstone is not predicted to be impacted by groundwater depressurisation associated with the Action, in consideration of Approval Condition 21(c), a nested monitoring location is proposed within Arrow Energy tenure some 9 km west of the lake. The nested monitoring location will serve as an early detection of changes to shallow groundwater levels prior to any impact being experienced at Lake Elphinstone. Should the early detection of impacts be identified at this monitoring site, or revised modelling indicates a risk of depressurisation impacts to Lake Elphinstone, a second nested monitoring location will be installed immediately east of the lake to monitor and manage Project related impacts to this MNES feature. | located in proximity to Lake Elphinstone, if warranted, will also serve to monitor and manage potential Project related impacts to this MNES feature. |

### 3.3. Monitoring network specifications

The groundwater monitoring network (detailed in Table 3-2) is specified separately for each of the Red Hill Central, Mavis Downs and the remainder of the BGP FDP (northern and southern development areas) phases of development due to their differences in gas development, both in a spatial and temporal context, and in some cases, targeting of different coal seam units.

The location of the identified groundwater monitoring sites is presented in Figure 8 Red Hill Central and Mavis Downs), Figure 9 (northern remainder of BGP FDP) and Figure 10 (southern remainder of BGP FDP).

Each location has been targeted to fulfil specific (primary and secondary) purposes and knowledge gaps to address the BGP GMMP Approval Conditions. All monitoring locations are intended to inform changes to the groundwater regime and the groundwater balance in the Project area and to assist in the ongoing review of the numerical groundwater modelling output and to serve as input to model recalibration, if required[2]. Selected monitoring bores are also identified for baseline data capture to ensure a sufficient level of coverage across the Project area and within key aquifers is achieved for these purposes.

Single or nested site monitoring sites are identified; the latter in circumstances where inter-formation connectivity monitoring is considered warranted, for example, in cases where the Rewan Formation may be absent or in proximity to inferred fault(s) which may provide interconnection by preferred pathways. It is emphasised that the groundwater model and its outputs represent the current state of knowledge concerning the extent and thickness of the Rewan Formation and geological faulting in the Project area.

In all formations overlying the target coal seams, the predicted Project area LAA groundwater level drawdown is less than 5 m, with the exception of two localised areas (spanning less than 1 km in diameter) in the southern part of ATP 742 (within the Tertiary age unit) and in ATP 1103 immediately to the north of Red Hill Central (within the Rewan Formation) (Figure 2); a likely local scale artefact of the numerical model (as described in the AGE (2018) model report)

While groundwater modelling indicates inter-formation connectivity is unlikely to contribute to impacts to connected receptors within overlying formations, pursuant to Approval Condition 21(a)(ii), targeted bores have been assigned in the GMMP for monitoring the potential influence of these primary and secondary exposure pathways. The monitoring bore installations will also provide additional information to support or revise the conceptualisation of the Rewan Formation in the groundwater model as necessary.

Selected monitoring sites are located in proximity to surface and underground coal mines across the Project area for the primary or secondary purpose of identifying and differentiating cumulative groundwater drawdown impacts arising due to the combined groundwater dewatering activities associated with coal mining and CSG operation. This approach relies on the comparison between modelled Project area drawdown and observed (monitored) groundwater level drawdown. Such comparisons will assist in developing an understanding of the proportion of groundwater level drawdown that can be attributed to coal mine dewatering relative to that occurring from Project related activities.

Each development area is assigned monitoring sites for groundwater quality monitoring. Both field and laboratory based quality monitoring will assist in aquifer characterisation and baselining, serving as a benchmark against which potential impacts can be assessed.

The identified monitoring locations will also supply ongoing monitoring data for groundwater model verification and re-calibration. In accordance with Approval Condition 21(f), the network will be periodically reviewed as the project development plans evolve, permitting changes to be made to the monitoring network and program, if necessary, based on any future revision to gas development or

[2] Groundwater level monitoring data from all sites in the BGP GMMP groundwater monitoring network will assist in the ongoing review of the numerical groundwater modelling output and to serve as input to model recalibration, if required. This purpose is termed “Model reference point” in Table 3-2 and Table 3-3.

model outputs. For example, in circumstances where ongoing modelling indicates that a reduced level of impact is predicted, monitoring locations specified as contingent may be re-located, or deleted in certain cases.

Finally, it is also recognised that ultimate location of the monitoring bores will be subject to site and access constraints and may be re-positioned if necessary.

### 3.3.1. Red Hill Central development area

Table 3-2 details the specific groundwater monitoring locations and their primary and secondary purpose identified for the Red Hill Central development area. Figure 9 presents the identified monitoring locations together with the predicted LAA 5 m drawdown contours for the RCM and MCM and the locations of existing landholder bores.

Three monitoring locations are identified (MB1, MB2 and MB3), one of which is intended as a nested monitoring location (MB1-S, MB1-I, MB1-D) to facilitate the assessment of inter-aquifer connection between the target coal seams and the overlying Tertiary/Quaternary age units, at a location close to the inferred boundary of the Rewan Formation.

Monitoring site MB4 is intended as a contingent location for the purposes of monitoring watertable levels in the unconfined alluvium in proximity to the Isaac River; a potential area of riparian vegetation and site of cultural or spiritual significance. While the watertable is not predicted to be impacted in this area, MB4 will be installed under contingency of the following conditions:

- ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or
- monitoring at MB1-S indicates the potential or likelihood of watertable level impacts as a consequence of the BGP.

The three monitoring locations (MB1, MB2 and MB3) are assigned as model reference points in the Red Hill Central development area, as is contingent site MB4 (if installed). Groundwater quality monitoring is specified for all intervals at MB1 (MB1-S, MB1-I and MB1-D).

It is noted that MB2 and MB3 have been re-purposed from existing CSG appraisal/production testing wells RH60 and RH51, respectively. Both sites are now instrumented and function as monitoring bores for this development area. MB1 will be re-purposed from existing CSG appraisal/production testing well RH28/RH30 to permit the monitoring of individual S/I/D horizons.[3] This activity is planned by mid-2019.

### 3.3.2. Mavis Downs development area

Table 3-2 details the groundwater monitoring location (MB5) for the Mavis Downs development area. Figure 8 presents the monitoring location together with the predicted LAA 5 m drawdown contours for the RCM and MCM and the locations of existing landholder bores.

MB5 is sited on the southwestern boundary of the Mavis Downs development area within the Tertiary/Triassic age Formation and has been assigned for baseline data capture, groundwater quality monitoring and as a model reference point. The monitoring site will also serve to identify cumulative groundwater level drawdown impacts that have the potential to occur from the coal mine immediately southwest of the development area.

[3] Additional field investigations will be undertaken to determine whether MB1 will be re-purposed from RH28 or RH30.

### 3.3.3. Remainder of BGP FDP

Table 3-2 details the groundwater monitoring locations for the remainder of the BGP FDP. Figure 9 and Figure 10 present the monitoring locations for the northern and southern development areas, respectively, together with the predicted LAA 5 m drawdown contours for the RCM and MCM and the locations of existing landholder bores.

**Northern remainder of BGP FDP**

In the northern remainder of the BGP FDP (Figure 9), six monitoring locations are identified (MB7, MB8, MB9, MB10, MB11 and MB12), three of which are intended as nested monitoring locations (MB7-S, MB7-D; MB9-S, MB9-I, MB9-D and MB11-S, MB11-D) to facilitate the assessment of inter-aquifer connection between the target coal seams and the overlying Tertiary/Quaternary age units in locations close to or beyond the inferred boundary of the Rewan Formation and/or via secondary exposure pathways in the presence of inferred mapped geological faults. MB8 and MB12 have also been sited in locations of inferred absence of Rewan Formation to assist in assessing the implications of inter-formation connectivity within the overlying Quaternary/Tertiary age formations.

While the primary objective of nested site MB11 is to monitor inter-aquifer connection, the location will also serve as an early detection of changes to shallow groundwater levels prior to any impact being experienced at Lake Elphinstone, some 9 km to the east. Should the early detection of impacts be identified at MB11, or revised modelling indicates a risk of depressurisation impacts to Lake Elphinstone, a second nested monitoring location (designated as contingent monitoring location MB17-S, MB17-I) will be installed immediately east of the lake to monitor and manage any Project related impacts to this MNES feature.

Monitoring site MB6 is intended as a contingent location for the purposes of assessing inter-aquifer connection in the presence of inferred mapped geological faults. Based on the current FDP and assessment of Project related drawdowns, MB6 will be installed under contingency of the following conditions:

- ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or
- monitoring of other sites in the northern development area indicate the potential or likelihood of preferential groundwater flow occurring across formations by way of geological fault(s).

The six monitoring locations (MB7, MB8, MB9, MB10, MB11 and MB12) are assigned as model reference points in the northern remainder of the BGP FDP, as is contingent sites MB6 and MB17 (if installed). Baseline data capture is assigned to four monitoring sites (MB7, MB9, MB11 and MB12), while groundwater quality monitoring is specified five sites: MB7-S/D, MB8, MB9-S/I/D, MB10 and MB11-S/D. The potential effects of coal mining activities on cumulative groundwater level depressurisation will be monitored in proximity to identified surface and underground coal mining operations at three monitoring sites: MB8, MB11 and MB12.

**Southern remainder of the BGP FDP**

In the southern remainder of the BGP FDP (Figure 10), four monitoring locations are identified (MB13-S, MB14, MB15 and MB16). MB14 is intended as a nested monitoring location (MB14-S, MB14-I, MB14-D) to facilitate the assessment of inter-aquifer connection between the target coal seams and the overlying Tertiary/Quaternary age units in a target location where the Rewan Formation is inferred to be absent. MB16 has also been sited in a location of inferred absence of Rewan Formation to assist in assessing the implications of inter-formation connectivity within the overlying Tertiary age formation.

MB13-S is located in proximity to an inferred fault (a potential secondary exposure pathway) to assess impacts to groundwater levels in the shallow Quaternary/Tertiary age units (if present) by way of this geological pathway. A second nested monitoring point; MB13-D to accompany shallow monitoring point MB13-S, is intended as a contingent monitoring point to compliment the monitoring of this potential secondary exposure pathway. Based on the current FDP and assessment of Project related drawdowns, MB13-D will be installed under contingency of the following conditions:

- ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or
- monitoring of MB13-S and/or other bores in the southern development area indicate the potential or likelihood of preferential groundwater flow occurring across formations by way of geological fault(s).

Nested monitoring location MB15-S and MB15-D is sited in an area of inferred mapping faults and will facilitate the assessment of potential inter-aquifer connection between the Triassic age units and the overlying Quaternary age alluvium. Although the watertable is not predicted to be impacted in this area, MB15-S will also serve to monitor water levels in proximity to Isaac River; a potential area of riparian vegetation.

The four monitoring locations (MB13, MB14, MB15, MB16) are assigned as model reference points in the southern remainder of the BGP FDP.

Baseline data capture is assigned to MB14, MB15 and MB16, while cumulative groundwater monitoring of coal mines is designated to MB14 and MB16. Groundwater quality monitoring is specified at MB14-S/I/D, MB13-S/D, MB15-S/I and MB16.

### 3.3.4. Summary

Table 3-3 summarises the intended function of each monitoring location constituting the BGP GMMP groundwater monitoring network. The content of the table demonstrates each requirement specified in the BGP GMMP Approval Conditions is fulfilled with a monitoring network totalling 8 single bores and 6 nested site bores (excluding the contingent monitoring bores), each with multiple monitoring objectives that target the monitoring and management of site specific project risks. It is noted that the monitoring bores listed may be considered for additional functions or purposes (outside of those listed in the table) at future dates.

Table 3-2 Specifications of the BGP monitoring network

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| MB1 (1)<br><br>(existing Red Hill bore RH28/RH30) (2) | S – Quaternary / Tertiary<br><br>I – RCM<br><br>D – MCM | Red Hill Central | Baseline data capture<br><br>Coal mine cumulative impact monitoring<br><br>Model reference point | Groundwater quality | 2019 |
| MB2 (1)<br><br>(existing Red Hill bore RH60) | MCM | | Baseline data capture<br><br>Formation hydraulic interconnectivity<br><br>Model reference point | | Current |
| MB3 (1)<br><br>(existing Red Hill bore RH51) | MCM | | Baseline data capture<br><br>Formation hydraulic interconnectivity<br><br>Model reference point | | Current |
| MB4 (3) | Unconfined alluvials | | Groundwater level monitoring in proximity to potential riparian vegetation and a site of cultural and/or spiritual significance<br><br>Model reference point | | Contingent |
| MB5 | Tertiary / Triassic | Mavis Downs | Baseline data capture<br><br>Coal mine cumulative impact monitoring | Groundwater quality | 2020 |

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| | | | Model reference point | | |
| MB6 (3) | Quaternary / Tertiary | BGP FDP (northern development area) | Interconnection via preferred pathway<br>Model reference point | | Contingent |
| MB7 | S – Tertiary<br>D – RCM | | Baseline data capture<br>Model reference point | Groundwater quality | 2029 |
| MB8 | Quaternary / Tertiary | | Formation hydraulic interconnectivity<br>Coal mine cumulative impact monitoring<br>Model reference point | Groundwater quality | 2030 |
| MB9 | S – Quaternary / Tertiary<br>I – RCM<br>D – MCM | | Baseline data capture<br>Formation hydraulic interconnectivity<br>Interconnection via preferred pathway<br>Model reference point | Groundwater quality | 2029 |
| MB10 | Tertiary | | Model reference point | Groundwater quality | 2030 |
| MB11 | S – Quaternary / Tertiary or Rewan Formation<br>D – RCM | | Baseline data capture<br>Formation hydraulic interconnectivity | Groundwater quality<br>Coal mine cumulative impact monitoring | 2029 |

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| | | | Interconnection via preferred pathway<br>Model reference point | MNES monitoring | |
| MB12 | Quaternary / Tertiary | | Baseline data capture<br>Coal mine cumulative impact monitoring<br>Formation hydraulic interconnectivity<br>Model reference point | | 2028 |
| MB13 | S – Quaternary / Tertiary (if present)<br>D – Blackwater Group (RCM / MCM) (3) | BGP FDP (southern development area) | Interconnection via preferred pathway<br>Model reference point | Groundwater quality | 2028<br>Contingent |
| MB14 | S – Quaternary / Tertiary<br>I – RCM<br>D - MCM | | Baseline data capture<br>Formation hydraulic interconnectivity<br>Model reference point | Coal mine cumulative impact monitoring<br>Groundwater quality | 2029 |
| MB15 | S – Unconfined alluvials<br>I – Tertiary / Triassic | | Baseline data capture<br>Interconnection via preferred pathway<br>Model reference point | Groundwater level monitoring in proximity to potential riparian vegetation<br>Groundwater quality | 2029 |
| MB16 | Tertiary | | Baseline data capture | Coal mine cumulative impact monitoring | 2029 |

| Monitoring location | Monitoring interval and target formation (4,5,6) | Development area | Primary purpose (7) | Secondary purpose | Installation by year (indicative) |
|---|---|---|---|---|---|
| | | | Formation hydraulic interconnectivity<br><br>Model reference point | Groundwater quality | |
| MB17 (3) | S – Unconfined alluvials<br><br>I – Rewan Formation | ATP 1103 (in proximity to Lake Elphinstone) | MNES monitoring<br><br>Groundwater-surface water connectivity<br><br>Formation hydraulic interconnectivity<br><br>Model reference point | Groundwater quality | Contingent |

***Notes:***

*(1) RH60 (now MB2) and RH51 (now MB3) are existing bores in the Red Hill development area that have been re-purposed and instrumented for groundwater level monitoring purposes in the BGP GMMP. RH28/RH30 (now MB1) requires conversion and instrumentation for monitoring across the three intervals. This activity is planned for 2019.*
*(2) Additional field investigations are required to determine whether MB1 will be re-purposed from RH28 or RH30.*
*(3) Contingent location. Monitoring location will only be installed under contingency of the conditions described in Section 3.3.*
*(4) Surficial aquifer assumed based on outcrop geology mapping. Refinement of surficial target aquifer may require refinement at the local scale.*
*(5) The exact number of bores required to achieve monitoring of the specified intervals will be determined during monitoring bore design and engineering.*
*(6) S: shallow monitoring point, I: intermediate monitoring point, D: deep monitoring point (monitoring points and monitoring intervals have the same meaning).*
*(7) Model reference point refers to the use of the groundwater level monitoring data in the regular review of numerical model outputs and to serve as input to the numerical groundwater model, if necessary.*

Table 3-3 Intended function of BGP monitoring sites [1,2]

| **Monitoring site**[1] | **Development area** | **Baseline** | **Groundwater quality** | **Formation hydraulic interconnectivity** | **Interconnection via preferential pathway** | **Coal mine cumulative impact** | **Riparian vegetation** | **Site of cultural and/or spiritual significance** | **Gw-Sw connectivity** | **MNES** | **Model reference point** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MB1-S MB1-I MB1-D [3] | Red Hill Central | ✓ | ✓ | | | ✓ | | | | | ✓ |
| MB2 [4] | | ✓ | | ✓ | | | | | | | ✓ |
| MB3 [5] | | ✓ | | ✓ | | | | | | | ✓ |
| MB4 [1] | | | | | | | | (✓) | | | (✓) |
| **Sum** | | **3** | **1** | **2** | **-** | **1** | **1** | **(1)** | **-** | **-** | **3(1)** |
| MB5 | Mavis Downs | ✓ | ✓ | | | ✓ | | | | | ✓ |
| **Sum** | | **1** | **1** | **-** | **-** | **1** | **-** | **-** | **-** | **-** | **1** |
| MB6 [1] | Northern remainder of the BGP FDP | | | | (✓) | | | | | | (✓) |
| MB7-S MB7-D | | ✓ | ✓ | | | | | | | | ✓ |
| MB8 | | | ✓ | ✓ | | ✓ | | | | | ✓ |

| Monitoring site(1) | Development area | Baseline | Groundwater quality | Formation hydraulic interconnectivity | Interconnection via preferential pathway | Coal mine cumulative impact | Riparian vegetation | Site of cultural and/or spiritual significance | Gw-Sw connectivity | MNES | Model reference point |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MB9-S<br>MB9-I<br>MB9-D | | ✓ | ✓ | ✓ | ✓ | | | | | | ✓ |
| MB10 | | | ✓ | | | | | | | | ✓ |
| MB11-S<br>MB11-D | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ |
| MB12 | | ✓ | | ✓ | | ✓ | | | | | ✓ |
| **Sum** | | **4** | **5** | **4** | **2 (1)** | **3** | **-** | **-** | **-** | **1** | **6 (1)** |
| MB13-S<br>MB13-D<br>(1) | Southern remainder of the BGP FDP | | ✓ | | ✓ | | | | | | ✓ |
| MB14-S<br>MB14-I<br>MB14-D | | ✓ | ✓ | ✓ | | ✓ | | | | | ✓ |
| MB15-S<br>MB15-I | | ✓ | ✓ | | ✓ | | ✓ | | | | ✓ |

| Monitoring site(1) | Development area | Baseline | Groundwater quality | Formation hydraulic interconnectivity | Interconnection via preferential pathway | Coal mine cumulative impact | Riparian vegetation | Site of cultural and/or spiritual significance | Gw-Sw connectivity | MNES | Model reference point |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MB16 | | ✓ | ✓ | ✓ | | ✓ | | | | | ✓ |
| **Sum** | | **3** | **4** | **2** | **2** | **2** | **1** | **-** | **-** | **-** | **4** |
| MB17-S (1)<br>MB17-I (1) | ATP 1103 (in proximity to Lake Elphinstone) | | (✓) | (✓) | | | | | (✓) | (✓) | (✓) |
| **Sum** | | **-** | **(1)** | **(1)** | **-** | **-** | **-** | | **(1)** | **(1)** | **(1)** |
| **Total across BGP** | | **11** | **11 (1)** | **8 (1)** | **4 (1)** | **7** | **1 (1)** | **(1)** | **(1)** | **1 (1)** | **14 (3)** |

***Note:***
*(1) MB4, MB6, MB13-D and MB17-S/D are contingent monitoring locations.*
*(2) The purpose of the contingent monitoring bores is separated in the table with the number of locations listed in brackets.*
*(3) MB1 represents existing Red Hill bore RH28/RH30.*
*(4) MB2 represents existing Red Hill bore RH60.*
*(5) MB3 represents existing Red Hill bore RH51.*

## 3.4. Proposed monitoring network – schedule

Table 3-4 presents the indicative schedule of the groundwater monitoring network. The installation schedule is phased according to the following:

- Monitoring locations with a primary purpose of baseline monitoring will be installed up to one year prior to the commencement of production in the corresponding development phase to enable the collection and interrogation of baseline data.
- Monitoring locations where baseline monitoring is not required will be installed immediately prior to the commencement of production in the corresponding development area.
- Contingent locations will be installed only in circumstances where the criteria for contingency (specified in Section 3.3) are met.

Multi-level monitoring systems are proposed for sites where nested monitoring (intermediate and deep formations) is specified, however open standpipe piezometers may also be suitable in some circumstances.

Arrow is committed to the principles of environmental sustainability. Consistent with these principles, the establishment of the monitoring network is intended to include and utilise existing monitoring bores, and to re-purpose CSG exploration or pilot bores where feasible to reduce the number of new drilling sites.

Table 3-4 BGP monitoring network – indicative installation schedule

| Development area | Monitoring location | Baseline data capture | Installation by (year) (indicative) |
|---|---|---|---|
| Red Hill Central | MB1-S<br>MB1-I<br>MB1-D | ✓ | 2019 |
| | MB2 | ✓ | Current |
| | MB3 | ✓ | Current |
| | MB4 | × | Contingent |
| Mavis Downs | MB5 | ✓ | 2020 |
| Northern remainder of the BGP FDP | MB6 | × | Contingent |
| | MB7-S<br>MB7-D | ✓ | 2029 |
| | MB8 | × | 2030 |
| | MB9-S<br>MB9-I<br>MB9-D | ✓ | 2029 |
| | MB10 | × | 2030 |
| | MB11-S | ✓ | 2029 |

| Development area | Monitoring location | Baseline data capture | Installation by (year) (indicative) |
|---|---|---|---|
| | MB11-D | | |
| | MB12 | ✓ | 2028 |
| Southern remainder of the BGP FDP | MB13-S<br>MB13-D | × | 2028<br>Contingent |
| | MB14-S<br>MB14-I<br>MB14-D | ✓ | 2029 |
| | MB15-S<br>MB15-I | ✓ | 2029 |
| | MB16 | ✓ | 2029 |
| ATP 1103 (in proximity to Lake Elphinstone) | MB17-S<br>MB17-I | × | Contingent |

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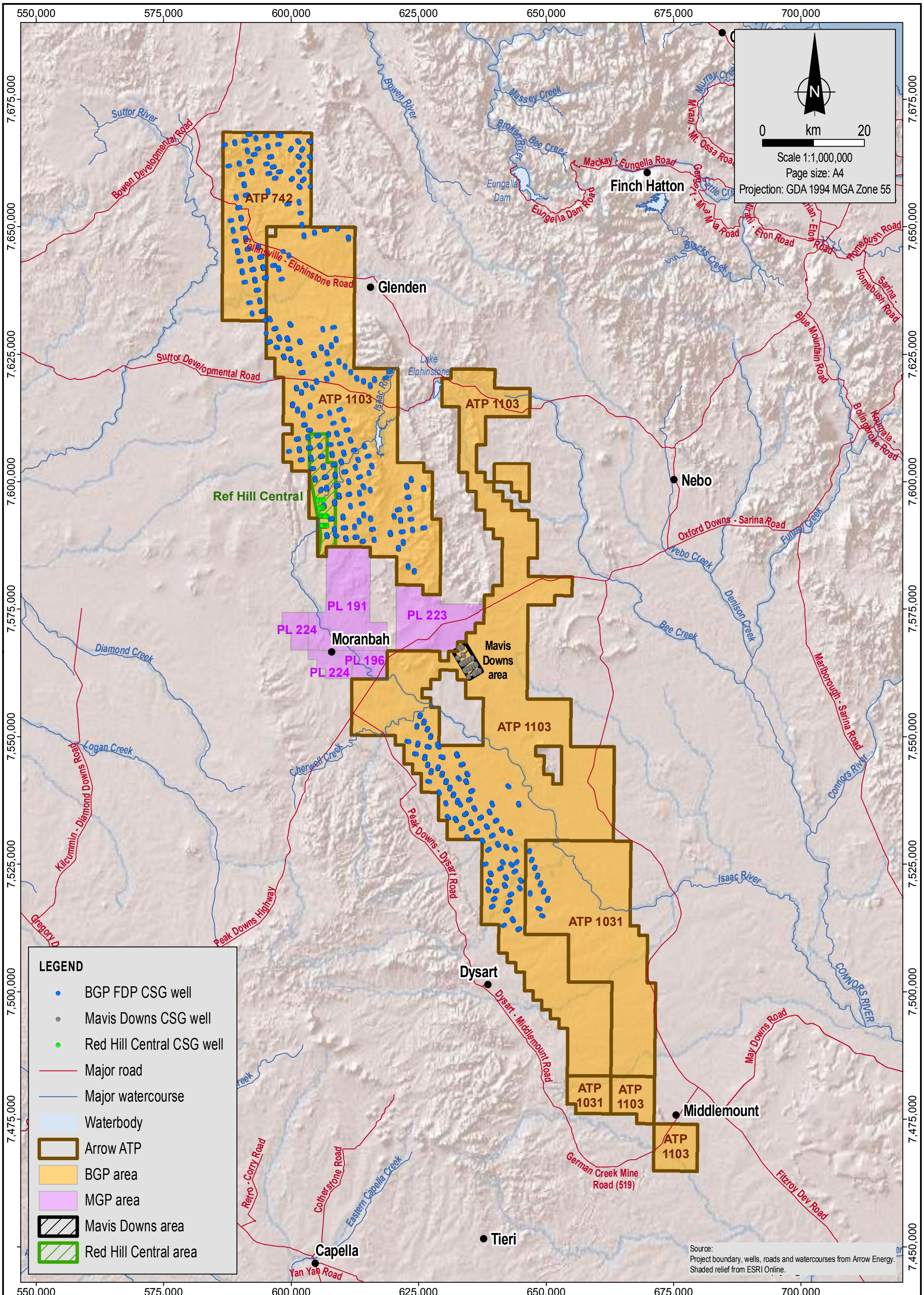
# Figures

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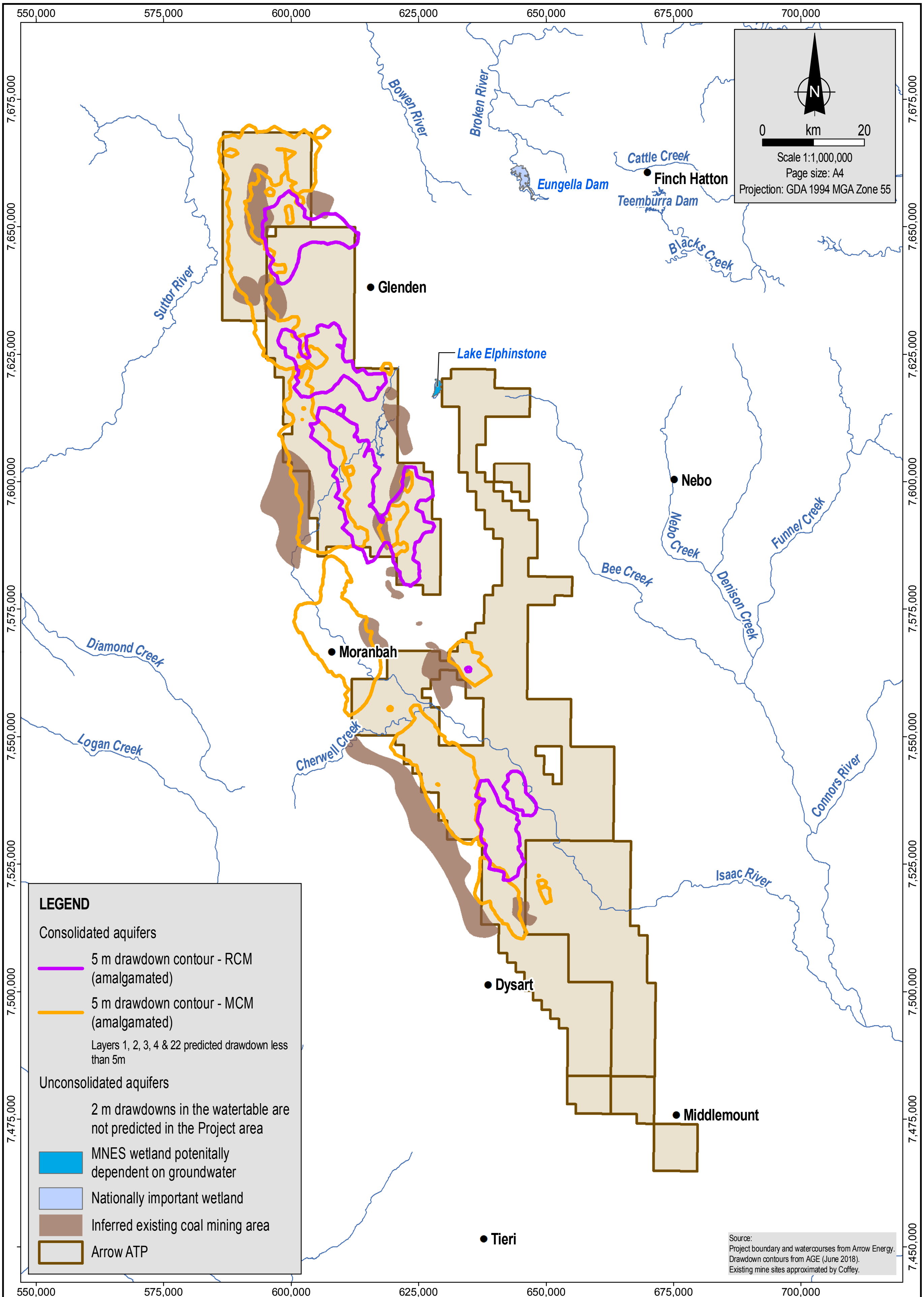
|---|---|---|---|---|---|

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|---|---|---|---|---|
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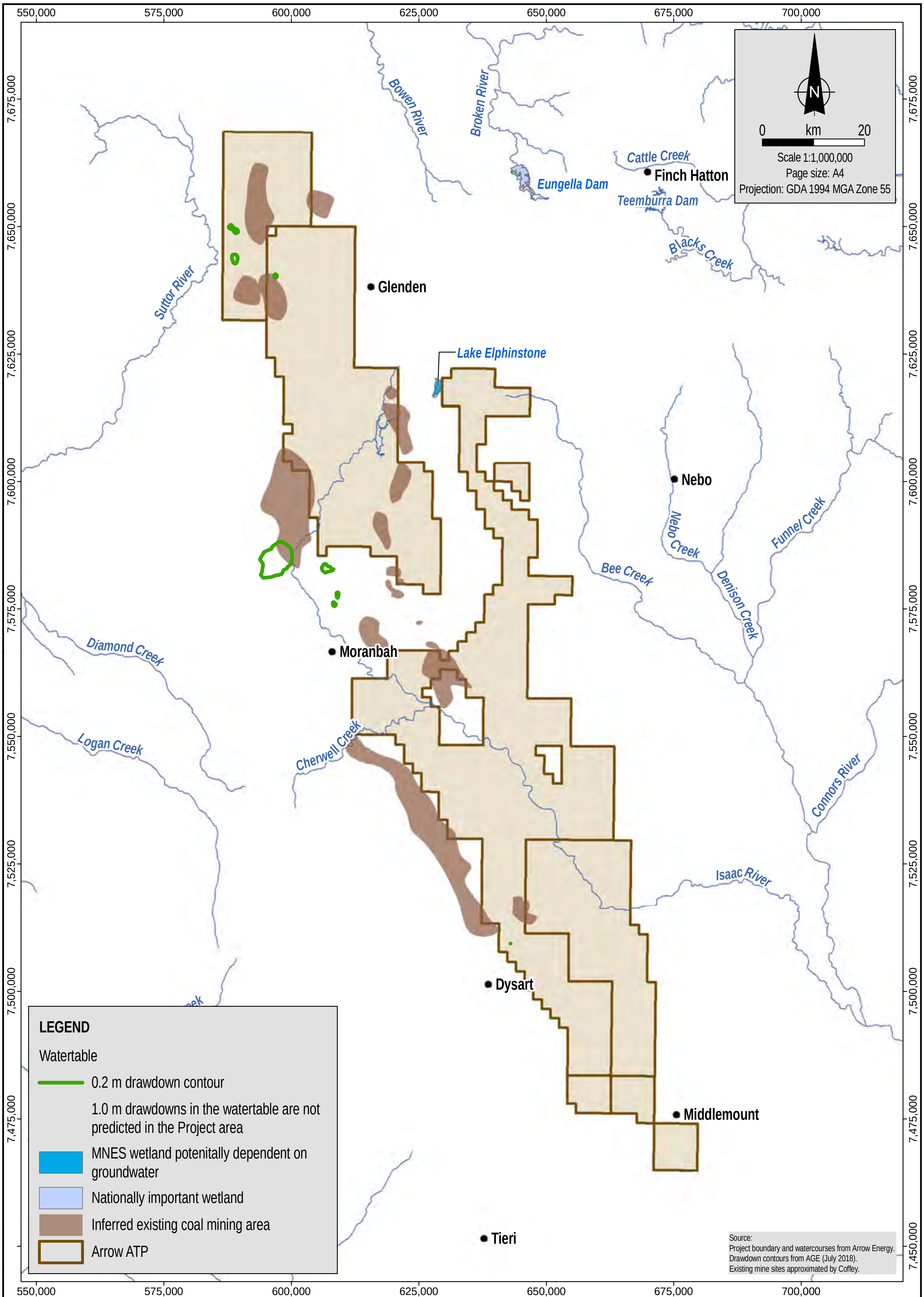


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| Date: 01.08.2018 | Arrow Energy | arrow energy go further | Predicted Project area LAA for the watertable | Figure No: 3 |
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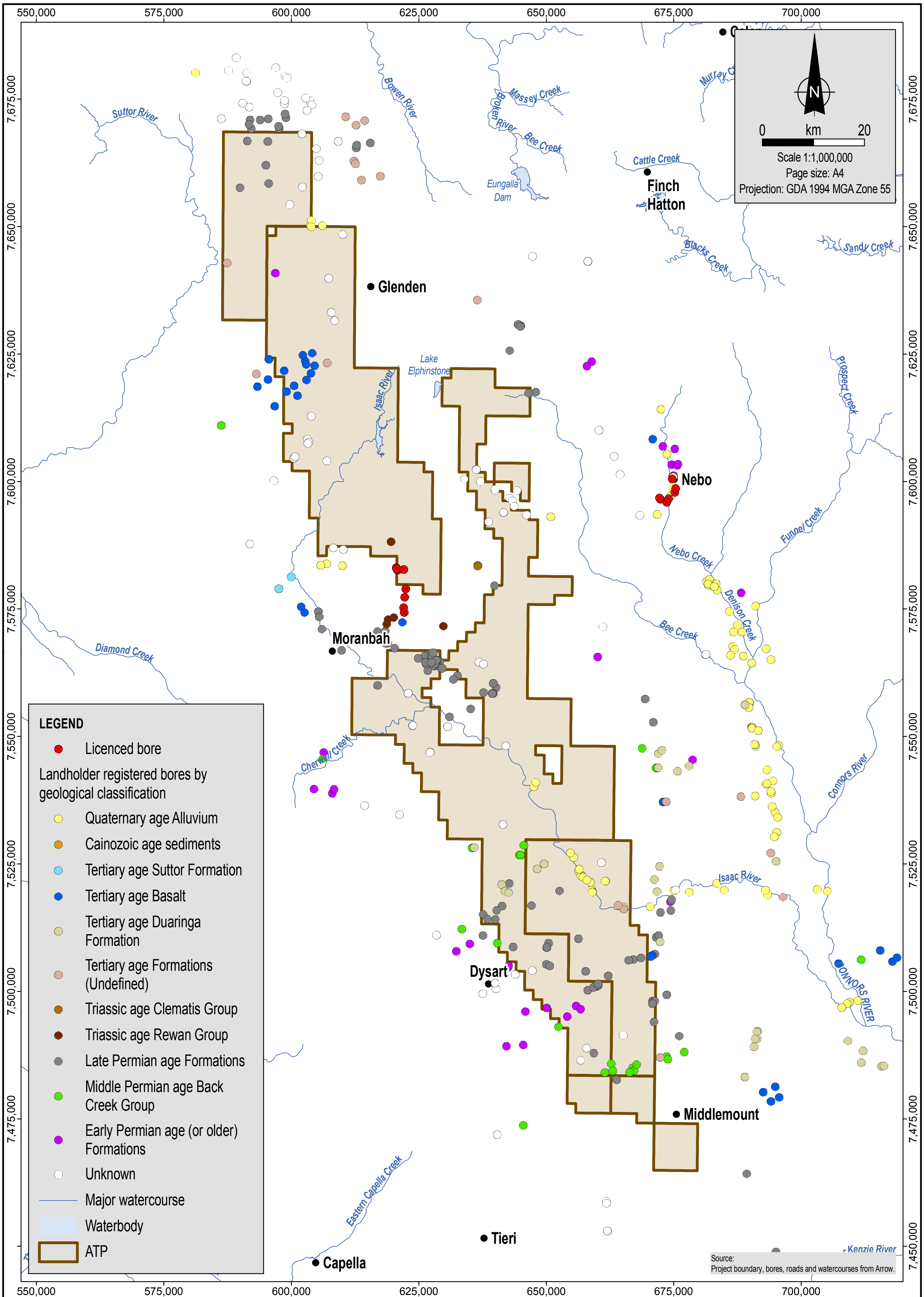


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Date: 10.09.2018
Project: 754-MELEN213220
File Name: 213220_M04_F004_GIS

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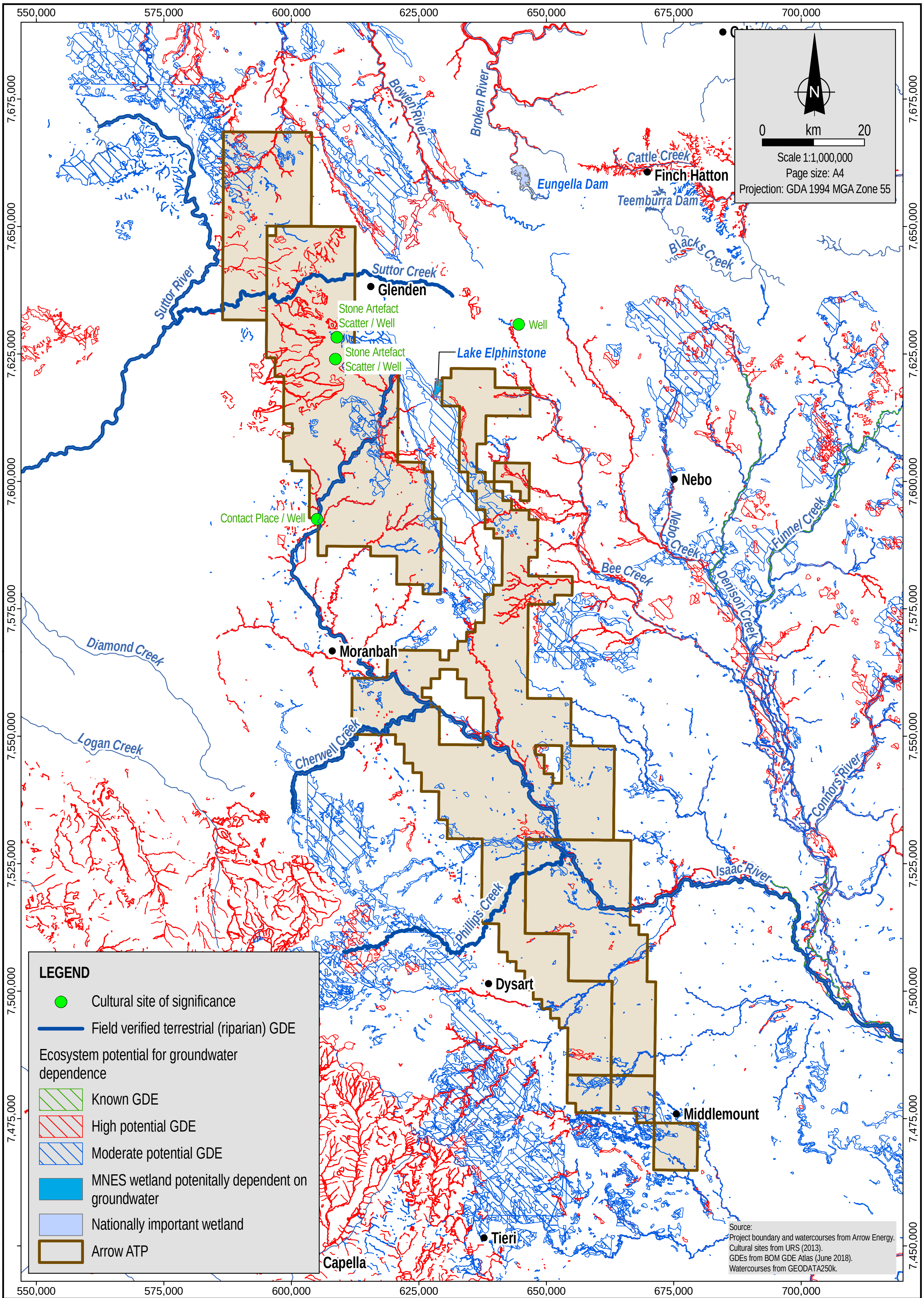
Water supply bores

Figure No: 4

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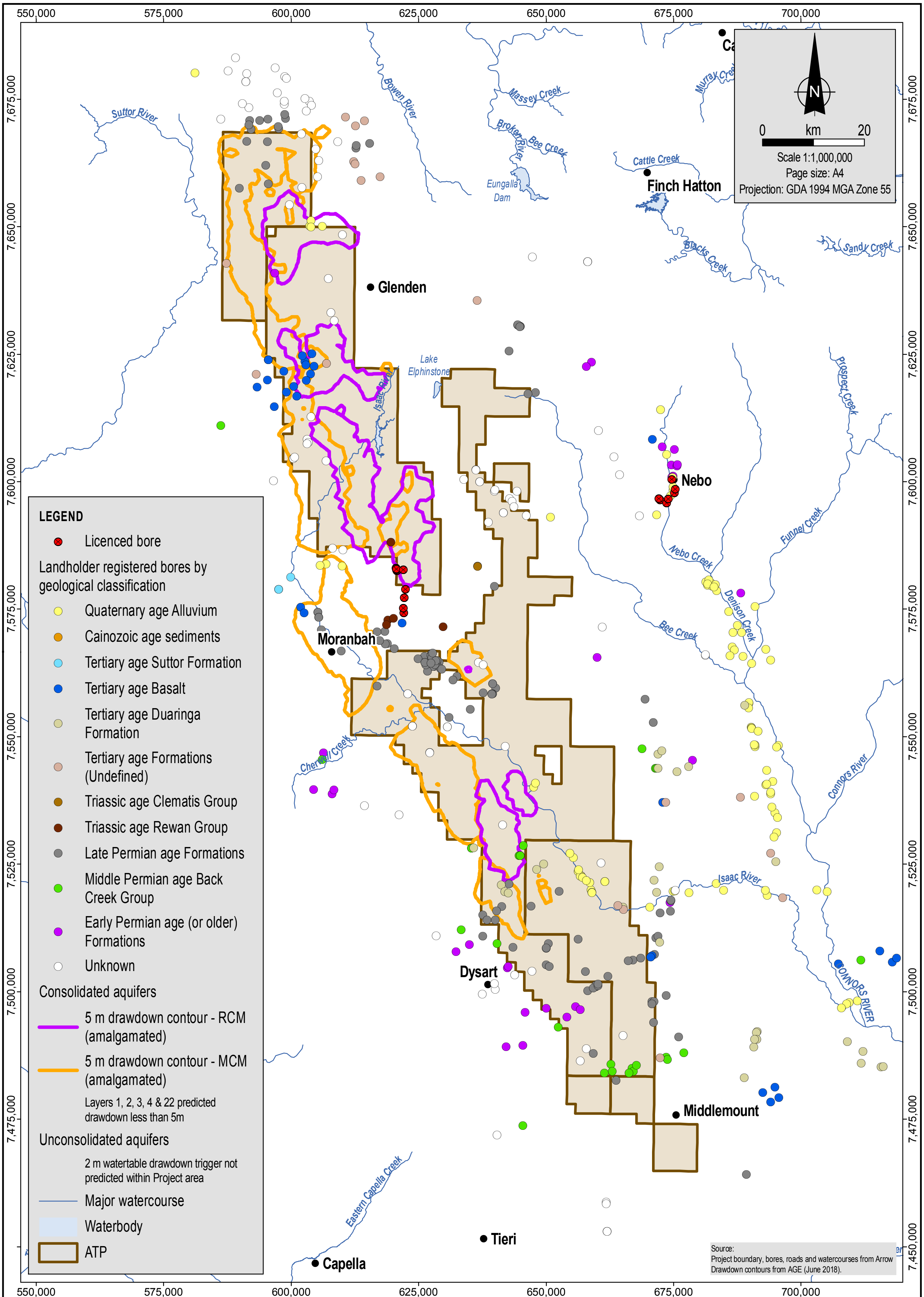
|---|---|---|---|---|---|

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| | Project: 754-MELEN213220 | Bowen Gas Project | | | DRAFT |
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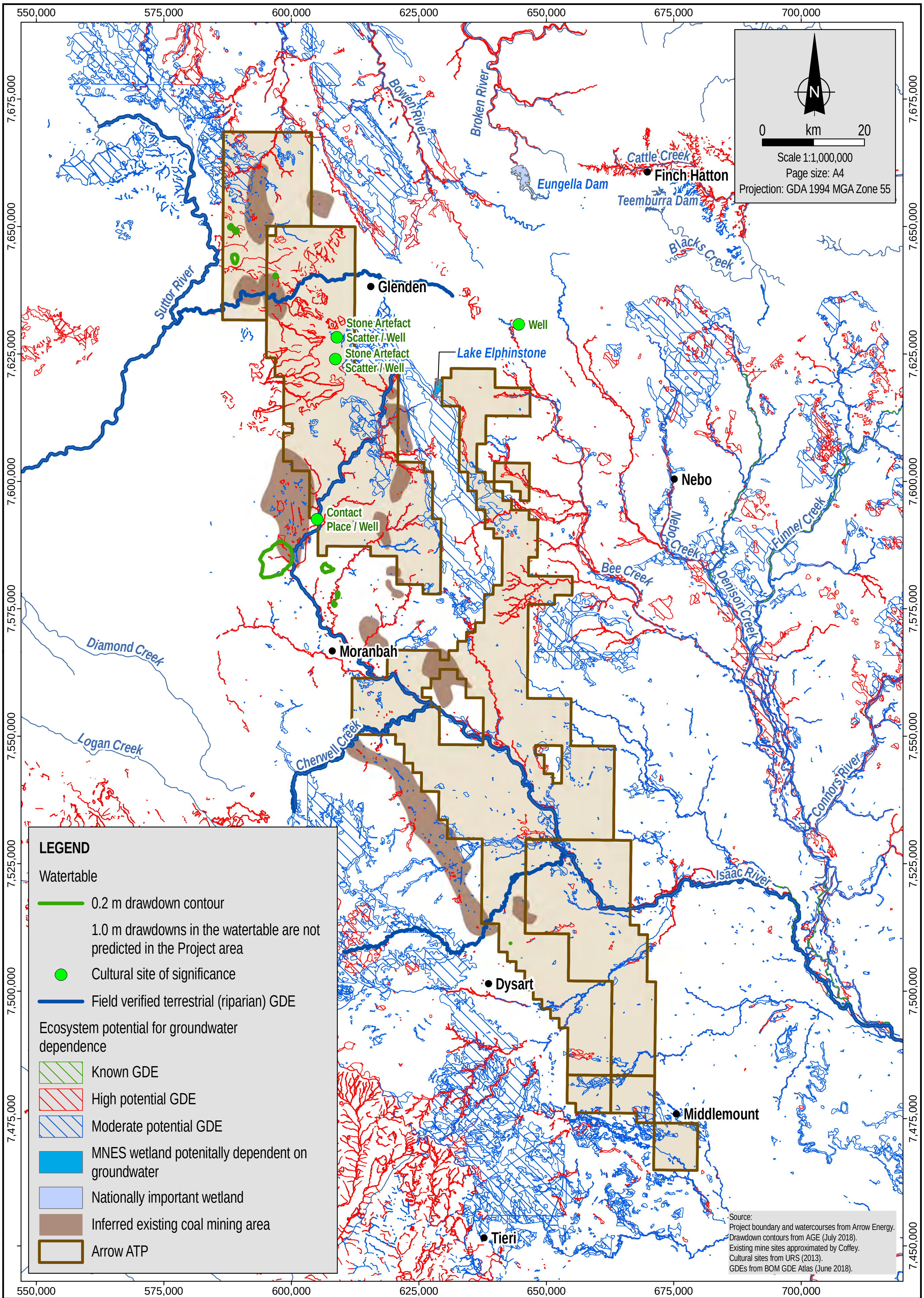


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coffey
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Date: 01.08.2018
Project: 754-MELEN213220
File Name: 213220_M04_F007_GIS

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Potential for predicted Project area LAA watertable drawdowns to impact identified and mapped GDEs and sites of cultural and spiritual significance

Figure No: 7

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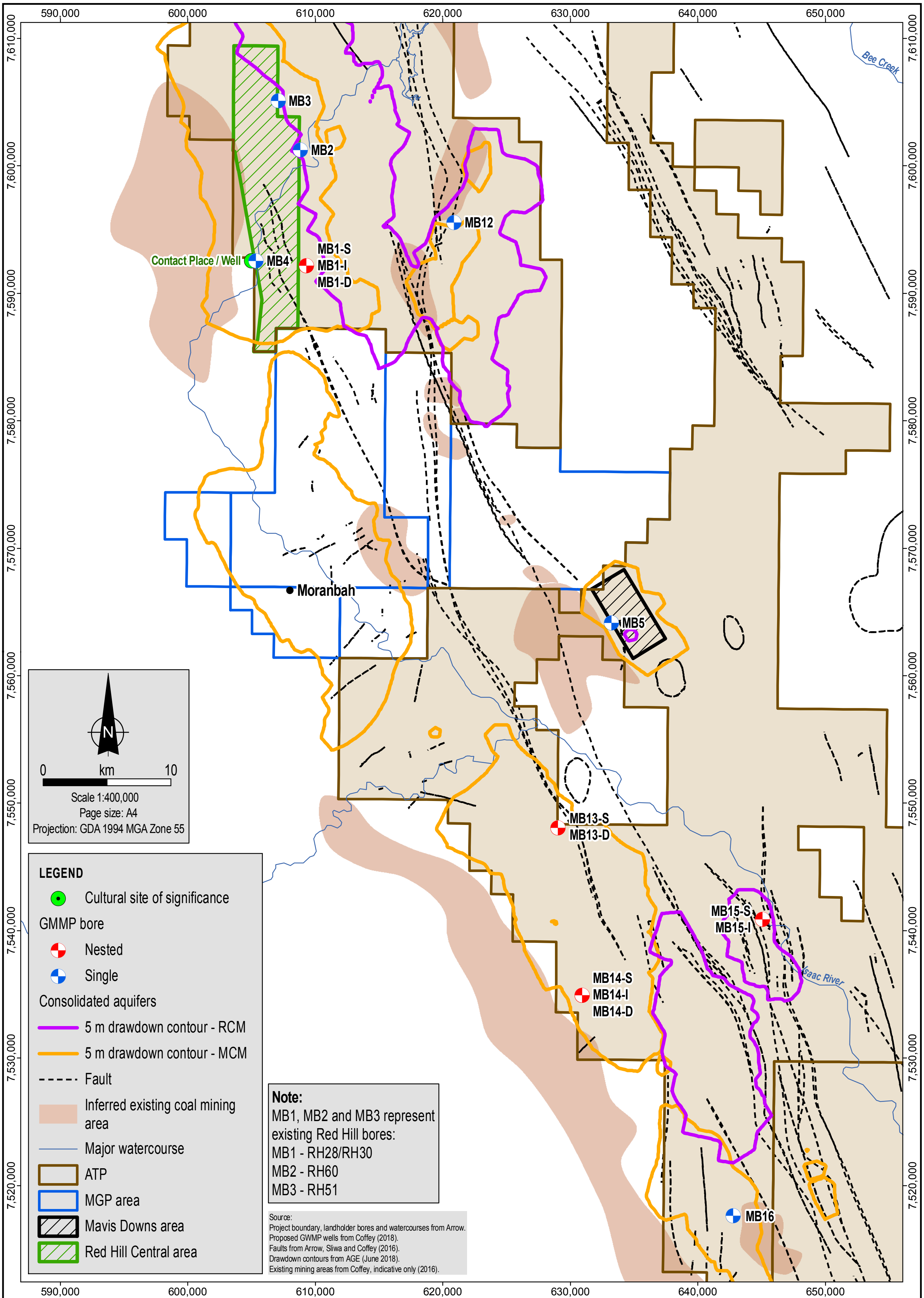


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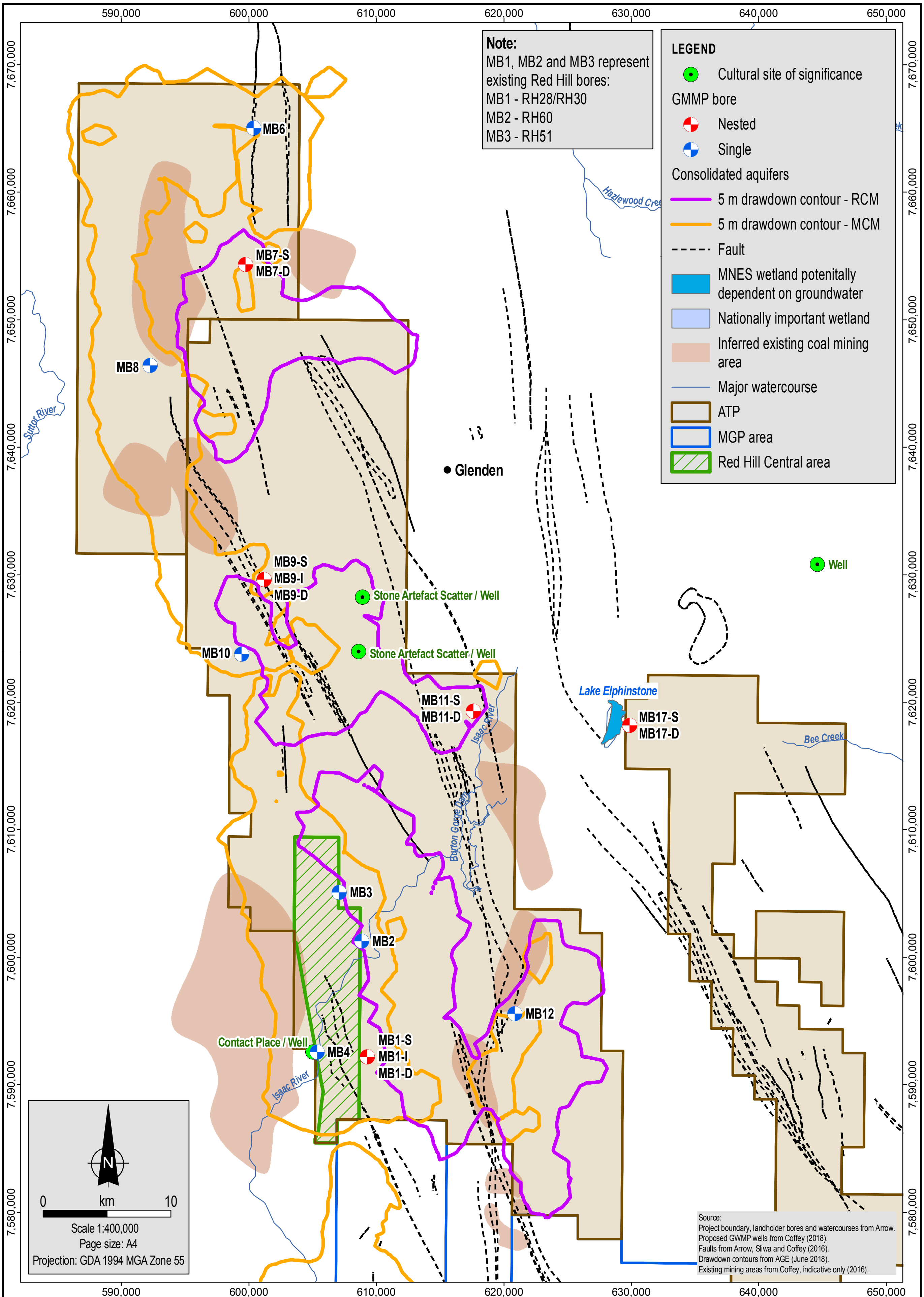
| coffey A TETRA TECH COMPANY | Date: 12.03.2019<br>Project: 754-MELEN213220<br>File Name: 213220_M04_F008_GIS | Arrow Energy<br>Bowen Gas Project | arrow energy go further | Red Hill Central and Mavis Downs development areas - BGP GMMP monitoring bore network | Figure No: 8 DRAFT |
|---|---|---|---|---|---|




MXD Reference: 213220_M04_GIS016_v0_9

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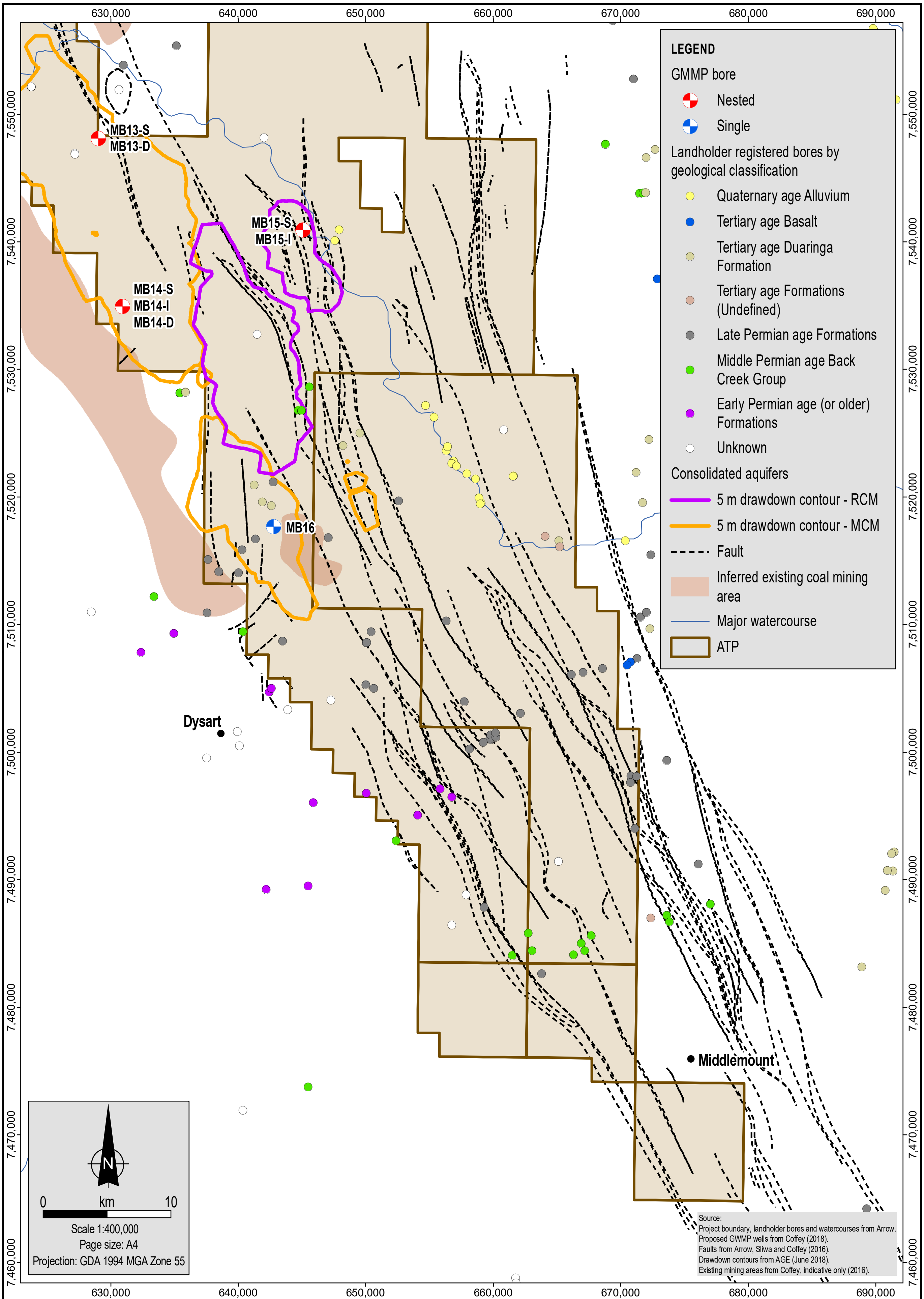
|---|---|---|---|---|---|
| coffey A TETRA TECH COMPANY | Date: 12.03.2019 Project: 754-MELEN213220 File Name: 213220_M04_F009_GIS | Arrow Energy / Bowen Gas Project | arrow energy go further | BGP FDP northern development area - BGP GMMP monitoring bore network | Figure No: 9 DRAFT |

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Date: 07.02.2019
Project: 754-MELEN213220
File Name: 213220_M04_F010_GIS

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**BGP FDP southern development area - BGP GMMP monitoring bore network**

Figure No: **10**
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# Appendices

Appendix 1 Rationalisation of mapped and known GDEs (Coffey 2016)

Level 1, 436 Johnston Street
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# Memorandum

| | | | |
|---|---|---|---|
| **Recipient name** | Kavita Singh | **Recipient company** | Arrow Energy |
| **Copied recipients** | Simon Gossmann, Barton Napier, Michael Blackam | **Memo date** | 6/10/2016 |
| **Author** | Brigid Moriarty | | |
| **Project number** | ENAUBRIS107043AE | | |
| **Memo Subject** | Bowen Gas Project GMMP<br>Rationalisation of mapped and known GDEs | | |

## 1. Introduction

The Bowen Gas Project (BGP) Groundwater Management and Monitoring Plan (GMMP) requires a groundwater monitoring network to be established that allows for the identification of potential impacts to groundwater dependent ecosystems (GDEs) (Commonwealth Approval Condition 21(a)(iii)).

To meet this condition the locations of potentially sensitive GDEs within the DG3 development case project area (the project area) need to be established.

The BGP Environmental Impact Statement (EIS) and Supplementary Report to the EIS (SREIS) identified a range of known and potential GDEs using existing information sources. This included known and potential GDEs as mapped in the Atlas of Groundwater Dependent Ecosystems (GDE Atlas), a publically available data set developed under the National Water Commission's Raising National Water Standards Program.

A site visit was carried out in November 2015 to visually inspect areas within the project area mapped in the GDE Atlas as having potential GDEs. This visit, attended by specialist hydrogeologists and an ecologist, identified the limited likelihood for ecosystem dependence on groundwater across most of the areas observed, including those mapped as being potential GDEs in the GDE Atlas.

This memorandum has therefore been developed to:

- Highlight the differences between the ecosystems mapped as being potentially dependent on groundwater in the GDE Atlas and the field observations made in November 2015, as well as observations made during detailed ecological surveys previously carried out across the project area.
- Provide robust justification for the identification of actual or likely GDEs that will subsequently be taken into consideration during the development of the BGP GMMP.

For the purpose of this memorandum and the development of the GMMP, groundwater is defined as water present within the saturated zone and associated capillary fringe. This does not include perched groundwater disconnected from underlying aquifers and unaffected by coal seam gas depressurisation activities.

## 2. GDE Atlas

The GDE Atlas is a database hosted by the Bureau of Meteorology (BoM) that presents a wide range of landscapes that may potentially contain ecosystems dependent on groundwater for some or all of their water requirements. It was developed as a broad-scale management tool to facilitate the groundwater needs of ecosystems being captured in water planning and allocation processes.

The GDE Atlas maps known and potential GDEs. Known GDEs are those identified during previous desktop or field studies, and potential GDEs are those derived through analysis of spatial data sets. Development of the derived GDEs relied heavily upon remote sensing data to identify vegetation growth response patterns.

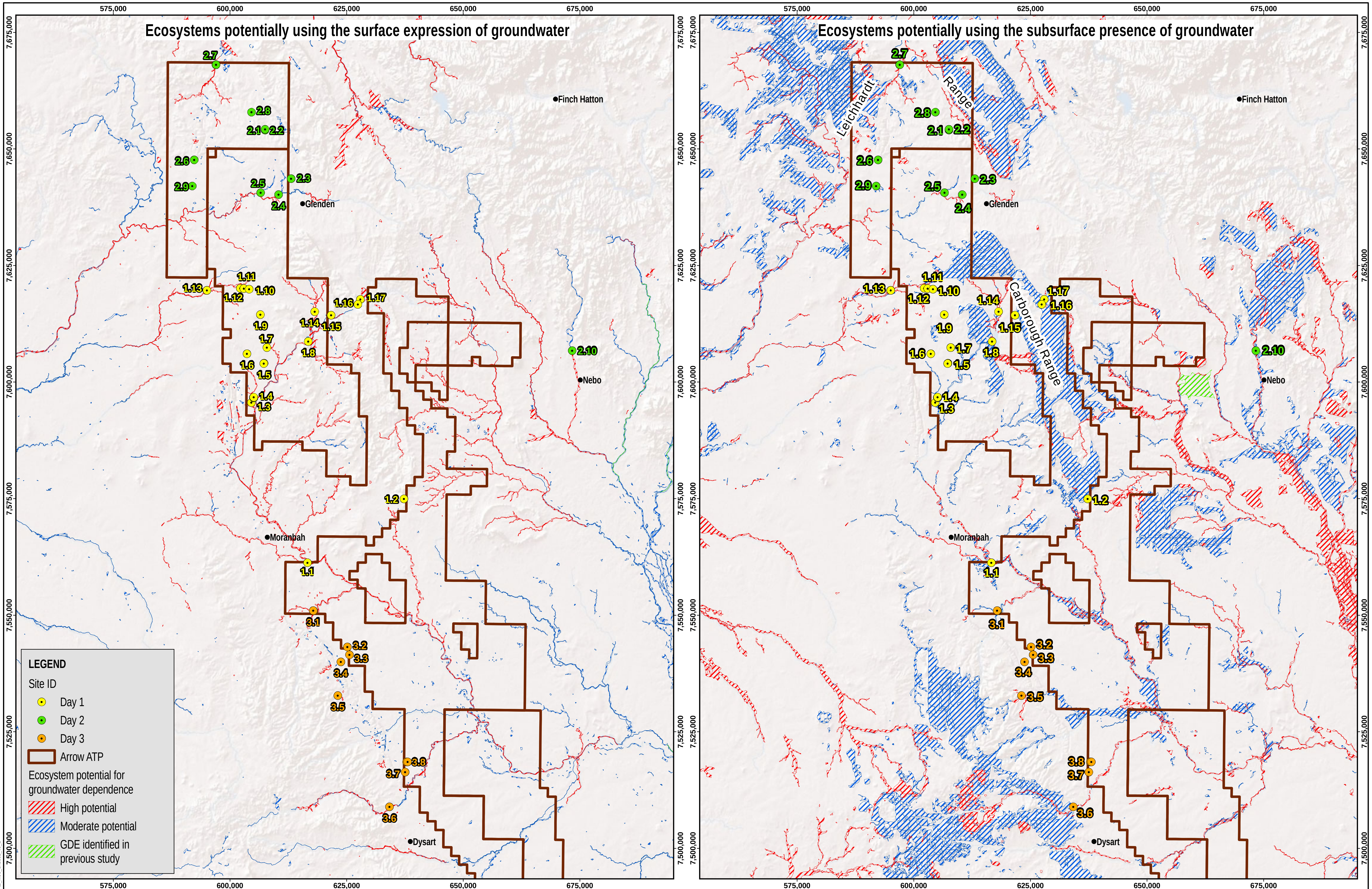
The GDE Atlas presents the following layers:

- Ecosystems reliant on the subsurface presence of groundwater (i.e. vegetation that is accessing the watertable and/or capillary fringe) (known and derived).
- Ecosystems reliant on the surface expression of groundwater (i.e. springs, wetlands and baseflow fed watercourses) (known and derived).
- Subterranean GDEs (caves and aquifers) (known only).

The GDE Atlas does not attribute a level of groundwater dependency to the identified features.

Figure 2.1 presents the location of GDEs as set out in the GDE Atlas across the project area, where they are attributed as having a high or moderate potential for groundwater dependency, or have been identified during previous studies.

Figure 2.1 shows that the majority of BoM mapped potential GDEs within the project area correlate with riparian environments and escarpments associated with the Carborough Range along the east of the project area (outcropping Clematis Sandstone) and the Leichhardt Range to the north-east and north-west of the project area (Clematis Sandstone and Suttor Formation respectively).




MXD Reference: 7043AE_M06_GIS001_v0_2

Source:
Arrow ATPs, towns and watercourses from Arrow.
GDE mapping from BoM. Site IDs from Coffey (3-5 November 2015).
Shaded relief imagery from ArcGIS online.

*Disclaimer: This figure has been produced for internal review only and may contain inconsistencies or omissions. It is not intended for publication.*

Scale 1:750,000
Page size: A3
Projection: GDA 1994 MGA Zone 55

N

0 km 20

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Date: 15.03.2016
Project: ENAUBRIS07043AE
File Name: 7043AE_M06_F02.1_GIS

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GDE Atlas
Mapped potential GDEs

Figure No: 2.1

## 3. Site reconnaissance

The site visit was conducted from 3 to 5 November 2015 and was attended by:

- Ray Hatley (Hydrogeologist - Arrow Energy).
- Glenn Harrington (Hydrogeologist - Innovative Groundwater Solutions and appointed Independent Peer Reviewer).
- Brigid Moriarty (Hydrogeologist - Coffey).
- David Stanton (Ecologist - 3D Environmental).

The site visit was limited to areas able to be accessed via public roads only and did not include intrusive work or sampling. Figure 2.1 presents the locations of the sites visited during the survey. Key observations made during the site reconnaissance regarding likely ecosystem groundwater dependence, and the potential for groundwater interaction with surface water features are presented in Attachment A, and are summarised as follows:

- Limited likelihood for ecosystem groundwater dependence along most surface drainage lines across most of the project area. This includes discharge of groundwater to the surface and access of groundwater by terrestrial vegetation.
- Limited potential for terrestrial vegetation groundwater dependence across areas away from surface drainage features given the observed vegetation type, which was dominated by Brigalow woodland and open grasslands including those dominated by native and exotic species.
- The potential for deeper-rooted vegetation (e.g., River Oaks and River Red Gums) along major drainage features, including the Isaac River, Cherwell Creek and Phillips Creek, to interact with groundwater.
- Limited potential for baseflow contribution to these major drainage features based on channel morphology and understanding of surface flow regime i.e. high surface flows that recede rapidly following significant rainfall events. Release of stream bank storage, which occur following recession of surface flows, is not considered to represent true groundwater baseflow contribution.
- Lake Elphinstone represents a significant regional surface water feature of high ecological importance. The potential for Lake Elphinstone to interact with, and have a dependence on groundwater is not fully understood, however it is considered likely there is some degree of groundwater dependence. The lake does not however coincide with an area of predicted drawdown in Layer 3 for the DG3 case development scenario.
- Significant open cut and underground mining operations in the Bowen Basin have resulted in a highly altered landscape across much of the project area. Where these operations exist there is limited potential for terrestrial GDEs to be present and for groundwater-surface water interaction to occur due to mine dewatering requirements having already lowered the watertable on a local scale, and the high level of surface disturbance.

# 4. GDE location reconciliation

Reconciliation of the BoM GDE mapping against available site data and the site observations outlined in Section 3 is required to provide a basis for the specification of actual or likely GDEs that will be considered during the development of the GMMP. Where sufficient uncertainty remains, specific GDEs will remain within the assessment framework for consideration during GMMP development.

This section presents the results of a review of available data and previous investigations to support the key findings of the site reconnaissance visit that there is a low potential for GDEs to be present in the project area away from major watercourses, where BoM mapping currently indicates there may be the potential for GDEs to be present.

Specifically this review aimed to confirm (or otherwise) the following:

- Depth to groundwater within the project area is generally too great for the observed vegetation communities to have dependence on groundwater, with the exception of the riparian environments of major watercourses.

- Groundwater discharge as baseflow does not occur within the project area.

## 4.1. Depth to groundwater

Groundwater level data for the project area is available from a network of Department of Natural Resources and Mines (DNRM) monitoring wells, CH4 production testing and reservoir monitoring data, Arrow's Moranbah Gas Project (MGP) monitoring obligations and registered groundwater bore drilling records (although it is noted that these 'time-of-drilling' records provide less reliable data).

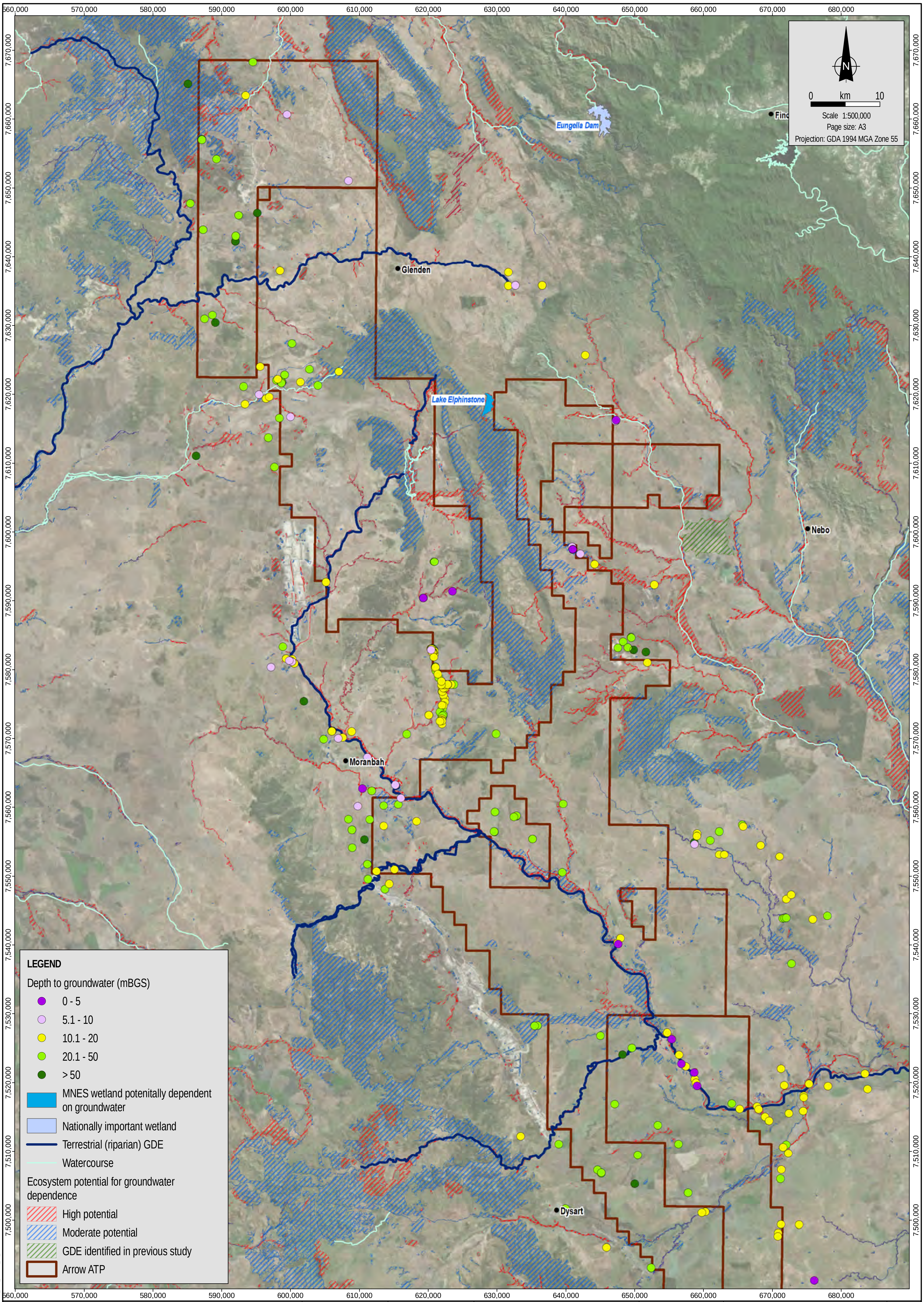
As presented in the underground water impact report (UWIR) for ATP 1103 (Arrow, 2014), groundwater levels in Quaternary, Tertiary and Triassic aquifers typically range from 10 to 30 m below ground surface. This is generally consistent with groundwater levels presented in Appendix L of the BGP EIS, which indicates average groundwater levels in Quaternary alluvium range between 6.9 and 16.5 m below ground surface, and between 12.2 and 44.4 m below ground surface in Tertiary basalt and sediments.

Table 4.1 presents a summary of the water level data across the study area by key aquifer relevant to the project area, noting there is no depth to groundwater information available for the Clematis Sandstone aquifer within the project area. The data summarised is from the DNRM database only, and further detail on the borehole data used to generate the summary statistics is provided in Attachment B. The data presented in Table 4.1 shows that with the exception of the Isaac River Alluvium, average groundwater levels, by aquifer, are > 18 m below ground surface. Average depth to groundwater in the Isaac River Alluvium is 10.8 m below ground surface.

Figure 4.1 also presents the depth to groundwater information provided in Attachment B and summarised in Table 4.1, as well as mapped potential GDEs (high and moderate potential to be reliant on the surface expression/subsurface presence of groundwater), MNES and nationally important wetlands and the inferred terrestrial (riparian) GDEs (refer Section 4.5).

As shown in Figure 4.1, there is currently insufficient data to accurately estimate depth to groundwater across much of the areas mapped by the BoM as potentially supporting GDEs however the available information indicates depth to groundwater increases away from watercourse features, and is typically >20 m below ground surface.

Previous work indicates that where depth to groundwater is >20 m, there is a low likelihood of terrestrial vegetation groundwater dependence (Coffey, 2014; DNRM, 2013).




MXD Reference: 7043AE_M06_GIS004_v0_1

Source:
Depth to water from DERM (2015).
Arrow ATPs and watercourses from Arrow.
Place names from GEODATA250k.
Imagery from Bing Maps Online (currency not stated).

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Date: 05.10.2016
Project: ENAUABTF07043AE
File Name: 7043AE_M06_F04.01_GIS

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Depth to groundwater

Figure No: 4.1

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Table 4.1: Depth to groundwater summary statistics

| Aquifer | No. bores with SWL (1) | Min SWL (m bgl) | Max SWL (m bgl) | Mean SWL (m bgl) | No. bores SWL ≤ 20 m bgl | No. bores SWL >20 and ≤ 50 m bgl | No. bores SWL >50 m bgl | Std dev of SWL |
|---|---|---|---|---|---|---|---|---|
| Isaac River Alluvium | 28 | 0.5 | 17.2 | 10.83 | 28 | 0 | 0 | 4.9 |
| Tertiary basalt | 91 | 3.4 | 99.90 | 19.65 | 61 | 29 | 1 | 11.92 |
| Tertiary sediments (2) | 32 | 8.6 | 77.0 | 24.35 | 16 | 14 | 2 | 14.3 |
| Rewan Formation | 21 | 2.74 | 46.0 | 18.02 | 16 | 5 | 0 | 11.1 |
| Coal Measures (RCM, FCCM, MCM) | 68 | 1.65 | 78.5 | 22.15 | 39 | 25 | 4 | 15.2 |
| Blackwater Group | 54 | 4.3 | 69.2 | 28.68 | 24 | 25 | 5 | 15.0 |
| Back Creek Group | 16 | 10 | 50.0 | 24.19 | 6 | 10 | 0 | 9.9 |

1: No. of bores within relevant DG3 project area –time of drilling SWL
2: Tertiary sediments includes Suttor Formation, Duaringa Formation and undifferentiated tertiary sediments
m bgl = metres below ground level

The spatial distribution of groundwater bores where depth to groundwater is <20 m below ground surface was also assessed. The locations of these bores generally correlate to drainage lines, floodplains or small surface depressions, significant mining operations and monitoring around water storage facilities. In some instances the reported groundwater level is considered to represent sub-artesian pressure associated with confined and semi-confined aquifers, not depth to watertable. Where the watertable appears to be within 10 to 15 m of the land surface it is typically in areas where significant land clearing has occurred and larger trees are not evident in aerial photography.

The majority of areas mapped by BoM as potentially supporting GDEs, that are not riparian environments, are associated with elevated areas of Clematis Sandstone outcrop to the east of the project area, Suttor Formation outcrop to the north-west of the project area and Back Creek Group outcrop to the south-west of the Project area.

Typical vegetation types within these elevated escarpments include woodlands of Lancewood (*Acacia shirleyi*), and habitats dominated by ironbark (*Eucalyptus crebra, Eucalyptus decorticans),* bloodwood (*Corymbia clarksoniana)* and other eucalyptus species including peppermint (*Eucalyptus exserta)* and small areas of Gympie messmate (*Eucalyptus cloeziana).* Brigalow (*Acacia harpophylla)* may also be associated with footslopes in some escarpment areas. Maximum rooting depth within species varies, often dependent on the substrate. However it is unlikely that any would exceed 11 m, which is the observed maximum rooting depth of bloodwoods on well drained alluvial soils (O'Grady *et al*, 2006). On these less fertile and friable escarpment areas it is reasonable to expect that rooting depths of bloodwoods would be considerably less.

Ironbarks have a much shallower rooting system than bloodwoods (Fensham and Fairfax, 2007; Rice *et al*, 2004) rendering them susceptible to drought induced dieback and it is not expected that rooting systems of ironbark would penetrate much below 4 m. Observations on breakaway escarpments suggest that *Acacia shirleyi* possesses an extremely shallow lateral root system with rooting depth not expected to significantly exceed 2 m.

Therefore the conceptual understanding of these elevated areas is that vegetation will be supported by direct rainfall infiltration, as well as soil interflow and potentially localised perched groundwater. The regional watertable will be present as a subdued reflection of topography at an elevation below the rooting depth of the vegetation.

Further discussion on vegetation types and their characteristics across the project area is presented in Section 4.3.

## 4.2. Hydrology

### 4.2.1. Streamflow

DNRM monitor streamflow at locations across the project area, including two active gauging stations on the Isaac River (at Goonyella and Deverill). Streamflow records (refer Figures 4.2 and 4.3) demonstrate the Isaac River at these locations is ephemeral, with stream discharge being closely correlated to rainfall as well as limited flow being recorded historically during the dry season spanning April to November.

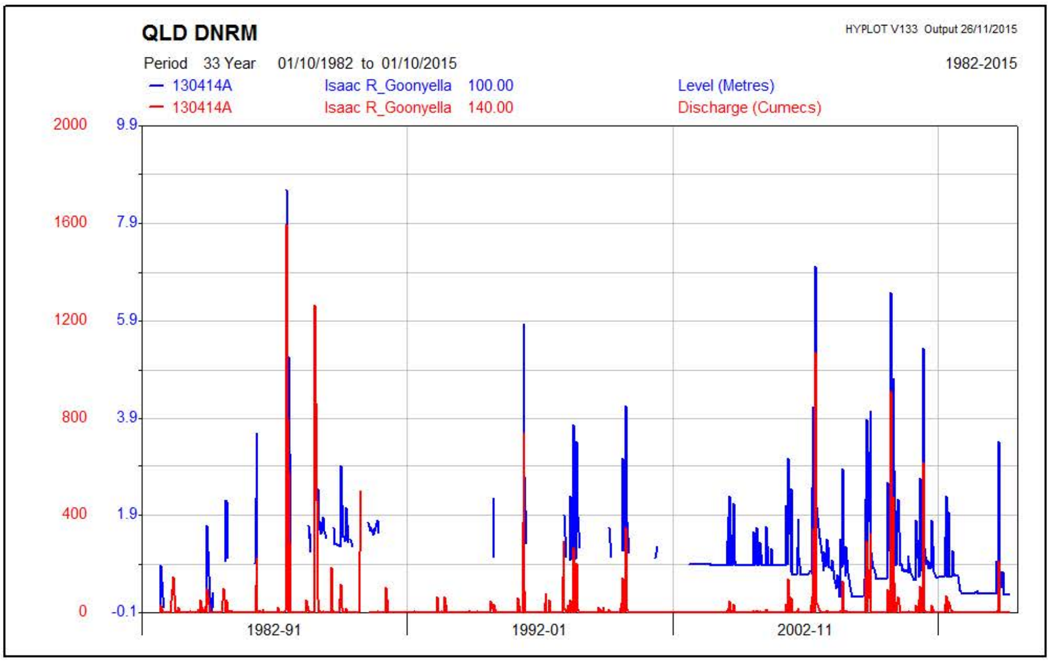



**Figure 4.2: Isaac River at Goonyella (130414A) historical flow data**

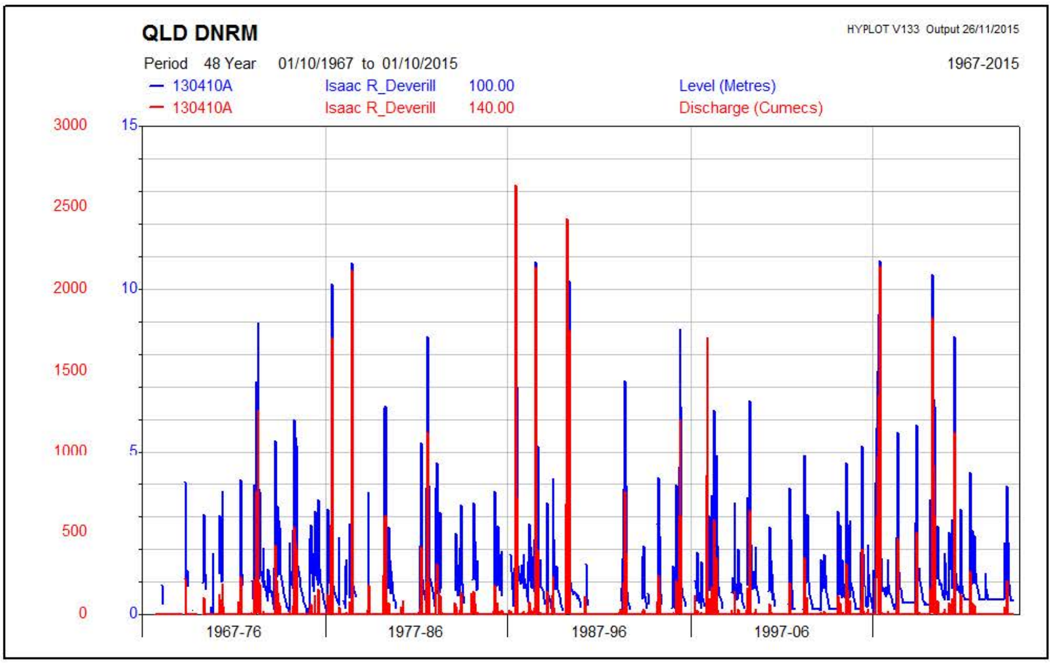



**Figure 4.3: Isaac River at Deverill (130410A) historical flow data**

A flow duration assessment of the Isaac River gauging data, carried out for the BGP EIS (Appendix N of the EIS), shows high flow for short periods, consistent with rain induced flood events (URS, 2012). This observation is supported by recent analysis of the upper Isaac River by Alluvium (2015) which states "*low and base flows are rarely present for more than a few days or weeks following a large runoff event other than in extended wet seasons*".

Whilst this streamflow data is for the Isaac River only, the ephemeral condition is considered to be representative of all tributaries upstream of these locations. It is also noted that Appendix N of the EIS (URS, 2012) concluded that the Suttor River (at Eaglefield gauging station, located to the west of the project area) and associated upstream tributaries are also ephemeral with rainfall controlled flow duration.

### 4.2.2. Fluvial geomorphology

The fluvial geomorphology of the project area was described in the BGP EIS (Appendix N of the EIS). A summary of the key characteristics of the main stream reaches studied (relevant to this assessment) is provided in Table 4.2, together with depth to watertable in the vicinity of these stream reaches (where available). Where depth to groundwater is greater than the depth of channel incision, baseflow cannot occur.

Depth to groundwater information is not available to adequately characterise the potential for all major stream reaches to interact with groundwater. Available data indicates depth to groundwater ranges between 9.5 to 17 m below ground surface for the Isaac River alluvium. The Isaac River represents the largest watercourse through the project area, and conceptually is expected to have the greatest potential for interaction with shallow groundwater.

**Table 4.2: Summary of fluvial geomorphology**

| Watercourse | General description | Depth of incision (below floodplain) | Recorded depth to groundwater |
|---|---|---|---|
| **Upper Isaac River** | Open cut and underground coal mining has resulted in channel diversions, altered hydrology regimes, channel subsidence and increased sediment loads.<br>The river is currently characterised by moderately steep banks that are generally well vegetated, with a significant portion of larger trees (>10m tall) and canopy height ranges typically from 21 to 30 m. Channel bed typically 15 to 40 m wide, consisting of a uniform sand sheet and some bedrock control. | Up to 5m | 9.5 to 17 m bgs |
| **Suttor Creek** | Incised channel set in broad, shallow valley. Receiving environment for coal mining discharge.<br>Riparian vegetation is semi-continuous to occasional. Numerous weirs have been placed along the creek which has resulted in a number of permanent waterbodies. The river channel has also been truncated by the Suttor Creek Mine and the flow diverted. | 3m | Not known |
| **Eaglefield Creek** | Flat floored channel set in a broad, shallow valley within an extensive basalt plain. The creek has near-vertical banks with a floodplain that widens downstream.<br>The riparian margins of Eaglefield Creek have 60% exotic grassland coverage with a typically exposed channel, occasional trees and some remnant patches dominated by coolabah (*Eucalyptus coolabah* subsp. *coolabah*). | < 2m[1] | 7.6 to 18 m bgs |

| Watercourse | General description | Depth of incision (below floodplain) | Recorded depth to groundwater |
|---|---|---|---|
| Cherwell Creek | Flat U-shaped channel set in a broad valley, infilled by a sandy sheet. Remnant riparian vegetation typical of regional ecosystem (RE)11.3.25 although some dieback of canopy trees noted, particularly in River Oak. | Up to 5 m[1] | 13 to 14 m bgs |
| Phillips Creek | Not described in URS (2012).<br>The 2015 site reconnaissance visit observed a dry creek bed with sandy bottom, incised into surrounding siltstones/mudstones of Back Creek Group.<br>River Oaks present along the stream channel indicate a deeper soil profile along the river channel with the species mixing with River Red Gums in a typical expression of RE11.3.25.<br>Site appears to have the potential for interaction with groundwater, given deeper rooted vegetation. The likely dependency of the habitat on groundwater diminishes rapidly with distance from the channel as vegetation stature decreases and depth of the alluvial soil profile over basement rock diminishes. | ~ 5 m[1] | Not known |
| North, Middle and South creeks | Not described in URS (2012).<br>The 2015 site reconnaissance visit observed a gently incised stream channel of up to 10 m width fringed with weeping tea tree at the crossing of Winchester Road. Indications are that alluvial sediments form a shallow mantle over sandstones of the Back Creek Group. | ~ 2m[1] | Not known |

1: Based on 2015 site reconnaissance observations (refer Attachment A)
m bgs = metres below ground surface

## 4.3. Terrestrial vegetation

Within the project area the riparian environments of the Isaac River and Cherwell, Phillips and Middle creeks were observed during the 2015 site reconnaissance visit to represent areas of potential terrestrial GDEs (refer Attachment A).

The riparian vegetation communities associated with these drainage features are distinct from surrounding vegetation, and described below.

### 4.3.1. Isaac River, Cherwell Creek and Phillips Creek

The riparian vegetation observed during the 2015 site reconnaissance visit is characterised by River Red Gum (*Eucalyptus camaldulensis*) dominant open forest typically with sub-dominant components of River-oak (*Casuarina cunninghamiana*), Moreton Bay Ash (*Corymbia tessellaris)* and Clarkson's Bloodwood (*Corymbia clarksoniana)* consistent with RE11.3.25.

The habitats are located on the inner levee banks and in-stream islands, typically deeply incised into the surrounding alluvial plain and often with broad sandy channel bottoms. Whilst the canopy of these riparian vegetation types is generally intact, it narrows in some locations where clearing has been undertaken to the upper margins of levee banks. Native ground covers have typically been replaced by Buffel Grass, an exotic pasture grass and levees have often been trampled by cattle.

Based on the observations of typical RE11.3.25 environments during the site reconnaissance, RE11.3.4, a tall open forest ecosystem comprising River Red Gum, Moreton Bay Ash and Clarkson's Bloodwood is also considered as a potential terrestrial GDE.

This RE typically forms isolated and discontinuous patches fringing major drainage features, occupying secondary alluvial terraces formed above the inner channel levee. RE 11.3.4 occupies a slightly higher (more elevated) position in the landscape than RE11.3.25 and as such, is likely to have reduced access and reliance on groundwater. The dominant canopy species associated with these REs are typically deeper rooted than surrounding vegetation on distal flood plains and footslopes. Whilst rooting depth is controlled to some degree by depth to groundwater, it is feasible that River Red Gum could be accessing groundwater at depths of up to 20 m with rooting depths recorded in other eucalypt species below 30 m (Zeincich *et al*, 2002; Canadell,1996). The riparian vegetation stature rapidly diminishes and floristic composition changes with distance from these watercourses, changing on a sharp boundary from tall open forest to woodland, and it is therefore inferred that so does vegetation groundwater dependence. This is consistent with findings of O'Grady et al (2002).

Eaglefield Creek, in contrast to the Isaac River and Cherwell and Phillips creeks, which is also mapped as RE11.3.25, provides a differing geomorphic and ecological setting and unlike these other streams assessed, is not considered likely to represent a GDE. This is due to the channel being shallowly incised into a broad basalt plain, lacking the well-developed alluvial features of the Isaac River, Cherwell Creek and Phillips Creek. Box trees (which include the *Eucalyptus coolabah* observed at Eaglefield Creek) typically have shallower rooting systems than bloodwood and River Red Gums, possibly a function of the heavy clay soils that these species are associated with. The significant clay content within the upper soil layers, associated with basaltic landforms in the assessment area, places a significant constraint on rooting depth due to cohesiveness of clay soils and a rapid decline in water potential (Eamus *et al,* 2006).

#### 4.3.2. Middle Creek

Middle Creek, located approximately half way between Moranbah and Dysart, is a much smaller watercourse to those outlined in Section 4.3.1, and is characterised by an open forest of Weeping Tea Tree (*Melaleuca leucadendra*) consistent with RE 11.3.25b (Riverine wetland or fringing riverine wetland. *Melaleuca leucadendra* and/or *M. fluviatilis, Nauclea orientalis* open forest).

Weeping Tea Tree is considered to be an obligate phreatophyte (i.e. only able to exist or survive by using groundwater resources) and confined to riparian zones where there is permanent access to surface or near surface water (McClean, 2014; O;Grady *et al*, 2002; O'Grady *et al*, 2006). The geological setting at Middle Creek is that of an alluvial deposit overlying Permian Back Creek Group. It is likely that Weeping Tea Tree is accessing groundwater perched on shallow Back Creek Group subcrop and disconnected from the regional watertable. This assessment is supported by the vegetation appearing to be completely unaffected by the major mining operations in the immediate vicinity, which would have resulted a declining regional watertable.

#### 4.3.3. Non-riparian vegetation

Away from riparian environments, vegetation across the project area is characterised by:

- Generally small (<5 ha) patches of Brigalow (*Acacia harpophylla* dominant and co-dominant communities) woodland and open forest to the north and south of Moranbah. Brigalow is not considered to be groundwater dependent due to a shallow rooted habitat and association with strongly vertic friable soils, typically underlain by impervious, heavy clays. Brigalow's shallow rooting habitat is evident with the tendency of mature trees to topple as a result of the 'shrink and swell' nature of the substrate, exposing a well-developed lateral root system.

- A range of eucalypt dominant woodlands on older Pleistocene - Tertiary alluvial plains, footslopes and hillslopes on Permian sedimentary rocks. These include:

    - Remnant woodlands dominated by Poplar Box (*Eucalyptus populnea*) (RE11.3.2) located at higher topographic levels on distal portions of alluvial floodplains.

  - Woodlands on older (Tertiary) sand plains situated on low rises and escarpments, typically occupied by Narrow Leaved Ironbark (*Eucalyptus crebra)* and sub-dominant proportions of Clarkson's Bloodwood (REs 11.5.9, 11.5.1) or dominant Poplar Box (RE11.5.3).
  - Extensive areas of Lancewood (*Acacia shirleyi)* open forest on lateritic Tertiary plateaus and arenitic sandstone escarpments represented by RE11.7.2 or 11.10.3; or eucalypt woodlands with dominant ironbark (*Eucalyptus crebra, Eucalyptus decorticans)* and other eucalyptus species (*Corymbia clarksoniana, Eucalyptus exserta)* represented as REs 11.7.4 and 11.10.4.
- Natural grassland, covering extensive areas between Moranbah and Glenden. The shallow-rooted grasslands that occur across the basaltic plains of the region are not considered to be groundwater dependent.
- Extensive areas of cleared and degraded pastoral land, typically occupied by dense cover of the exotic Buffel Grass (*Cenchrus ciliaris)* and regrowth shrubs.

Poplar Box woodland on alluvium (RE11.3.2) is the most extensive remnant floodplain habitat away from open forest on the immediate riparian fringe (RE11.3.25). In a similar manner to ironbark species, Poplar Box has a relatively low investment in deep root architecture when compared to bloodwoods (Fensham and Fairfax, 2007). This makes it particularly susceptible to drought due to its inability to tap moisture deep in the soil profile (including groundwater) during extended dry periods. Woodland dominated by Poplar Box or ironbark is therefore not considered to be dependent on groundwater.

## 4.4. Existing sources of impact or disturbance

Significant open cut and underground longwall mining has resulted in a highly disturbed landscape across the northern Bowen Basin, including altered hydrogeological and hydrological regimes, as well as clearing of vegetation. Extensive land clearing for agricultural activities has also resulted in the degradation of vegetation communities across large parts of the Bowen Basin.

Typically, mapped GDEs do not coincide with existing mining operations, however some mine water storage facilities and stream reaches that have been diverted since the commencement of mining operations, have been mapped as potential GDEs in the BoM GDE Atlas.

These features are not considered to represent GDEs and have not been included in the assessment of GDEs for GMMP development.

Where land has been cleared extensively this has typically removed larger tree species which have been replaced with exotic pasture grasses (exotic open grassland) with no anticipated groundwater access or utilisation. It is noted that these degraded areas do not coincide with areas mapped as potential GDEs in the BoM GDE Atlas.

## 4.5. Conclusions

The review of available information and project area conceptualisation supports the following conclusions regarding the location of actual or likely GDEs in the project area:

- Depth to groundwater data and mapped vegetation communities indicate riparian vegetation along major watercourses may be supported by groundwater on a facultative basis (i.e. use groundwater but capable of functioning without it). Within the project area this includes the following watercourses:
  - Upper Isaac River.
  - Suttor Creek.
  - Cherwell Creek.
  - Phillips Creek.
- Terrestrial vegetation away from immediate riparian environments is not supported by regional groundwater systems. This conclusion is based on:
  - Available depth to groundwater information and known rooting depth characteristics of the vegetation in these areas.
  - Site observation which includes rapidly diminished vegetation stature with distance from watercourse channels and/or as depth of the alluvial soil profile over basement rock diminishes.
- Groundwater baseflow contribution to stream reaches does not occur. This is supported by the ephemeral nature of all streams in the project area, rainfall correlated flow duration and depth to groundwater exceeding channel incision depth. Release of bank storage, which will occur following recession of surface flows, is not considered to represent groundwater baseflow contribution.

It is noted that the riparian environments identified above as being potentially dependent on groundwater do not necessarily represent all groundwater dependent riparian environments across the project area. Rather, they represent what has been identified to date. Where impact to the watertable aquifer in the vicinity of a major watercourse is predicted (by numerical modelling) the riparian environment should be adequately assessed to identify whether similar characteristics exist, indicating the potential for groundwater dependence.

# 5. GDEs within the DG3 development case area of predicted impact

## 5.1. Groundwater drawdown predictions

Following the completion of the EIS, an assessment of parameter and predictive error and uncertainty was completed by Ausenco – Norwest. This was conducted to better understand the model limitations and to identify data gaps.

Results of the Null Space Monte Carol (NSMC) and Pareto front analysis indicate that the BGP numerical groundwater model base case is overall conservative in estimates of predicted drawdown associated with the BGP production i.e. predicting the largest likely impacts. The maximum predicted drawdown and aerial extent of drawdown in the base case was at the higher end of predictions (upper 95 % confidence intervals) compared to the majority of the simulations undertaken in the uncertainty analysis.

Based on this, no other realisations were considered as part of the SRIES or UWIR Bowen groundwater modelling. The BGP numerical groundwater model base case is considered appropriate for the purpose of predicting impacts under the DGE development case as it captures the overall envelope of potential impacts associated with the Bowen Gas Project.

## 5.2. Potential impacts to GDEs

As there are no known or anticipated fault-controlled springs, it is reasonable to assume that GDEs in the project area, where present, will be dependent on the watertable aquifer. Depressurisation predicted in Layer 3 of the BGP numerical groundwater model has been conservatively adopted as representing drawdown in the watertable across the project area.

A review of predicted drawdown at the end of production (2049) indicates there are isolated areas of 0.2 m drawdown predicted in Layer 3. Figure 5.1 presents these areas, along with the GDE Atlas mapping and likely GDEs identified as a result of the field reconnaissance (refer Section 4). Table 5.1 provides further detail on each area, and an assessment of whether each area of 0.2 m drawdown in Layer 3 has the potential to impact GDEs.

**Table 5.1: Summary of risk to GDEs**

| Figure 5.1 location reference | Development phase | GDE Atlas mapping within 0.2m drawdown area | Location observations[1] | Assessment of risk to GDEs |
|---|---|---|---|---|
| 1 | 1 | Moderate potential for ecosystem dependence on the surface expression of groundwater. | Mapped GDEs overlie current mine workings. Minor drainage lines present within drawdown areas do not correlate with mapped GDEs. | No GDEs inferred to be at risk from predicted drawdown. |
| 2 | 1 | High potential for ecosystem dependence on the surface expression and subsurface presence of groundwater. | Mapped GDEs correlate with historical course of Suttor Creek and now overlie mine workings.<br><br>Creek diversion to the south will be a highly altered environment and affected by mine dewatering. | No GDEs inferred to be at risk from predicted drawdown. |

| Figure 5.1 location reference | Development phase | GDE Atlas mapping within 0.2m drawdown area | Location observations[1] | Assessment of risk to GDEs |
|---|---|---|---|---|
| 3 | 2 | No mapped GDEs. | No watercourses or drainage lines evident in aerial imagery. | No GDEs inferred to be at risk from predicted drawdown. |
| 4 | 2 | High potential for ecosystem dependence on the surface expression of groundwater. | Mapped GDEs overlie current mine workings.<br><br>Minor drainage lines are present within the area of predicted drawdown (away from mine workings) however vegetation associated with these features is not considered to be groundwater dependent based on drainage line geomorphology and general lack of mapped GDEs. | No GDEs inferred to be at risk from predicted drawdown. Metaphorically |
| 5 | 3 | No mapped GDEs. | No watercourses or drainage lines evident in aerial imagery. | No GDEs inferred to be at risk from predicted drawdown. |
| 6 | 3 | No mapped GDEs. | Minor drainage lines are present within the area of predicted drawdown however vegetation associated with these features is not considered to be groundwater dependent based on typical drainage line geomorphology, lack of mapped GDEs and site reconnaissance observation which indicated no groundwater dependent vegetation to be present. | No GDEs inferred to be at risk from predicted drawdown. |
| 7 | 3 | Moderate potential for ecosystem dependence on the subsurface presence of groundwater. | Minor watercourses also evident in aerial imagery. Correlates with mapped GDE areas. | Insufficient information currently available to characterise area and actual groundwater dependence of mapped potential GDEs.<br><br>Location will therefore be considered during the development of the GMMP monitoring network. |

| Figure 5.1 location reference | Development phase | GDE Atlas mapping within 0.2m drawdown area | Location observations[1] | Assessment of risk to GDEs |
|---|---|---|---|---|
| 8 | 3 | No mapped GDEs. | No watercourses or drainage lines evident in aerial imagery. | No GDEs inferred to be at risk from predicted drawdown. |

1: based on observations made during 2015 site reconnaissance and desktop information including aerial photography

Figure 5.1 and Table 5.1 show that there are no ecosystems considered to be potentially dependent on groundwater that coincide with areas of 0.2 m predicted drawdown in Layer 3 for development Phase 1 and 2 areas.

Location 7, which is represented by two discreet areas of 0.2 m Layer 3 drawdown in the Phase 3 development area, overlies some minor watercourses as well as BoM GDE mapping that indicates there is a moderate potential for ecosystem dependence on groundwater along the watercourses. RE mapping (coarse scale) also indicates there is the potential for facultative users of groundwater to be present (RE11.3.25 is indicated as potentially being present).

Whilst it is considered unlikely this area actually supports GDEs given the geomorphology and vegetation types of minor watercourses in the project area, as well as the significant mining operations to the west that are likely to have lowered the watertable (at least on a local scale), there is currently insufficient site-specific information to rule this area out as a potential GDE. It will therefore be carried forward in the development of the GMMP monitoring network.

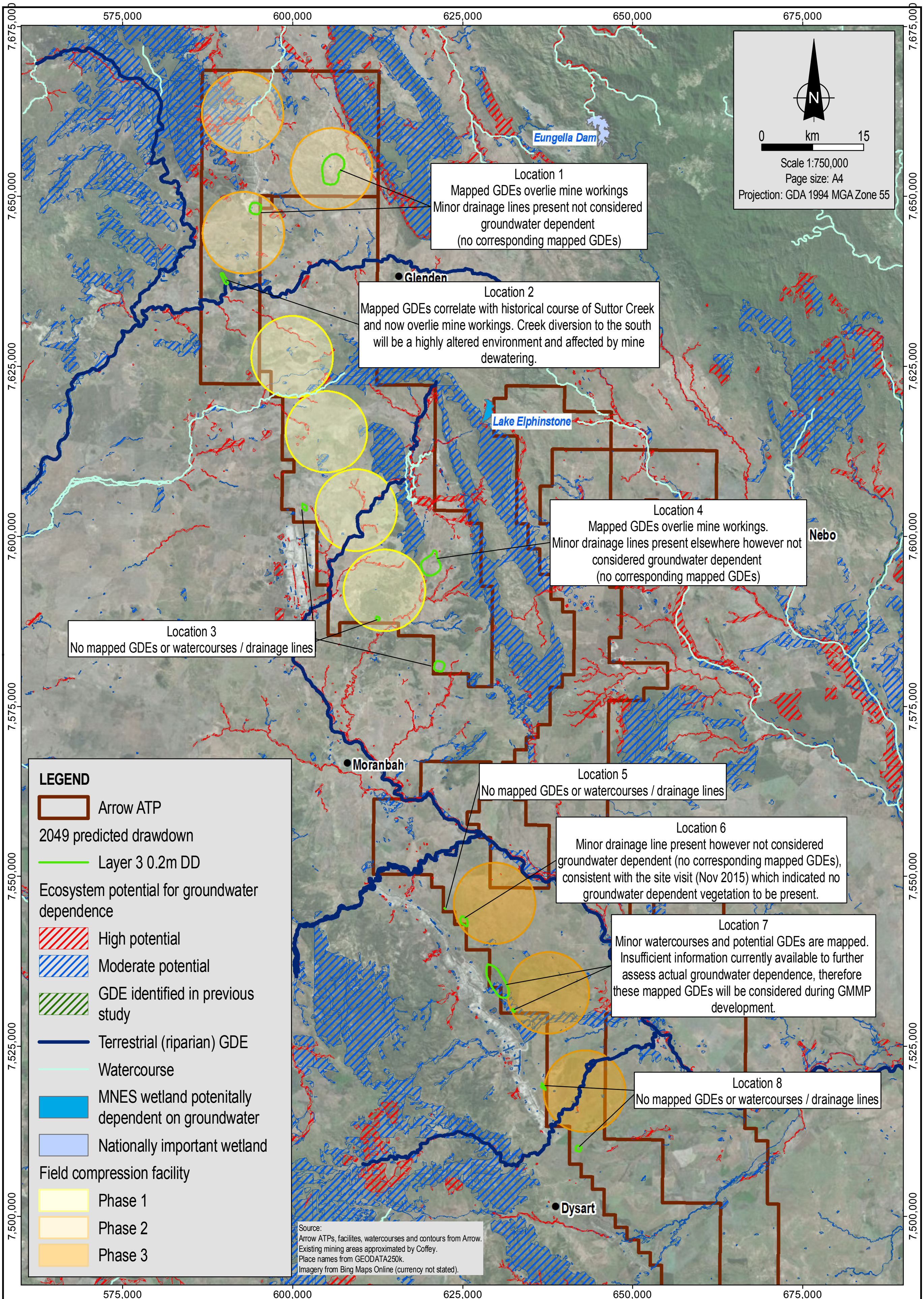
However as this location is within the Phase 3 development area, and the production forecast will change, further assessment including site visit and development of a detailed conceptual site model (refer Section 3 of Attachment A) will not be carried out at this stage. Should future revisions of the project field development plans continue to indicate the potential for impact at this location; further assessment will be carried out as needed.

All other areas of 0.2 m drawdown in Layer 3 are discounted, and considered as having no potential to impact GDEs based on:

- There being no BoM-mapped potential GDEs present in the predicted area of 0.2 m drawdown, or
- Where potential GDEs are mapped by BoM within an area of 0.2 m drawdown, they directly overlie active mine workings therefore are not considered to be real GDEs.

This assessment is supported by the general discussion of vegetation communities expected across the Project area, which identifies that away from major watercourses, ecosystems are not considered to be dependent on groundwater on either an obligate or facultative basis.

It is recognised that the BGP development scenario will continue to evolve, in particular during Phase 2 and 3 development, and this memorandum is intended to assist with the identification of potentially impacted GDEs during future revisions of the GMMP that capture the revised development scenarios, updated groundwater modelling, and improved site knowledge.




MXD Reference: 7043AE_M06_GIS002_v0_1

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| coffey A TETRA TECH COMPANY | Date: 15.03.2016<br>Project: ENAUBRIS07043AE<br>File Name: 7043AE_M06_F005.1_GIS | Arrow Energy<br>Bowen Gas Project GMMP | arrow energy go further | Predicted extent of Layer 3 drawdown (2049) and likely and potential GDEs | Figure No: 5.1 |

*Disclaimer: This figure has been produced for internal review only and may contain inconsistencies or omissions. It is not intended for publication.*

## 6. References

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# Important information about your **Coffey** Environmental Report

## Introduction

This report has been prepared by Coffey for you, as Coffey's client, in accordance with our agreed purpose, scope, schedule and budget.

The report has been prepared using accepted procedures and practices of the consulting profession at the time it was prepared, and the opinions, recommendations and conclusions set out in the report are made in accordance with generally accepted principles and practices of that profession.

The report is based on information gained from environmental conditions (including assessment of some or all of soil, groundwater, vapour and surface water) and supplemented by reported data of the local area and professional experience. Assessment has been scoped with consideration to industry standards, regulations, guidelines and your specific requirements, including budget and timing. The characterisation of site conditions is an interpretation of information collected during assessment, in accordance with industry practice,

This interpretation is not a complete description of all material on or in the vicinity of the site, due to the inherent variation in spatial and temporal patterns of contaminant presence and impact in the natural environment. Coffey may have also relied on data and other information provided by you and other qualified individuals in preparing this report. Coffey has not verified the accuracy or completeness of such data or information except as otherwise stated in the report. For these reasons the report must be regarded as interpretative, in accordance with industry standards and practice, rather than being a definitive record.

## Your report has been written for a specific purpose

Your report has been developed for a specific purpose as agreed by us and applies only to the site or area investigated. Unless otherwise stated in the report, this report cannot be applied to an adjacent site or area, nor can it be used when the nature of the specific purpose changes from that which we agreed.

For each purpose, a tailored approach to the assessment of potential soil and groundwater contamination is required. In most cases, a key objective is to identify, and if possible quantify, risks that both recognised and potential contamination pose in the context of the agreed purpose. Such risks may be financial (for example, clean up costs or constraints on site use) and/or physical (for example, potential health risks to users of the site or the general public).

## Limitations of the Report

The work was conducted, and the report has been prepared, in response to an agreed purpose and scope, within time and budgetary constraints, and in reliance on certain data and information made available to Coffey.

The analyses, evaluations, opinions and conclusions presented in this report are based on that purpose and scope, requirements, data or information, and they could change if such requirements or data are inaccurate or incomplete.

This report is valid as of the date of preparation. The condition of the site (including subsurface conditions) and extent or nature of contamination or other environmental hazards can change over time, as a result of either natural processes or human influence. Coffey should be kept appraised of any such events and should be consulted for further investigations if any changes are noted, particularly during construction activities where excavations often reveal subsurface conditions.

In addition, advancements in professional practice regarding contaminated land and changes in applicable statues and/or guidelines may affect the validity of this report. Consequently, the currency of conclusions and recommendations in this report should be verified if you propose to use this report more than 6 months after its date of issue.

The report does not include the evaluation or assessment of potential geotechnical engineering constraints of the site.

## Interpretation of factual data

Environmental site assessments identify actual conditions only at those points where samples are taken and on the date collected. Data derived from indirect field measurements, and sometimes other reports on the site, are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact with respect to the report purpose and recommended actions.

Variations in soil and groundwater conditions may occur between test or sample locations and actual conditions may differ from those inferred to exist. No environmental assessment program, no matter how comprehensive, can reveal all subsurface details and anomalies. Similarly, no professional, no matter how well qualified, can reveal what is hidden by earth, rock or changed through time.

The actual interface between different materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions.

For this reason, parties involved with land acquisition, management and/or redevelopment should retain the services of a suitably qualified and experienced environmental consultant through the development and use of the site to identify variances, conduct additional tests if required, and recommend solutions to unexpected conditions or other unrecognised features encountered on site. Coffey would be pleased to assist with any investigation or advice in such circumstances.

## Recommendations in this report

This report assumes, in accordance with industry practice, that the site conditions recognised through discrete sampling are representative of actual conditions throughout the investigation area. Recommendations are based on the resulting interpretation.

Should further data be obtained that differs from the data on which the report recommendations are based (such as through excavation or other additional assessment), then the recommendations would need to be reviewed and may need to be revised.

## Report for benefit of client

Unless otherwise agreed between us, the report has been prepared for your benefit and no other party. Other parties should not rely upon the report or the accuracy or completeness of any recommendation and should make their own enquiries and obtain independent advice in relation to such matters.

Coffey assumes no responsibility and will not be liable to any other person or organisation for, or in relation to, any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report.

To avoid misuse of the information presented in your report, we recommend that Coffey be consulted before the report is provided to another party who may not be familiar with the background and the purpose of the report. In particular, an environmental disclosure report for a property vendor may not be suitable for satisfying the needs of that property's purchaser. This report should not be applied for any purpose other than that stated in the report.

## Interpretation by other professionals

Costly problems can occur when other professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, a suitably qualified and experienced environmental consultant should be retained to explain the implications of the report to other professionals referring to the report and then review plans and specifications produced to see how other professionals have incorporated the report findings.

Given Coffey prepared the report and has familiarity with the site, Coffey is well placed to provide such assistance. If another party is engaged to interpret the recommendations of the report, there is a risk that the contents of the report may be misinterpreted and Coffey disowns any responsibility for such misinterpretation.

## Data should not be separated from the report

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, laboratory data, drawings, etc. are customarily included in our reports and are developed by scientists or engineers based on their interpretation of field logs, field testing and laboratory evaluation of samples. This information should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

This report should be reproduced in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties.

## Responsibility

Environmental reporting relies on interpretation of factual information using professional judgement and opinion and has a level of uncertainty attached to it, which is much less exact than other design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. As noted earlier, the recommendations and findings set out in this report should only be regarded as interpretive and should not be taken as accurate and complete information about all environmental media at all depths and locations across the site.

# Attachment A

# Site reconnaissance summary and follow up actions memorandum

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## Memorandum

| | | | |
|---|---|---|---|
| **Recipient name** | Kavita Singh | **Recipient company** | Arrow Energy |
| **Copied recipients** | Simon Gossmann, Barton Napier, Michael Blackam | **Memo date** | 17/03/2016 |
| **Author** | Brigid Moriarty | | |
| **Project number** | ENAUBRIS107043AE | | |
| **Memo Subject** | Bowen Gas Project GMMP<br>Site reconnaissance summary and follow up actions | | |

This document provides an overview of the Bowen Gas Project (BGP) Groundwater Management and Monitoring Plan (GMMP) site reconnaissance visit, as well as a summary of the actions agreed following the site visit in relation to assessment of potential groundwater dependent ecosystems (GDEs) as mapped by the Bureau of Meteorology.

## 1. Site reconnaissance objectives

The site reconnaissance visit was carried out to:

- Provide key staff involved in the development and review of the BGP GMMP with an appreciation of the general landscape.
- Visually inspect areas mapped as having the potential to support GDEs, with a focus on areas where current modelling predicts 0.2 m drawdown in Layer 3 (identified as priority sites).
- Visually inspect significant surface water features across the project area to assist with general hydrogeological conceptualisation.
- Gain an appreciation for the extent of surface coal mining operations, and how these correlate with predicted areas of drawdown and mapped GDEs.
- Collect information to assist with the prioritisation of areas of interest and inform the requirement for any subsequent, more detailed site investigations, including vegetation mapping and water quality sampling.

## 2. Site reconnaissance findings

The site visit was conducted from 3 to 5 November 2015 and was attended by:

- Ray Hatley (Arrow Energy).
- Glenn Harrington (Innovative Groundwater Solutions).
- Brigid Moriarty (Coffey).
- David Stanton (3D Environmental).

The site reconnaissance was limited to areas able to be accessed via public roads only. Key observations made during the site reconnaissance regarding likely groundwater dependence of vegetation, and the potential for groundwater interaction with surface water features, include:

- Limited likelihood for ecosystem groundwater dependence along most surface drainage lines across most of the project area. This includes discharge of groundwater to the surface and access of groundwater by terrestrial vegetation.
- Limited potential for terrestrial vegetation groundwater dependence across areas away from surface drainage features given the observed vegetation type, which was dominated by Brigalow woodland and open grasslands.
- The potential for deeper-rooted vegetation (e.g., River Oaks and River Red Gums) along major drainage features, including the Isaac River and Cherwell Creek, to interact with groundwater. The nature of the groundwater flow system(s) supporting the shallow alluvial system accessed by the deeper-rooted vegetation needs to be better understood to assess whether the development of the BGP may impact these GDEs. However it is noted that there is no drawdown in Layer 3 of the modelling predicted along the Isaac River or Cherwell Creek.
- Limited potential for baseflow contribution to these major drainage features. Surface flows in these rivers and creeks is expected to result in a hydraulic gradient towards groundwater, and given the observed geomorphology this gradient is expected to be maintained even as high flow events / floodwaters recede.
- Lake Elphinstone represents a significant regional surface water feature of high ecological importance (it is identified as a nationally important wetland in the Directory of Important Wetlands in Australia (DIWA)). The potential for Lake Elphinstone to interact with, and have a dependence on groundwater is not well understood. The lake does not coincide with an area of predicted drawdown in Layer 3 for the DG3 case development scenario. Given its national significance a management strategy (potentially including further investigations) may still be warranted.
- In the Phase 1 development area, four discreet areas of 0.2 m drawdown in Layer 3 are predicted in the 20 years following the commencement of gas production (2019). These areas do not coincide with mapped surface drainage features (major or minor) or mapped potential GDEs and were not able to be accessed during the recent site visit.

In addition to the improved understanding of the hydrogeological and ecological project setting, the site reconnaissance also provided the opportunity to gain an appreciation of the magnitude of the existing surface coal mining operations in the region, and the extent of disturbance associated with these operations. In many areas across the BGP tenements, these existing operations are significant and have resulted in a highly altered landscape.

A summary of the sites visited and general observation made at each is provided in Table 1. The general route taken, including the location of each stop made, is presented in the attached figures.

**Table 1: Site reconnaissance summary**

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| **DAY 1 – 3 NOVEMBER 2015** | | | | |
| **1.1** | Isaac River crossing at Peak Downs Highway. | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High and moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Dry river bed with sandy bottom, known to receive significant surface flow during summer (wet season). Some significant riparian vegetation with a well-developed fringe of *Eucalyptus camaldulensis* dominant open forest consistent with regional ecosystem (RE)11.3.25.<br>Vegetation appears to be in good condition with the exception of a weedy ground-layer. Potential for vegetation to be accessing groundwater, however the nature of connectivity is not clear/known. Watertable generally thought to be present, close to or below the base of the alluvial channel.<br>Stream gauging station noted to be present. Does not correlate with any mapped DRNM stations. |  |
| **1.2** | Road cutting (Peak Downs Highway) into Clematis Sandstone near Coppabella. | Moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Site visited for observation of Clematis Sandstone appearance. Outcrop shows arenitic sandstone, interbanded in mudstones/laminated siltstone (1-2m thick); joint/fracture 1-3m spacing. |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 1.3 | View east towards the Isaac River along Red Hill Road. In distant treeline only. | None mapped. | Poor view of river however shows the influence of the major watercourse on vegetation in comparison to surrounding areas. |  |
| 1.4 | View to Isaac River where it comes close to Red Hill Road. | High and moderate potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>Moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Dry riverbed with sandy bottom. Outcropping rock appears to be sandstone. Significant amounts of petrified wood observed.<br>Geology mapping indicates poorly consolidated Quaternary/Tertiary sediments overlying shallow Blackwater Group subcrop at this location.<br>Vegetation formed by a continuous narrow fringe of *Eucalyptus camaldulensis* dominant open forest (RE11.3.25). |  |
| 1.5 | Basalt quarry adjacent to Red Hill Road | None mapped. | Site visited for general observation of the Tertiary basalt appearance. |  |
| 1.6 | Goonyella North Mine access road looking south west toward area of potential Layer 3 drawdown (Site 5). | None mapped. | Vegetation dominated by degraded grazing land on a broad basalt plain with minor areas of Coolibah dominated woodland associated with narrow drainage channels. Unlikely to represent GDEs. | No photos taken. |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| **1.7** | Farm dam on Red Hill – Burton road. | None mapped. | Reasonable volume of water in comparison to general observation of surrounding landscape.<br>Aquatic macrophytes (predominantly *Typha orientalis)* on dam margins also indicates some water permanency.<br>Interpreted to be artificially fed. No windmills / pumping infrastructure observed. |  |
| **1.8** | Burton Gorge Dam | High and moderate potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>Moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Represents largest artificial surface water feature in the region. The dam is fed by a number of drainage lines, including the Isaac River, and Anna Creek, and water flow out to the Isaac River is controlled by the dam spillway.<br>Blue-green algae outbreak is sign-posted. |  |
| **1.9** | Lenton Downs Red Hill Road (off BMA pipeline) | None mapped. | Native grassland dominated by Blue grass species (*Dicanthium sericeum / Dicanthium queenslandicum*). Endangered Ecological Community under the EPBC Act. |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| **1.10** | Suttor Developmental Road | None mapped. | Depco rig on Arrow tenure.<br>BMA coal drilling rig. Blue grass vegetation noted on and around drill site. |  |
| **1.11** | Suttor Developmental Road | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Old windmill with new solar panels and pump. |  |
| **1.12** | Suttor Developmental Road | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Drainage line represents a shallow linear depression within a landscape formed on a broad basalt plain.<br>Considered unlikely to represent an area of surface expression GDEs as the depth to groundwater is expected to be well below the drainage feature. |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 1.13 | Eaglefield Creek crossing on Suttor Developmental Road | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Considered unlikely to represent an area of GDEs.<br>Vegetation is dominated by Coolibah (*Eucalyptus coolabah;* RE11.3.3) on the immediate drainage channel merging with a woodland of Mountain Coolibah (*Eucalyptus orgadophila;* RE11.8.5) which is associated with the surrounding basalt landscape).<br>There is no indication in riparian vegetation that surface expression of groundwater plays any significant role in habitat maintenance. The associated flood channel geomorphology is indicative of an ephemeral system that flows in response to episodic high rainfall events rather than sustained baseflow.<br>Eucalyptus coolabah dominant habitats are generally maintained by the wetting /drying cycles of episodic flood events and are intolerant to long-term waterlogging. The species can persist through long term drying cycles and there is no requisite reliance on groundwater for the persistence of Eucalyptus coolabah woodlands. The species may however utilise the groundwater on a facultative basis. |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 1.14 | Isaac River crossing on Suttor Developmental Road | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Dry river bed with sandy bottom. Gauging station observed. Indicators of high floodwaters observed. Potential for vegetation to interact with groundwater where the watertable is sufficiently shallow.<br>The vegetation is dominated by River-oak (*Casuarina cunninghamiana)* and River Red Gum (*Eucalyptus camaldulensis*) typical of RE11.3.25. Both species favour well drained and fertile alluvial soils which are nourished by seasonal flooding. |  |
| 1.15 | Suttor Developmental Road | View to GDEs on hills mapped as having a moderate potential for dependence on the subsurface presence of groundwater. | If present, likely to be disconnected from regional flow systems.<br>Also likely to be indicative of ephemeral springs responding to seasonal rainfall. No permanent springs have been noted in prior field survey nor is there any indication of the presence of vegetation that is permanently adapted to wet ground conditions in the Clematis Sandstone escarpments on a local basis. |  |
| 1.16 | Lake Elphinstone | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>Moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Significant natural expanse of surface water in region. Die back of trees along lake perimeter is evident. Dieback of Melaleuca trees appears to be response a period of sustained high water levels in the lake which has drowned fringing vegetation. |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 1.17 | Lake Elphinstone | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>Moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Southern end of the lake near spill point to the Isaac River. Outcropping sandstone (Clematis) observed. Water levels indicated to have been significantly higher for an extended period of time given tree root development. This is the likely mechanism that has resulted in dieback of fringing vegetation. |  |
| **DAY 2 – 4 NOVEMBER 2015** | | | | |
| 2.1 | Collinsville – Lake Elphinstone Road at eastern extent of Eastern Creek mine (Newlands expansion project) | None mapped. | Significant mining operations. Area shows considerable disturbance. |  |
| 2.2 | Collinsville – Lake Elphinstone Road | None mapped. | Road no longer accessible due to mining operation – general observation only. | No photos taken. |
| 2.3 | Collinsville – Lake Elphinstone Road | None mapped. | General area observation only. |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| **2.4** | Suttor Creek crossing of Newlands Access Road | High and moderate potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Water present, however expected to be a result of mine discharge. Aerial imagery indicates bigger pools are present upstream.<br>Bedrock control on stream channel noted in some localities. |  |
| **2.5** | Unnamed creek crossing of Newlands Access Road | High and moderate potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High and moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Dry creek bed. Considered unlikely to be an area supporting GDEs. | No photos taken. |
| **2.6** | Newlands Access Road | None mapped. | Looking north to area of predicted 0.2m drawdown. Vegetation is Brigalow regrowth. Not considered to be groundwater dependent. Brigalow is typically shallow rooted with the bulk of the rooting system in the upper friable soil layers which are often strongly vertic (shrink and swell) in nature. |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 2.7 | Kangaroo Creek crossing of Collinsville – Elphinstone Road | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Reasonable amount of water observed in creek given generally dry conditions in region. 40 mm of rain recorded in days preceding the site visit.<br>ALS onsite completing maintenance on telemetered stream gauge (including WQ) – indicated the creek had not had water since March and does not flow unless there is rainfall.<br>Site located on mapped Blackwater Group outcrop near boundary of Rewan Formation subcrop (overlain with Quaternary sediments along creek channel). Site observations indicated outcropping Rewan Formation (green lithic sandstone).<br>Vegetation is open riparian woodland with *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* with < 25% canopy cover. A poorly developed example of RE11.3.25 when compared to riparian vegetation at Site 1.1 and 1.14. |  |
| 2.8 | Collinsville – Elphinstone Road | None mapped. | Towards northern extent of Eastern Creek mine – cannot get any further south. | No photos taken. |
| 2.9 | Wollombi Road | None mapped. | Private road - cannot access further south towards Suttor Creek mine.<br>The restricted portion of this road would give access to the reach of the Suttor River which has been diverted by mining operations. Field visitation on the Suttor River would provide some indication of the resilience of riparian vegetation to groundwater drawdown. | No photos taken. |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 2.10 | Nebo Creek crossing of Suttor Developmental Road | High and moderate potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>Moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Site is east of Arrow's tenure however provides good comparison to stream reach with likely baseflow contribution.<br><br>Catchment also receives greater surface water contribution (higher rainfall and up-catchment area) which provides for more reliable flow. |  |
| **DAY 3 – 5 NOVEMBER 2015** | | | | |
| 3.1 | Cherwell Creek crossing on Winchester Road | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>Moderate potential for ecosystems to be dependent on the subsurface presence of groundwater. | Dry river bed. Evidence of recent flow (debris in place).<br><br>Similar vegetation types to the Isaac River observed, including a mix of River Red Gum (*Eucalyptus camaldulensis*) and river oak (*Casuarina cunninghamiana*) typical of RE11.3.25. Some dieback of mature River Oak is noted.<br><br>Gauging station also noted. |  |
| 3.2 | Diverted Winchester Road | None mapped. | Area of Brigalow regrowth woodland and buffel grass in mining lease area. | No photos taken. |
| 3.3 | Winchester Road | None mapped. | View south west to major mining operations (Peak Downs). |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 3.4 | Winchester Road as it intersects Peak Downs Mine | None mapped. | View to the west to Peak Downs Mine. |  |
| 3.5 | Middle Creek crossing of Winchester Road | High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Location: down-gradient of mine/dump.<br>Noticeable change in vegetation type from sites further north. Vegetation on creek line is occupied by an open forest of Weeping Tee Tree (*Melaleuca leucadendra*). This species is considered to be an obligate user of groundwater and its presence is considered to be indicative of a shallow water table. Hence it is expected that the habitat has some degree of dependency on groundwater for its maintenance.<br>Site does not appear to be affected by mining operations in the immediately surrounding area, and the habitat is a mature functioning ecosystem, therefore not likely to be a function of mine water discharge etc.<br>Back Creek Group mapped to outcrop nearby (between mine and creek crossing). |  |

| Site ID (day.stop) | Site description | GDE Atlas mapping at site (within 200m)[1] | General site observations | Site photo |
|---|---|---|---|---|
| 3.6 | Phillips Creek crossing of Dysart-Moranbah Road | High potential for ecosystems to be dependent on the surface expression of groundwater.<br><br>High potential for ecosystems to be dependent on the subsurface presence of groundwater. | Creek incised into siltstones/mudstones of Back Creek Group.<br>Dry creek bed with sandy bottom.<br>Channel is deeply incised into surrounding sedimentary rocks. River Oaks present along the stream channel indicate a deeper soil profile along the river channel with the species mixing with River Red Gums in a typical expression of RE11.3.25.<br>Site appears to have the potential for interaction with groundwater given deeper rooted vegetation. The likely dependency of the habitat on groundwater diminishes rapidly with distance from the channel as vegetation stature decreases and depth of the alluvial soil profile over basement rock diminishes. |  |
| 3.7 | Lake Vermont Road | None mapped. | View west to New Saraji Mine. Brown Gidgee patch having very green signature on the aerial photography, potentially implying higher soil moisture patch present. Brigalow / Dawson Gum patch also. |  |
| 3.8 | Lake Vermont Road | None mapped. | No access further north or west. Area of mapped moderate potential GDEs to east is a patch of Brigalow on clay soil.<br>Brigalow is a shallow rooted species which has its root mass concentrated in the upper soil profile where nutrients are cycled. Soil profiles associated with Brigalow habitats typically form a friable upper profile over an impervious heavy clay horizon at depth.<br>Brigalow is not considered groundwater dependent. |  |

1: GDEs mapped as being present within a 200 m buffer zone around the point location

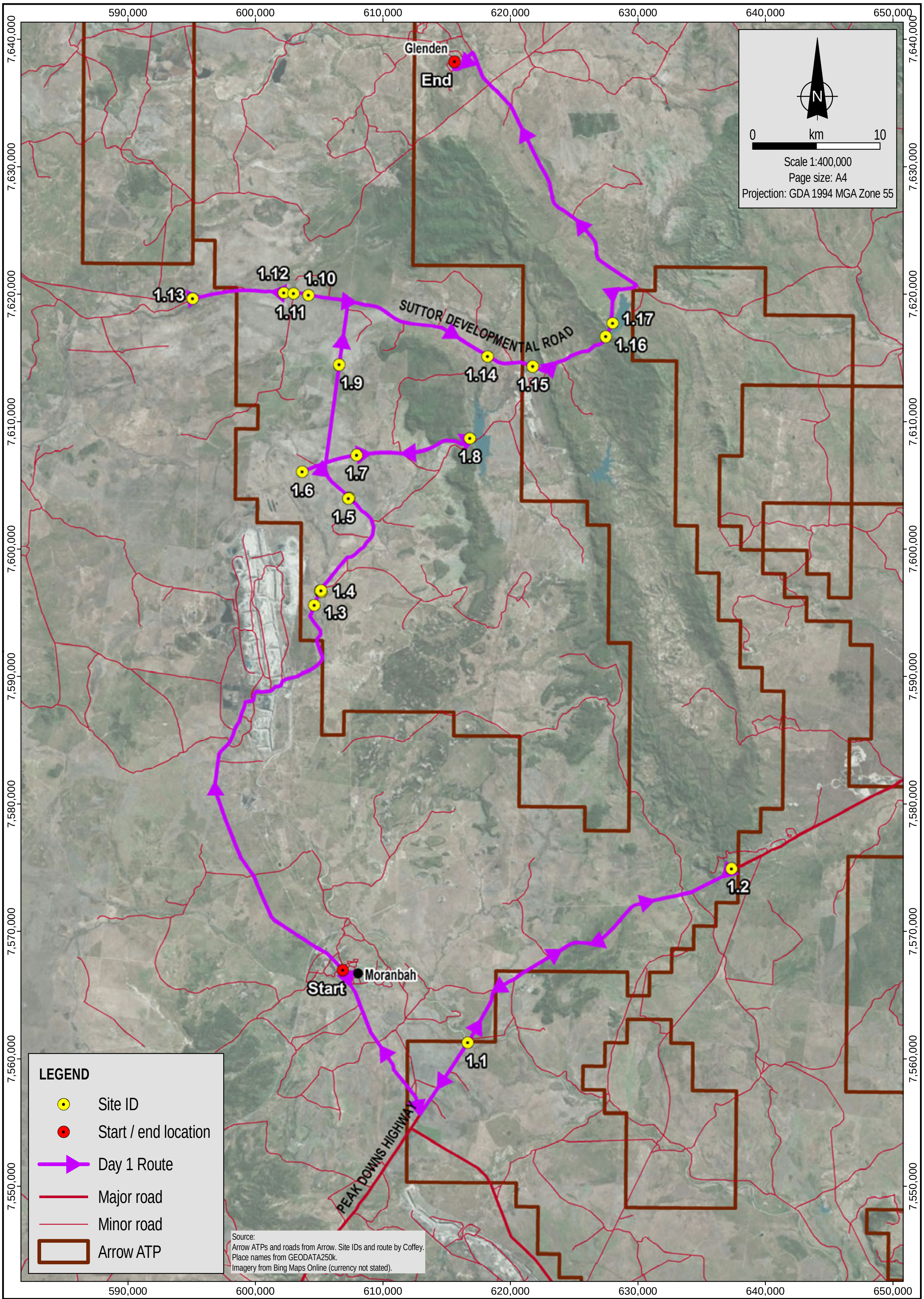
# 3. Proposed actions

The following actions are recommended to support completion of the GMMP, specifically in relation identifying and justifying a monitoring framework and network for non-spring GDEs:

- Develop a revised list of priority sites taking into account knowledge gained from the site reconnaissance and consideration for predicted impact timing. Where required, this will include documentation of discrepancies between the mapped potential GDEs and the observed site conditions, and robust justification for the adopted stance on the presence or absence of GDEs. The focus of detailed monitoring network design will be on areas associated with Phase 1 production, given the likelihood for changed production scenarios and well placement for Phases 2 and 3.
- Source detailed regional ecosystem and vegetation mapping from 3D Environmental for prioritised sites. In the first instance this will relate to mapping completed by 3D Environmental on behalf of Arrow. Where 3D Environmental hold additional, relevant data prepared for other parties, further discussions will be required to ensure appropriate permissions are obtained prior to use.
- Liaise with the Queensland Herbarium to confirm the list of specific regional ecosystems within the catchments intersected by the project area (Isaac, Bowen and Suttor Creek) that may have groundwater dependence.
- Review ecological data received, in conjunction with areas of predicted drawdown and/or ecological significance, to identify any requirements for additional field investigation. It is expected that additional field investigations would only be completed for Phase 1 areas for this stage of the GMMP.
- If required, prepare a list of field sites and supporting documentation for land access purposes. We understand the lead time for approvals could be 3 months.
- If required, mobilise Brigid Moriarty and David Stanton to the revised areas of interest to complete more detailed vegetation mapping and conceptualisation of hydrogeology and ecosystem potential groundwater dependence. This may include water quality monitoring if relevant. The requirement for more detailed intrusive investigations (i.e. piezometer installation) will be discussed with Arrow if it becomes apparent this is needed to support the network specification process.
- Present the information collected by way of conceptual models for each area of interest, focusing on Phase 1 sites where there is more certainty regarding the timing and location of predicted impacts. The conceptual models will typically include a schematic and supporting text describing:
  - Topography.
  - Geology and structure.
  - Approximate depth to groundwater and groundwater flow direction.
  - Surface water features and hydrology.
  - Potential groundwater – surface water interaction.
  - Vegetation types and likely/maximum documented rooting depth.
  - Relationship to predicted drawdown.
  - Impact source, pathway and receptor information.

- Use the information in the conceptual models to inform and justify an appropriate monitoring framework (including location, frequency and parameters). In some cases conceptual models will also be used to justify why no monitoring is considered necessary at a location, in particular where existing mapping data sets indicate the potential for GDEs however site observations indicate to be absent.

# Figures




MXD Reference: 7043AE_M02_GIS001_v0_2

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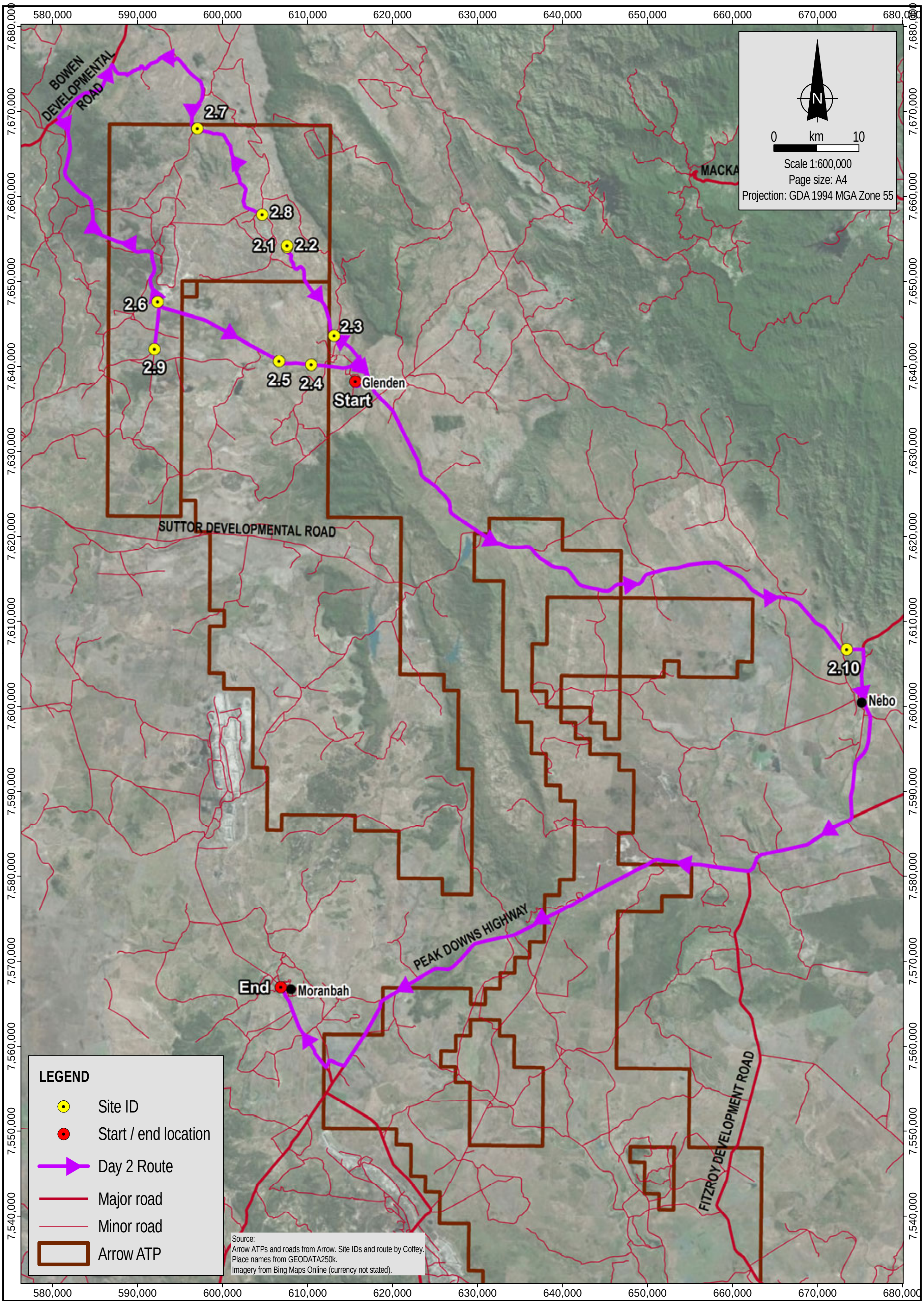


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| Date: 15.03.2016 | Arrow Energy | arrow energy go further | Day 2 | Figure No: |
| Project: ENAUBRIS07043AE | | | 4 November 2015 | 2 |
| File Name: 7043AE_M02_F002_GIS | Bowen Gas Project GMMP | | | |

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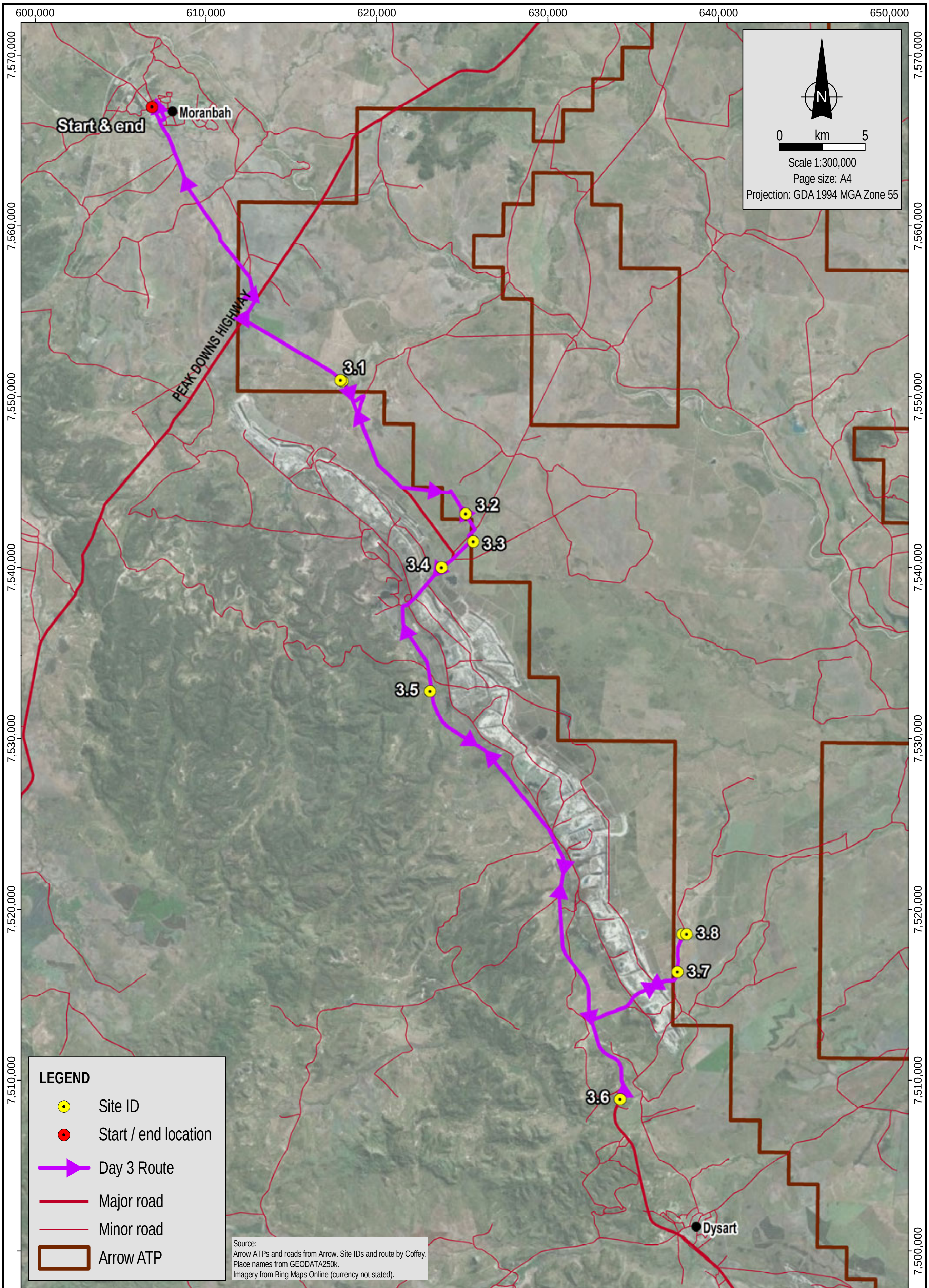


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|---|---|---|---|---|---|

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# Attachment B

# DNRM borehole summary data

| RN | DRILLED_DA | EASTING | NORTHING | ZONE | GIS_LAT | GIS_LNG | TOP | BOTTOM | QUALITY | YIELD | SWL | RDATE | FORM_DESC | Aquifer | Comment | Use in summary statistics ? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 132496 | 13/05/2007 | 586258 | 7611031 | 55 | -21.60 | 147.83 | 62.00 | 79.60 | SALTY | 1.100 | -50.00 | 13/05/2007 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 162326 | 26/05/2014 | 585419 | 7647725 | 55 | -21.27 | 147.82 | 65.00 | 0.00 | | 0.130 | -39.70 | 26/05/2014 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 132631 | 18/01/2007 | 635440 | 7528179 | 55 | -22.35 | 148.32 | 321.00 | 328.00 | 7290 US/CM | 15.000 | -31.00 | 18/01/2007 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 43991 | 1/01/1974 | 676631 | 7486986 | 55 | -22.72 | 148.72 | 45.00 | 46.00 | BRACKISH | 1.130 | -30.05 | 25/05/1973 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 37147 | 2/08/1971 | 652385 | 7493059 | 55 | -22.66 | 148.48 | 34.00 | 36.00 | COND 11,000 | 0.610 | -27.40 | 2/08/1971 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 122458 | 21/03/2006 | 644983 | 7526770 | 55 | -22.36 | 148.41 | 35.00 | 50.50 | COND 4000 | 1.880 | -26.00 | 21/03/2005 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 43064 | 19/11/1972 | 663042 | 7484421 | 55 | -22.74 | 148.59 | 67.00 | 73.00 | 8500 US/CM | 0.500 | -24.40 | 19/11/1972 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 111824 | 3/09/2003 | 671498 | 7543807 | 55 | -22.20 | 148.66 | 47.50 | 48.10 | 3000 US/CM | 1.260 | -24.00 | 3/09/2003 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 111878 | 21/11/2003 | 671750 | 7543836 | 55 | -22.20 | 148.67 | 44.00 | 67.00 | 700 US/CM | 0.250 | -24.00 | 21/11/2003 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 158220 | 9/03/2013 | 639923 | 7501629 | 55 | -22.59 | 148.36 | 57.00 | 66.50 | BRACKISH | 0.490 | -22.00 | 9/03/2013 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 13040291 | 24/09/2004 | 671257 | 7499371 | 55 | -22.60 | 148.67 | 22.00 | 24.00 | 4450 | 0.000 | -19.00 | 24/09/2004 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 38971 | 17/11/1972 | 677044 | 7488083 | 55 | -22.71 | 148.72 | 24.00 | 30.00 | 2510 US/CM | 1.600 | -16.90 | 23/11/1972 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 43602 | 9/05/1973 | 673839 | 7486693 | 55 | -22.72 | 148.69 | 18.00 | 24.00 | SALTY | 1.000 | -15.50 | 9/05/1973 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 47037 | 19/11/1972 | 666315 | 7484118 | 55 | -22.74 | 148.62 | 21.00 | 24.00 | 8850 US/CM | 0.390 | -15.10 | 19/11/1972 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 136092 | 31/10/2002 | 633416 | 7512196 | 55 | -22.49 | 148.30 | 18.00 | 0.00 | | 1.100 | -12.00 | 30/10/2002 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 158763 | 12/07/2014 | 645904 | 7496037 | 55 | -22.64 | 148.42 | 130.00 | 148.00 | 7.5 PH, POTABLE | 0.300 | -10.00 | 12/07/2014 | BACK CREEK GROUP | BACK CREEK GROUP | | |
| 141166 | 26/11/2011 | 598579 | 7621727 | 55 | -21.50 | 147.95 | 40.00 | 146.00 | POTABLE | 37.500 | -99.90 | 26/11/2011 | BASALT | BASALT | | |
| 81447 | 24/09/1993 | 601912 | 7575422 | 55 | -21.92 | 147.99 | 59.00 | 108.00 | | 0.750 | -50.00 | 24/09/1993 | BASALT | BASALT | | |
| 162061 | 7/11/2011 | 597639 | 7609406 | 55 | -21.62 | 147.94 | 49.00 | 0.00 | | 0.460 | -41.46 | 7/11/2011 | BASALT | BASALT | | |
| 85442 | 12/12/1990 | 587485 | 7630927 | 55 | -21.42 | 147.84 | 48.00 | 62.00 | | 1.000 | -40.00 | 12/12/1990 | BASALT | BASALT | | |
| 13040281 | 26/08/2004 | 598875 | 7583323 | 55 | -21.85 | 147.96 | 42.00 | 59.50 | COND 13840 | 0.000 | -35.18 | 7/04/2005 | BASALT | BASALT | | |
| 162226 | 17/01/2014 | 592014 | 7642993 | 55 | -21.31 | 147.89 | 79.00 | 83.00 | SALTY | 1.600 | -35.00 | 17/01/2014 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162226 | 17/01/2014 | 592014 | 7642993 | 55 | -21.31 | 147.89 | 54.00 | 0.00 | SALTY | 5.400 | -35.00 | 17/01/2014 | BASALT | BASALT | | |
| 162054 | 12/11/2011 | 598569 | 7621725 | 55 | -21.50 | 147.95 | 141.00 | 0.00 | | 20.020 | -32.00 | 12/11/2011 | BASALT | BASALT | | |
| 162023 | 4/07/2005 | 621512 | 7578807 | 55 | -21.89 | 148.18 | 72.00 | 0.00 | BRACKISH | 1.940 | -32.00 | 4/07/2005 | BASALT | BASALT | | |
| 162054 | 12/11/2011 | 598569 | 7621725 | 55 | -21.50 | 147.95 | 52.00 | 0.00 | | 12.000 | -32.00 | 12/11/2011 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 88992 | 9/08/1993 | 672757 | 7537240 | 55 | -22.26 | 148.68 | 39.00 | 59.00 | 980 US/CM | 0.750 | -31.00 | 9/08/1993 | BASALT | BASALT | | |
| 85445 | 26/11/1990 | 602717 | 7623622 | 55 | -21.49 | 147.99 | 50.00 | 65.00 | | 0.880 | -30.00 | 26/11/1990 | BASALT | BASALT | | |
| 162044 | 14/05/2012 | 615613 | 7560397 | 55 | -22.06 | 148.12 | 47.00 | 70.00 | COND 1780 | 1.800 | -30.00 | 14/05/2012 | BASALT | BASALT | | |
| 141458 | 3/07/2005 | 622102 | 7573101 | 55 | -21.94 | 148.18 | 42.00 | 0.00 | POTABLE | 2.900 | -29.92 | 3/07/2005 | BASALT | BASALT | | |
| 141162 | 18/10/2011 | 598360 | 7616500 | 55 | -21.55 | 147.95 | 92.00 | 98.00 | | 0.000 | -28.96 | 18/10/2011 | BASALT | BASALT | | |
| 162055 | 30/10/2011 | 598766 | 7621733 | 55 | -21.50 | 147.95 | 140.00 | 0.00 | BRACKISH | 0.000 | -28.00 | 30/10/2011 | BASALT | BASALT | | |
| 141163 | 16/10/2011 | 596778 | 7613647 | 55 | -21.58 | 147.93 | 63.00 | 69.00 | | 0.000 | -27.55 | 16/10/2011 | BASALT | BASALT | | |
| 131002 | 18/11/2005 | 621997 | 7574302 | 55 | -21.93 | 148.18 | 45.00 | 60.00 | 1022 US/CM | 6.000 | -27.00 | 18/11/2005 | BASALT | BASALT | | |
| 162028 | 4/07/2005 | 622165 | 7573319 | 55 | -21.94 | 148.18 | 61.00 | 0.00 | POTABLE | 9.400 | -27.00 | 4/07/2005 | BASALT | BASALT | | |
| 141981 | 29/06/2005 | 622210 | 7573376 | 55 | -21.94 | 148.18 | 33.00 | 0.00 | FRESH | 0.000 | -27.00 | 29/06/2005 | BASALT | BASALT | | |
| 141981 | 29/06/2005 | 622210 | 7573376 | 55 | -21.94 | 148.18 | 54.00 | 0.00 | FRESH | 0.000 | -27.00 | 29/06/2005 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 141456 | 3/07/2005 | 622097 | 7574303 | 55 | -21.93 | 148.18 | 38.00 | 0.00 | POTABLE | 1.900 | -26.99 | 3/07/2005 | BASALT | BASALT | | |
| 162064 | 14/11/2011 | 598675 | 7621616 | 55 | -21.51 | 147.95 | 148.60 | 0.00 | | 25.180 | -26.91 | 14/11/2011 | BASALT | BASALT | | |
| 162169 | 19/05/2008 | 611129 | 7551675 | 55 | -22.14 | 148.08 | 22.00 | 30.00 | COND 1690 | 0.000 | -26.23 | 8/06/2008 | BASALT | BASALT | | |
| 162164 | 20/05/2008 | 608384 | 7558233 | 55 | -22.08 | 148.05 | 24.00 | 35.00 | COND 2180 | 0.000 | -25.65 | 8/06/2008 | BASALT | BASALT | | |
| 162165 | 16/05/2008 | 608920 | 7556710 | 55 | -22.09 | 148.06 | 17.50 | 26.50 | COND 10930 | 0.000 | -25.49 | 8/06/2008 | BASALT | BASALT | | |
| 162020 | 3/07/2005 | 622073 | 7573245 | 55 | -21.94 | 148.18 | 56.00 | 0.00 | POTABLE | 2.900 | -24.77 | 4/07/2005 | BASALT | BASALT | | |
| 162021 | 4/07/2005 | 621103 | 7579809 | 55 | -21.88 | 148.17 | 37.00 | 0.00 | BRACKISH | 2.770 | -24.36 | 4/07/2005 | BASALT | BASALT | | |
| 85444 | 6/12/1990 | 603968 | 7621287 | 55 | -21.51 | 148.00 | 45.00 | 47.20 | | 6.300 | -22.00 | 6/12/1990 | BASALT | BASALT | | |
| 162050 | 11/09/2011 | 597926 | 7621985 | 55 | -21.50 | 147.95 | 61.00 | 0.00 | | 1.530 | -20.84 | 11/09/2011 | BASALT | BASALT | | |
| 141864 | 4/07/2005 | 621978 | 7572901 | 55 | -21.94 | 148.18 | 31.00 | 0.00 | POTABLE | 3.600 | -20.66 | 4/07/2005 | BASALT | BASALT | | |
| 141807 | 3/07/2005 | 621693 | 7573807 | 55 | -21.94 | 148.18 | 30.00 | 0.00 | POTABLE | 3.500 | -20.15 | 3/07/2005 | BASALT | BASALT | | |
| 141457 | 3/07/2005 | 621946 | 7573298 | 55 | -21.94 | 148.18 | 37.00 | 0.00 | POTABLE | 2.600 | -20.14 | 3/07/2005 | BASALT | BASALT | | |
| 85447 | 8/11/1990 | 599144 | 7622824 | 55 | -21.49 | 147.96 | 51.80 | 59.40 | | 1.500 | -20.00 | 8/11/1990 | BASALT | BASALT | | |
| 162043 | 10/05/2012 | 613496 | 7560208 | 55 | -22.06 | 148.10 | 30.00 | 68.00 | COND 1440 | 0.800 | -20.00 | 10/05/2012 | BASALT | BASALT | | |
| 162029 | 3/07/2005 | 621026 | 7580398 | 55 | -21.88 | 148.17 | 26.00 | 0.00 | BRACKISH | 0.170 | -20.00 | 3/07/2005 | BASALT | BASALT | | |
| 141441 | 2/07/2005 | 622399 | 7575299 | 55 | -21.92 | 148.19 | 29.00 | 0.00 | POTABLE | 1.300 | -19.87 | 2/07/2005 | BASALT | BASALT | | |
| 162019 | 4/07/2005 | 621876 | 7578278 | 55 | -21.90 | 148.18 | 32.00 | 0.00 | BRACKISH | 3.100 | -19.82 | 4/07/2005 | BASALT | BASALT | | |
| 162024 | 4/07/2005 | 621028 | 7580202 | 55 | -21.88 | 148.17 | 29.00 | 0.00 | BRACKISH | 0.090 | -18.63 | 4/07/2005 | BASALT | BASALT | | |
| 162025 | 4/07/2005 | 621035 | 7580333 | 55 | -21.88 | 148.17 | 37.00 | 0.00 | BRACKISH | 3.390 | -18.50 | 4/07/2005 | BASALT | BASALT | | |
| 105678 | 16/06/2005 | 621020 | 7580303 | 55 | -21.88 | 148.17 | 31.00 | 43.60 | 2640US/CM | 3.900 | -18.35 | 16/06/2005 | BASALT | BASALT | | |
| 85448 | 9/11/1990 | 593359 | 7618591 | 55 | -21.53 | 147.90 | 31.50 | 34.50 | | 0.560 | -18.00 | 9/11/1990 | BASALT | BASALT | | |
| 162052 | 18/10/2011 | 596406 | 7619366 | 55 | -21.53 | 147.93 | 12.00 | 0.00 | | 0.020 | -18.00 | 18/10/2011 | BASALT | BASALT | | |
| 162053 | 24/10/2011 | 596751 | 7619457 | 55 | -21.53 | 147.93 | 30.00 | 0.00 | | 21.000 | -18.00 | 24/10/2011 | BASALT | BASALT | | |
| 162070 | 29/06/2008 | 606033 | 7571055 | 55 | -21.96 | 148.03 | 33.00 | 0.00 | POTABLE | 1.060 | -18.00 | 29/06/2008 | BASALT | BASALT | | |
| 162070 | 29/06/2008 | 606033 | 7571055 | 55 | -21.96 | 148.03 | 51.00 | 59.00 | | 1.010 | -18.00 | 29/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162070 | 29/06/2008 | 606033 | 7571055 | 55 | -21.96 | 148.03 | 65.00 | 79.00 | | 1.010 | -18.00 | 29/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162070 | 29/06/2008 | 606033 | 7571055 | 55 | -21.96 | 148.03 | 82.00 | 0.00 | | 1.200 | -18.00 | 29/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162026 | 4/07/2005 | 622311 | 7577879 | 55 | -21.90 | 148.18 | 41.00 | 0.00 | POTABLE | 1.280 | -18.00 | 4/07/2005 | BASALT | BASALT | | |

| RN | DRILLED_DA | EASTING | NORTHING | ZONE | GIS_LAT | GIS_LNG | TOP | BOTTOM | QUALITY | YIELD | SWL | RDATE | FORM_DESC | Aquifer | Comment | Use in summary statistics ? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 162071 | 30/06/2008 | 605990 | 7571006 | 55 | -21.96 | 148.03 | 26.94 | 0.00 | | 0.050 | -17.65 | 30/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162071 | 30/06/2008 | 605990 | 7571006 | 55 | -21.96 | 148.03 | 38.94 | 44.00 | | 0.150 | -17.65 | 30/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162071 | 30/06/2008 | 605990 | 7571006 | 55 | -21.96 | 148.03 | 44.94 | 48.00 | | 0.220 | -17.65 | 30/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162071 | 30/06/2008 | 605990 | 7571006 | 55 | -21.96 | 148.03 | 20.00 | 25.00 | | 0.000 | -17.65 | 30/06/2008 | BASALT | BASALT | | |
| 162068 | 29/06/2008 | 605993 | 7571041 | 55 | -21.96 | 148.03 | 39.00 | 0.00 | | 0.800 | -17.40 | 29/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162068 | 29/06/2008 | 605993 | 7571041 | 55 | -21.96 | 148.03 | 51.00 | 0.00 | | 0.920 | -17.40 | 29/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162068 | 29/06/2008 | 605993 | 7571041 | 55 | -21.96 | 148.03 | 68.00 | 71.00 | | 1.590 | -17.40 | 29/06/2008 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 162068 | 29/06/2008 | 605993 | 7571041 | 55 | -21.96 | 148.03 | 23.00 | 24.00 | | 0.000 | -17.40 | 29/06/2008 | BASALT | BASALT | | |
| 162051 | 15/09/2011 | 598111 | 7622184 | 55 | -21.50 | 147.95 | 67.00 | 0.00 | | 2.550 | -17.30 | 15/09/2011 | BASALT | BASALT | | |
| 162013 | 3/07/2005 | 621998 | 7572002 | 55 | -21.95 | 148.18 | 34.00 | 0.00 | BRACKISH | 1.340 | -17.20 | 3/07/2005 | BASALT | BASALT | | |
| 85446 | 25/11/1990 | 601413 | 7621726 | 55 | -21.50 | 147.98 | 33.00 | 41.00 | | 2.500 | -17.00 | 25/11/1990 | BASALT | BASALT | | |
| 162048 | 19/06/2012 | 613513 | 7557249 | 55 | -22.09 | 148.10 | 23.00 | 72.00 | COND 1290 | 1.520 | -16.70 | 19/06/2012 | BASALT | BASALT | | |
| 141865 | 4/07/2005 | 621974 | 7572779 | 55 | -21.95 | 148.18 | 21.00 | 0.00 | POTABLE | 4.200 | -16.68 | 4/07/2005 | BASALT | BASALT | | |
| 162014 | 4/07/2005 | 621993 | 7572501 | 55 | -21.95 | 148.18 | 19.00 | 0.00 | | 0.010 | -16.22 | 4/07/2005 | BASALT | BASALT | | |
| 162027 | 4/07/2005 | 622312 | 7577815 | 55 | -21.90 | 148.18 | 31.00 | 42.00 | POTABLE | 4.760 | -16.00 | 4/07/2005 | BASALT | BASALT | | |
| 85415 | 29/11/1990 | 595582 | 7623993 | 55 | -21.48 | 147.92 | 33.00 | 45.00 | | 4.400 | -15.00 | 29/11/1990 | BASALT | BASALT | | |
| 162017 | 4/07/2005 | 621699 | 7572436 | 55 | -21.95 | 148.18 | 24.00 | 0.00 | BRACKISH | 0.400 | -14.92 | 4/07/2005 | BASALT | BASALT | | |
| 141429 | 2/07/2005 | 622198 | 7576304 | 55 | -21.91 | 148.18 | 20.00 | 0.00 | POTABLE | 0.800 | -14.59 | 2/07/2005 | BASALT | BASALT | | |
| 141455 | 3/07/2005 | 622404 | 7575801 | 55 | -21.92 | 148.19 | 25.00 | 0.00 | POTABLE | 1.800 | -14.50 | 3/07/2005 | BASALT | BASALT | | |
| 141381 | 2/07/2005 | 622008 | 7576801 | 55 | -21.91 | 148.18 | 27.00 | 0.00 | POTABLE | 0.100 | -14.17 | 2/05/2005 | BASALT | BASALT | | |
| 141808 | 3/07/2005 | 621794 | 7572499 | 55 | -21.95 | 148.18 | 21.00 | 0.00 | BRACKISH | 3.500 | -14.15 | 3/07/2005 | BASALT | BASALT | | |
| 141986 | 2/07/2005 | 622452 | 7577802 | 55 | -21.90 | 148.19 | 16.10 | 0.00 | BRACKISH | 0.200 | -14.00 | 2/07/2005 | BASALT | BASALT | | |
| 141986 | 2/07/2005 | 622452 | 7577802 | 55 | -21.90 | 148.19 | 33.50 | 0.00 | BRACKISH | 0.010 | -14.00 | 2/07/2005 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 141986 | 2/07/2005 | 622452 | 7577802 | 55 | -21.90 | 148.19 | 37.33 | 0.00 | BRACKISH | 0.180 | -14.00 | 2/07/2005 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 141269 | 2/07/2005 | 622359 | 7577792 | 55 | -21.90 | 148.18 | 25.00 | 0.00 | COND 1360 | 2.800 | -13.67 | 2/07/2005 | BASALT | BASALT | | |
| 141291 | 2/07/2005 | 622405 | 7577797 | 55 | -21.90 | 148.18 | 20.00 | 0.00 | COND 1440 | 4.100 | -13.52 | 2/07/2005 | BASALT | BASALT | | |
| 141812 | 4/07/2005 | 620901 | 7582285 | 55 | -21.86 | 148.17 | 52.00 | 0.00 | | 0.000 | -13.50 | 4/07/2005 | BASALT | BASALT | | |
| 141190 | 2/07/2005 | 622311 | 7577787 | 55 | -21.90 | 148.18 | 20.50 | 0.00 | COND 1340 | 9.500 | -13.35 | 2/07/2005 | BASALT | BASALT | | |
| 162030 | 4/07/2005 | 622313 | 7577692 | 55 | -21.90 | 148.18 | 26.00 | 0.00 | BRACKISH | 8.360 | -13.00 | 4/07/2005 | BASALT | BASALT | | |
| 141987 | 2/07/2005 | 622505 | 7577805 | 55 | -21.90 | 148.19 | 16.50 | 0.00 | POTABLE? | 3.200 | -13.00 | 2/07/2005 | BASALT | BASALT | | |
| 141987 | 2/07/2005 | 622505 | 7577805 | 55 | -21.90 | 148.19 | 26.70 | 0.00 | POTABLE? | 6.250 | -13.00 | 2/07/2005 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 141422 | 2/07/2005 | 621968 | 7576801 | 55 | -21.91 | 148.18 | 13.00 | 0.00 | POTABLE | 0.200 | -12.84 | 2/07/2005 | BASALT | BASALT | | |
| 162022 | 4/07/2005 | 621404 | 7579305 | 55 | -21.89 | 148.18 | 42.00 | 0.00 | POTABLE | 1.180 | -12.75 | 4/07/2005 | BASALT | BASALT | | |
| 141165 | 2/07/2005 | 622260 | 7577783 | 55 | -21.90 | 148.18 | 15.00 | 0.00 | POTABLE | 3.200 | -12.61 | 2/07/2005 | BASALT | BASALT | | |
| 162011 | 4/07/2005 | 621951 | 7572589 | 55 | -21.95 | 148.18 | 23.00 | 0.00 | | 0.900 | -12.27 | 4/07/2005 | BASALT | BASALT | | |
| 162033 | 3/07/2005 | 622020 | 7577200 | 55 | -21.91 | 148.18 | 27.00 | 0.00 | POTABLE | 1.500 | -12.13 | 3/07/2005 | BASALT | BASALT | | |
| 141421 | 2/07/2005 | 622199 | 7577302 | 55 | -21.90 | 148.18 | 20.00 | 0.00 | POTABLE | 6.260 | -12.10 | 2/07/2005 | BASALT | BASALT | | |
| 141159 | 2/07/2005 | 622211 | 7577781 | 55 | -21.90 | 148.18 | 22.00 | 0.00 | POTABLE | 3.680 | -12.00 | 2/07/2005 | BASALT | BASALT | | |
| 162031 | 3/07/2005 | 622046 | 7577326 | 55 | -21.90 | 148.18 | 19.00 | 0.00 | POTABLE | 0.500 | -12.00 | 3/07/2005 | BASALT | BASALT | Duplicated borehole entry and SWL | N |
| 141696 | 3/07/2005 | 621998 | 7574807 | 55 | -21.93 | 148.18 | 33.00 | 0.00 | BRACKISH | 1.700 | -11.69 | 3/07/2005 | BASALT | BASALT | | |
| 141998 | 2/07/2005 | 622167 | 7577778 | 55 | -21.90 | 148.18 | 20.00 | 0.00 | POTABLE | 3.390 | -11.61 | 2/07/2005 | BASALT | BASALT | | |
| 141997 | 2/07/2005 | 622118 | 7577774 | 55 | -21.90 | 148.18 | 16.00 | 0.00 | POTABLE | 1.900 | -11.28 | 2/07/2005 | BASALT | BASALT | | |
| 162065 | 17/11/2011 | 596880 | 7619640 | 55 | -21.52 | 147.94 | 115.00 | 0.00 | POTABLE | 25.000 | -11.18 | 13/11/2011 | BASALT | BASALT | | |
| 141417 | 2/07/2005 | 622299 | 7577301 | 55 | -21.90 | 148.18 | 12.00 | 0.00 | POTABLE | 0.540 | -11.15 | 2/07/2005 | BASALT | BASALT | | |
| 141605 | 3/07/2005 | 622186 | 7574781 | 55 | -21.93 | 148.18 | 24.00 | 0.00 | BRACKISH | 1.800 | -10.96 | 3/07/2005 | BASALT | BASALT | | |
| 141995 | 2/07/2005 | 622017 | 7577764 | 55 | -21.90 | 148.18 | 25.00 | 0.00 | POTABLE | 1.040 | -10.93 | 2/07/2005 | BASALT | BASALT | | |
| 162032 | 3/07/2005 | 622082 | 7577383 | 55 | -21.90 | 148.18 | 23.00 | 0.00 | BRACKISH | 5.200 | -10.60 | 3/07/2005 | BASALT | BASALT | | |
| 162018 | 3/07/2005 | 620803 | 7581793 | 55 | -21.86 | 148.17 | 16.00 | 0.00 | POTABLE | 2.200 | -10.55 | 3/07/2005 | BASALT | BASALT | | |
| 162347 | 2/11/2014 | 636524 | 7635796 | 55 | -21.37 | 148.32 | 26.00 | 28.00 | POTABLE | 0.060 | -10.50 | 2/11/2014 | BASALT | BASALT | | |
| 141418 | 2/07/2005 | 622393 | 7577303 | 55 | -21.90 | 148.18 | 14.00 | 0.00 | BRACKISH | 0.100 | -10.42 | 2/07/2005 | BASALT | BASALT | | |
| 141996 | 2/07/2005 | 621968 | 7577763 | 55 | -21.90 | 148.18 | 22.00 | 0.00 | POTABLE | 0.400 | -10.38 | 2/07/2005 | BASALT | BASALT | | |
| 162348 | 4/11/2014 | 636534 | 7635796 | 55 | -21.37 | 148.32 | 29.00 | 40.00 | POTABLE | 0.060 | -10.00 | 4/11/2014 | BASALT | BASALT | | |
| 162143 | 11/08/2012 | 616018 | 7561336 | 55 | -22.05 | 148.12 | 11.00 | 19.00 | COND 10230 | 0.140 | -9.30 | 11/08/2012 | BASALT | BASALT | | |
| 141962 | 10/10/2011 | 599820 | 7581300 | 55 | -21.87 | 147.97 | 36.00 | 0.00 | POTABLE | 0.500 | -9.00 | 10/10/2011 | BASALT | BASALT | | |
| 141958 | 26/09/2011 | 600190 | 7581130 | 55 | -21.87 | 147.97 | 30.00 | 0.00 | SALTY | 0.130 | -8.00 | 26/09/2011 | BASALT | BASALT | | |
| 162062 | 8/11/2011 | 599963 | 7616685 | 55 | -21.55 | 147.97 | 28.00 | 0.00 | | 0.540 | -7.83 | 8/11/2011 | BASALT | BASALT | Inconsistent with surrounding SWLs for quite a number of basalt bores that indicate SWLs more like 15-30m | |
| 63064 | 4/12/1981 | 595410 | 7619986 | 55 | -21.52 | 147.92 | 19.00 | 43.00 | | 3.790 | -7.60 | 4/12/1981 | BASALT | BASALT | Inconsistent with surrounding SWLs for quite a number of basalt bores that indicate SWLs more like 15-30m | |
| 162140 | 10/07/2012 | 610436 | 7562717 | 55 | -22.04 | 148.07 | 11.80 | 13.00 | COND 2800 | 0.490 | -3.40 | 10/07/2012 | BASALT | BASALT | Located 50m from Isaac River tributary south of Moranbah. Appears to be on a dammed creek. Expect water level to be influenced by this. Other basalt SWLs in general area more like 15-30m deep | |

| RN | DRILLED_DA | EASTING | NORTHING | ZONE | GIS_LAT | GIS_LNG | TOP | BOTTOM | QUALITY | YIELD | SWL | RDATE | FORM_DESC | Aquifer | Comment | Use in summary statistics ? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90475 | 25/07/1973 | 645463 | 7513291 | 55 | -22.48 | 148.41 | 56.69 | 60.96 | | 0.010 | -304.50 | 25/07/1973 | BLACKWATER GROUP | BLACKWATER GROUP | Not considered to be reliable data. Total bore depth is 61m therefore the SWL cannot be correct. | N |
| 141668 | 8/11/2009 | 650852 | 7584036 | 55 | -21.84 | 148.46 | 18.00 | 112.00 | | 0.100 | -112.00 | 8/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | Not considered to be reliable data. The bore depth is 112m therefore this is likely to be a data entry/transcription error and not represent the SWL. It is also inconsistent with neighbouring bore SWLs also in the Blackwater Group which range from 18 to 65mbgl, but typically 40m. All overlie footprint of open cut mine. | N |
| 141655 | 1/11/2009 | 658644 | 7554874 | 55 | -22.10 | 148.54 | 83.00 | 130.00 | | 0.100 | -69.18 | 1/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141673 | 8/11/2009 | 651605 | 7582574 | 55 | -21.85 | 148.47 | 110.00 | 118.00 | | 0.100 | -64.99 | 8/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141671 | 6/11/2009 | 649810 | 7582855 | 55 | -21.85 | 148.45 | 95.00 | 101.00 | | 0.100 | -55.00 | 6/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 37861 | 18/12/1970 | 650015 | 7505297 | 55 | -22.55 | 148.46 | 78.00 | 81.00 | BRACKISH | 3.000 | -55.00 | 18/12/1970 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 85441 | 13/12/1990 | 589056 | 7630385 | 55 | -21.43 | 147.86 | 80.00 | 81.00 | | 0.880 | -54.00 | 13/12/1990 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141664 | 7/11/2009 | 649432 | 7584695 | 55 | -21.84 | 148.45 | 91.00 | 104.00 | | 0.600 | -49.23 | 7/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141666 | 8/11/2009 | 648307 | 7584036 | 55 | -21.84 | 148.44 | 108.00 | 119.00 | | 1.000 | -48.90 | 8/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141669 | 8/11/2009 | 648986 | 7583197 | 55 | -21.85 | 148.44 | 68.00 | 73.00 | | 2.200 | -48.45 | 8/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141675 | 6/11/2009 | 647547 | 7583162 | 55 | -21.85 | 148.43 | 81.00 | 86.00 | | 0.100 | -47.65 | 6/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 43305 | 26/12/1972 | 647075 | 7516837 | 55 | -22.45 | 148.43 | 82.00 | 91.00 | VERY GOOD | 0.390 | -45.70 | 26/12/1972 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 89454 | 18/10/1972 | 653338 | 7513734 | 55 | -22.48 | 148.49 | 58.00 | 67.00 | COND 16000 | 1.300 | -45.70 | 18/10/1972 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 111656 | 23/04/2002 | 671139 | 7506021 | 55 | -22.54 | 148.66 | 43.50 | 47.00 | SALTY | 0.020 | -43.50 | 23/04/2002 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141670 | 7/11/2009 | 648986 | 7583197 | 55 | -21.85 | 148.44 | 0.00 | 43.00 | | 0.100 | -40.28 | 7/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141665 | 7/11/2009 | 649491 | 7584642 | 55 | -21.84 | 148.45 | 36.00 | 46.00 | | 0.000 | -39.08 | 7/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 131615 | 18/04/2006 | 620661 | 7582919 | 55 | -21.85 | 148.17 | 50.00 | 97.10 | 3660US/CM | 11.800 | -38.92 | 18/04/2006 | BLACKWATER GROUP - UNDIFF. | BLACKWATER GROUP | | |
| 44625 | 2/08/1973 | 650437 | 7509443 | 55 | -22.51 | 148.46 | 51.00 | 54.00 | GOOD | 2.270 | -36.60 | 2/08/1973 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 162252 | 17/05/2012 | 639451 | 7550502 | 55 | -22.15 | 148.35 | 54.00 | 0.00 | BRACKISH | 0.500 | -35.00 | 17/05/2014 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 131614 | 18/04/2006 | 620575 | 7583096 | 55 | -21.85 | 148.17 | 65.00 | 101.20 | 1080US/CM | 2.600 | -32.64 | 18/04/2006 | BLACKWATER GROUP - UNDIFF. | BLACKWATER GROUP | | |
| 85443 | 11/12/1990 | 588640 | 7631494 | 55 | -21.42 | 147.86 | 55.00 | 61.50 | | 3.500 | -30.00 | 11/12/1990 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 43639 | 1/08/1973 | 638939 | 7511033 | 55 | -22.50 | 148.35 | 40.00 | 41.00 | COND 7300 | 0.750 | -29.50 | 14/08/1973 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 132733 | 3/05/2011 | 645138 | 7506836 | 55 | -22.54 | 148.41 | 30.00 | 35.00 | SALTY | 0.500 | -28.00 | 3/05/2011 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 132732 | 2/05/2011 | 645138 | 7506836 | 55 | -22.54 | 148.41 | 30.00 | 35.00 | SALTY | 0.500 | -28.00 | 2/05/2011 | BLACKWATER GROUP | BLACKWATER GROUP | SWL duplicated the following day for same bore - omit this entry from statistics | N |
| 85464 | 17/11/1990 | 600169 | 7627369 | 55 | -21.45 | 147.97 | 53.00 | 66.40 | | 0.700 | -26.00 | 17/11/1990 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 132731 | 5/05/2011 | 644569 | 7507274 | 55 | -22.53 | 148.41 | 23.00 | 28.00 | SALTY | 0.100 | -26.00 | 5/05/2011 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 132736 | 6/05/2011 | 645120 | 7506786 | 55 | -22.54 | 148.41 | 23.00 | 28.00 | SALTY | 0.100 | -26.00 | 6/05/2011 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141658 | 1/11/2009 | 665595 | 7557432 | 55 | -22.08 | 148.61 | 65.00 | 86.00 | | 0.300 | -26.00 | 1/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 90441 | 10/11/1995 | 672015 | 7510960 | 55 | -22.50 | 148.67 | 24.00 | 36.00 | | 1.600 | -25.90 | 10/11/1995 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141157 | 27/04/2007 | 639587 | 7560479 | 55 | -22.05 | 148.35 | 30.00 | 50.00 | | 1.260 | -25.00 | 27/04/2007 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 151965 | 29/11/2013 | 657731 | 7503980 | 55 | -22.56 | 148.53 | 48.00 | 42.00 | COND 1400 | 0.620 | -24.00 | 29/11/2013 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 105435 | 12/07/2004 | 616874 | 7570584 | 55 | -21.97 | 148.13 | 0.00 | 0.00 | | 0.000 | -23.00 | 12/07/2004 | BLACKWATER GROUP - UNDIFF. | BLACKWATER GROUP | | |
| 141657 | 10/11/2009 | 660949 | 7555175 | 55 | -22.10 | 148.56 | 42.00 | 84.00 | | 1.250 | -22.00 | 10/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141660 | 31/10/2009 | 662270 | 7556435 | 55 | -22.09 | 148.57 | 77.00 | 84.70 | | 0.600 | -20.00 | 31/10/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 103210 | 22/09/1999 | 616869 | 7560018 | 55 | -22.06 | 148.13 | 25.91 | 27.43 | POTABLE | 0.380 | -19.81 | 22/09/1999 | BLACKWATER GROUP | BLACKWATER GROUP | Duplicated borehole entry and SWL | N |
| 103210 | 22/09/1999 | 616869 | 7560018 | 55 | -22.06 | 148.13 | 62.48 | 65.53 | POTABLE | 0.780 | -19.81 | 22/09/1999 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 44053 | 25/06/1974 | 660230 | 7501203 | 55 | -22.59 | 148.56 | 42.00 | 44.00 | 1190 US/CM | 1.670 | -19.60 | 30/07/1995 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141654 | 2/11/2009 | 659021 | 7555813 | 55 | -22.10 | 148.54 | 25.00 | 29.00 | | 0.200 | -19.00 | 2/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 67248 | 28/05/1985 | 659733 | 7501055 | 55 | -22.59 | 148.55 | 31.00 | 36.00 | 700 US/CM | 3.520 | -19.00 | 25/06/1985 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141661 | 1/11/2009 | 662270 | 7553121 | 55 | -22.12 | 148.57 | 30.00 | 36.00 | | 0.200 | -18.90 | 1/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 38339 | 1/09/1973 | 668267 | 7554480 | 55 | -22.11 | 148.63 | 88.00 | 118.00 | COND 23500 | 0.700 | -18.70 | 17/08/1987 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141676 | 6/11/2009 | 651820 | 7580980 | 55 | -21.87 | 148.47 | 21.00 | 24.00 | | 0.000 | -18.60 | 6/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 90074 | 1/01/1963 | 671554 | 7510596 | 55 | -22.50 | 148.67 | 40.23 | 46.33 | GOOD | 0.450 | -18.30 | 1/01/1963 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 90440 | 10/11/1995 | 674443 | 7515854 | 55 | -22.45 | 148.70 | 21.00 | 36.00 | | 1.000 | -18.30 | 10/11/1995 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141662 | 1/11/2009 | 662988 | 7553121 | 55 | -22.12 | 148.58 | 88.00 | 103.00 | | 1.000 | -18.00 | 1/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 141659 | 1/11/2009 | 665723 | 7557183 | 55 | -22.08 | 148.61 | 22.00 | 33.00 | | 0.100 | -18.00 | 1/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 136082 | 26/11/2002 | 671289 | 7507338 | 55 | -22.53 | 148.67 | 26.00 | 42.00 | POTABLE | 1.430 | -18.00 | 26/11/2002 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 103082 | 8/10/1997 | 674522 | 7517822 | 55 | -22.44 | 148.70 | 21.00 | 26.00 | | 0.400 | -18.00 | 8/10/1997 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 131612 | 18/04/2006 | 620803 | 7582641 | 55 | -21.86 | 148.17 | 45.00 | 100.50 | 2900US/CM | 6.940 | -17.91 | 18/04/2006 | BLACKWATER GROUP - UNDIFF. | BLACKWATER GROUP | | |
| 90075 | 1/01/1992 | 674554 | 7518068 | 55 | -22.43 | 148.70 | 11.50 | 35.00 | GOOD | 0.630 | -17.06 | 1/01/1993 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 67251 | 28/06/1985 | 670780 | 7497623 | 55 | -22.62 | 148.66 | 17.60 | 19.80 | 3000 US/CM | 0.590 | -17.00 | 28/06/1985 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 43902 | 14/02/1974 | 673882 | 7499308 | 55 | -22.60 | 148.69 | 114.00 | 115.00 | 3900 US/CM | 1.290 | -15.95 | 7/08/1975 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 105838 | 19/05/2002 | 642816 | 7625689 | 55 | -21.47 | 148.38 | 29.87 | 32.00 | | 0.000 | -13.72 | 19/05/2002 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 131613 | 18/04/2006 | 620721 | 7582804 | 55 | -21.85 | 148.17 | 40.00 | 100.50 | 1680US/CM | 4.640 | -12.00 | 18/04/2006 | BLACKWATER GROUP - UNDIFF. | BLACKWATER GROUP | | |
| 67249 | 14/06/1985 | 670825 | 7498141 | 55 | -22.62 | 148.66 | 20.00 | 26.00 | 3800 US/CM | 0.590 | -11.30 | 24/06/1985 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 90076 | 19/09/1968 | 672380 | 7515478 | 55 | -22.46 | 148.68 | 16.46 | 17.07 | GOOD | 1.000 | -10.80 | 1/01/1993 | BLACKWATER GROUP | BLACKWATER GROUP | | |

| RN | DRILLED_DA | EASTING | NORTHING | ZONE | GIS_LAT | GIS_LNG | TOP | BOTTOM | QUALITY | YIELD | SWL | RDATE | FORM_DESC | Aquifer | Comment | Use in summary statistics ? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 141656 | 1/11/2009 | 658655 | 7554618 | 55 | -22.11 | 148.54 | 2.00 | 6.00 | | 0.100 | -5.45 | 1/11/2009 | BLACKWATER GROUP | BLACKWATER GROUP | Potentially incorrect aquifer assigned. Located in close proximity to river with mapped alluvium outcrop and shallow screened interval. | |
| 43509 | 23/11/1972 | 676080 | 7491233 | 55 | -22.68 | 148.71 | 24.00 | 28.00 | 2300 US/CM | 0.650 | -4.30 | 11/11/1973 | BLACKWATER GROUP | BLACKWATER GROUP | | |
| 132628 | 28/04/2007 | 648220 | 7524052 | 55 | -22.38 | 148.44 | 85.00 | 120.00 | | 0.760 | -77.00 | 28/04/2007 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 136689 | 18/01/2007 | 635868 | 7528234 | 55 | -22.35 | 148.32 | 321.00 | 328.00 | 7290 US/CM | 15.000 | -31.00 | 18/01/2007 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 132627 | 29/04/2007 | 649564 | 7525028 | 55 | -22.37 | 148.45 | 35.00 | 70.00 | | 0.950 | -30.00 | 29/04/2007 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 90474 | 31/07/1993 | 656354 | 7511038 | 55 | -22.50 | 148.52 | 43.00 | 46.00 | SALTY | 4.300 | -30.00 | 31/07/1993 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 158490 | 17/12/2013 | 650984 | 7483324 | 55 | -22.75 | 148.47 | 28.00 | 29.00 | | 0.010 | -26.50 | 17/12/2013 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 47119 | 2/10/1974 | 677964 | 7544192 | 55 | -22.20 | 148.73 | 27.00 | 52.00 | COND 505 | 0.400 | -24.50 | 14/10/1974 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 136081 | 17/12/2002 | 671979 | 7543874 | 55 | -22.20 | 148.67 | 42.67 | 51.82 | COND 2500 | 1.010 | -23.77 | 17/12/2002 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 88526 | 6/02/1992 | 671710 | 7519574 | 55 | -22.42 | 148.67 | 36.00 | 40.40 | 12300 US/CM | 2.500 | -19.00 | 6/02/1992 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 91078 | 22/11/1992 | 672299 | 7509699 | 55 | -22.51 | 148.68 | 21.50 | 41.00 | | 0.010 | -19.00 | 22/11/1992 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 161242 | 7/10/2014 | 671987 | 7546623 | 55 | -22.18 | 148.67 | 70.00 | 78.00 | POTABLE | 0.500 | -18.00 | 7/10/2014 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 161243 | 20/10/2014 | 672711 | 7547277 | 55 | -22.17 | 148.68 | 66.00 | 77.00 | POTABLE | 0.500 | -18.00 | 20/10/2014 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 88525 | 4/02/1992 | 671221 | 7521945 | 55 | -22.40 | 148.66 | 33.50 | 38.30 | 4000 US/CM | 1.250 | -17.00 | 4/02/1992 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 161241 | 29/09/2014 | 671018 | 7552799 | 55 | -22.12 | 148.66 | 66.00 | 72.00 | POTABLE | 0.500 | -15.00 | 29/09/2014 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 158489 | 16/12/2013 | 649824 | 7484391 | 55 | -22.74 | 148.46 | 17.00 | 21.00 | POTABLE | 0.000 | -13.00 | 16/12/2013 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 97769 | 2/12/1997 | 675724 | 7543186 | 55 | -22.20 | 148.71 | 31.00 | 36.00 | COND 1020 | 1.000 | -12.00 | 2/12/1998 | DUARINGA FORMATION | DUARINGA FORMATION | | |
| 141935 | 6/09/2011 | 591997 | 7642215 | 55 | -21.32 | 147.89 | 102.00 | 119.00 | | 0.100 | -78.50 | 6/09/2011 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 141936 | 7/09/2011 | 592422 | 7645985 | 55 | -21.29 | 147.89 | 54.00 | 67.00 | | 0.500 | -36.50 | 7/09/2011 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 153229 | 8/09/2011 | 589229 | 7654175 | 55 | -21.21 | 147.86 | 46.00 | 52.00 | | 0.400 | -33.70 | 8/09/2011 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162004 | 18/04/2006 | 620370 | 7583006 | 55 | -21.85 | 148.16 | 21.00 | 29.00 | COND 2491 | 0.040 | -20.00 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162145 | 19/08/2012 | 615081 | 7550890 | 55 | -22.14 | 148.12 | 16.70 | 22.70 | COND 3200 | 0.010 | -19.70 | 19/08/2012 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162046 | 15/06/2012 | 618281 | 7557938 | 55 | -22.08 | 148.15 | 34.00 | 0.00 | COND 3660 | 0.010 | -19.70 | 15/06/2012 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162340 | 14/11/2014 | 631649 | 7635770 | 55 | -21.38 | 148.27 | 24.00 | 0.00 | BRACKISH | 0.630 | -18.00 | 14/11/2014 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162071 | 30/06/2008 | 605990 | 7571006 | 55 | -21.96 | 148.03 | 75.00 | 0.00 | | 2.970 | -17.65 | 30/06/2008 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162039 | 18/04/2006 | 620459 | 7583039 | 55 | -21.85 | 148.17 | 58.00 | 65.00 | COND 924 | 0.900 | -16.50 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | Duplicated borehole entry and SWL | N |
| 162039 | 18/04/2006 | 620459 | 7583039 | 55 | -21.85 | 148.17 | 32.00 | 34.00 | | 1.770 | -16.50 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162008 | 18/04/2006 | 620463 | 7583047 | 55 | -21.85 | 148.17 | 35.00 | 41.00 | COND 1100 | 2.110 | -14.18 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 141168 | 18/04/2006 | 620595 | 7582651 | 55 | -21.86 | 148.17 | 28.00 | 31.00 | 3200 US/CM | 5.020 | -13.40 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 141168 | 18/04/2006 | 620595 | 7582651 | 55 | -21.86 | 148.17 | 31.00 | 33.05 | 3200 US/CM | 3.420 | -13.40 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162003 | 18/04/2006 | 620521 | 7582801 | 55 | -21.85 | 148.17 | 36.00 | 40.00 | | 1.480 | -13.34 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162002 | 18/04/2006 | 620597 | 7582672 | 55 | -21.86 | 148.17 | 38.00 | 42.00 | COND 2940 | 4.020 | -12.70 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162038 | 18/04/2006 | 620562 | 7582547 | 55 | -21.86 | 148.17 | 13.00 | 17.00 | COND 1693 | 0.040 | -12.04 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 141950 | 11/12/2011 | 608854 | 7570954 | 55 | -21.96 | 148.05 | 19.00 | 0.00 | | 0.040 | -11.00 | 11/12/2011 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162037 | 18/04/2006 | 620481 | 7582701 | 55 | -21.86 | 148.17 | 14.00 | 14.80 | COND 2100 | 0.040 | -10.20 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162368 | 11/02/2015 | 652819 | 7592303 | 55 | -21.77 | 148.48 | 12.00 | 15.10 | POTABLE | 0.020 | -10.00 | 11/02/2015 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162036 | 18/04/2006 | 620411 | 7582854 | 55 | -21.85 | 148.17 | 14.00 | 14.50 | COND 1187 | 0.010 | -9.56 | 18/04/2006 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 162338 | 11/11/2014 | 632651 | 7635777 | 55 | -21.38 | 148.28 | 18.00 | 0.00 | BRACKISH | 0.400 | -9.20 | 11/11/2014 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 141944 | 28/11/2011 | 611156 | 7567228 | 55 | -22.00 | 148.08 | 7.90 | 0.00 | SALTY | 0.000 | -7.90 | 28/11/2011 | FORT COOPER COAL MEASURES | FORT COOPER COAL MEASURES | | |
| 13040180 | 7/12/1970 | 667759 | 7516513 | 55 | -22.45 | 148.63 | 24.00 | 30.00 | 6000 US/CM | 0.000 | -17.20 | 7/12/1970 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 13040183 | 29/03/1971 | 668911 | 7514985 | 55 | -22.46 | 148.64 | 15.70 | 19.80 | | 0.000 | -15.72 | 23/09/1971 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 13040181 | 4/05/1971 | 667995 | 7516067 | 55 | -22.45 | 148.63 | 14.90 | 15.80 | 726 US/CM | 0.000 | -15.12 | 4/05/1971 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 97183 | 15/06/1996 | 657419 | 7522279 | 55 | -22.40 | 148.53 | 14.02 | 18.29 | GOOD | 0.510 | -14.78 | 15/06/1996 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 97182 | 14/06/1996 | 657151 | 7522448 | 55 | -22.40 | 148.53 | 14.02 | 18.29 | GOOD | 0.510 | -14.78 | 14/06/1996 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | Duplicated borehole entry and SWL (over 2 consecutive days) | N |
| 103016 | 18/12/1996 | 678043 | 7519449 | 55 | -22.42 | 148.73 | 13.41 | 18.90 | POTABLE | 1.600 | -14.60 | 8/12/1996 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 13040184 | 20/04/1971 | 669488 | 7514387 | 55 | -22.47 | 148.65 | 18.00 | 19.80 | 36800 US/CM | 0.000 | -14.42 | 20/04/1971 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 97185 | 12/06/1996 | 658897 | 7519944 | 55 | -22.42 | 148.54 | 14.63 | 17.68 | GOOD | 2.530 | -14.33 | 12/06/1996 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 141959 | 26/09/2011 | 600191 | 7581129 | 55 | -21.87 | 147.97 | 12.00 | 0.00 | SALTY | 0.130 | -13.80 | 26/09/2011 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 97184 | 25/06/1996 | 658710 | 7520443 | 55 | -22.41 | 148.54 | 13.41 | 18.29 | GOOD | 2.600 | -13.79 | 25/06/1996 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 97181 | 22/06/1996 | 656434 | 7523988 | 55 | -22.38 | 148.52 | 14.33 | 18.29 | GOOD | 12.000 | -13.41 | 22/06/1996 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 44164 | 23/02/1974 | 647938 | 7540971 | 55 | -22.23 | 148.44 | 27.10 | 28.10 | | 4.500 | -13.10 | 23/02/1974 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 141942 | 13/12/2011 | 607531 | 7570131 | 55 | -21.97 | 148.04 | 13.00 | 0.00 | | 0.000 | -13.00 | 13/12/2011 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 38319 | 11/07/1973 | 683805 | 7519029 | 55 | -22.43 | 148.79 | 9.00 | 36.00 | 31000 US/CM | 0.010 | -12.20 | 11/07/1992 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 97180 | 11/06/1996 | 654694 | 7527196 | 55 | -22.35 | 148.50 | 12.19 | 15.85 | GOOD | 0.760 | -12.19 | 11/06/1996 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 141047 | 29/04/2006 | 600220 | 7581503 | 55 | -21.87 | 147.97 | 12.00 | 19.00 | | 0.000 | -11.93 | 29/04/2006 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 44161 | 18/12/1973 | 647509 | 7540289 | 55 | -22.24 | 148.43 | 23.50 | 25.90 | COND 3700 | 8.800 | -11.90 | 18/12/1973 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 47010 | 23/01/1979 | 683412 | 7521222 | 55 | -22.41 | 148.78 | 17.00 | 21.00 | 750 US/CM | 3.000 | -11.10 | 23/01/1979 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 141961 | 8/10/2011 | 599339 | 7581569 | 55 | -21.87 | 147.96 | 15.00 | 0.00 | SALTY | 0.130 | -10.80 | 8/10/2011 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 141787 | 29/04/2006 | 605120 | 7592687 | 55 | -21.77 | 148.02 | 13.00 | 15.00 | NOT TESTED | 0.010 | -10.48 | 29/04/2006 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 141957 | 25/09/2011 | 600529 | 7580876 | 55 | -21.87 | 147.97 | 12.00 | 0.00 | SALTY | 0.130 | -10.00 | 25/09/2011 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 162144 | 12/08/2012 | 615206 | 7563211 | 55 | -22.03 | 148.12 | 10.50 | 16.50 | COND 1770 | 0.080 | -9.60 | 12/08/2012 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 141943 | 14/12/2011 | 606903 | 7570002 | 55 | -21.97 | 148.04 | 9.50 | 0.00 | | 0.000 | -9.50 | 14/12/2011 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |

| RN | DRILLED_DA | EASTING | NORTHING | ZONE | GIS_LAT | GIS_LNG | TOP | BOTTOM | QUALITY | YIELD | SWL | RDATE | FORM_DESC | Aquifer | Comment | Use in summary statistics ? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 136090 | 15/12/2002 | 647570 | 7540125 | 55 | -22.24 | 148.43 | 24.38 | 27.43 | 690 | 0.440 | -1.83 | 15/12/2002 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | | |
| 67216 | 18/06/1996 | 655364 | 7526286 | 55 | -22.36 | 148.51 | 0.00 | 4.57 | GOOD | 0.500 | -1.80 | 18/06/1984 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | Located about 200m from Isaac River. Nearby wells with similar construction indicate water levels of 12-13m | |
| 67217 | 1/10/1984 | 656764 | 7522670 | 55 | -22.39 | 148.52 | 0.00 | 3.30 | GOOD | 0.800 | -0.50 | 12/12/1986 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | Shallow level and borehole total depth. Located south of Project area and inconsistent SWLs with surrounding alluvium boreholes which indicate SWLs between 12-14mbgl | |
| 67218 | 1/10/1984 | 658629 | 7521429 | 55 | -22.41 | 148.54 | 0.00 | 3.30 | | 0.800 | -0.50 | 11/12/1986 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | Shallow level and borehole total depth. Located south of Project area and inconsistent SWLs with surrounding alluvium boreholes which indicate SWLs between 12-14mbgl | |
| 67219 | 1/10/1984 | 659064 | 7519525 | 55 | -22.42 | 148.55 | 0.00 | 3.00 | REASONABLE | 0.800 | -0.50 | 12/12/1986 | ISAAC RIVER ALLUVIUM | ISAAC RIVER ALLUVIUM | Shallow level and borehole total depth. Located south of Project area and inconsistent SWLs with surrounding alluvium boreholes which indicate SWLs between 12-14mbgl | |
| 153234 | 13/09/2011 | 585089 | 7665060 | 55 | -21.11 | 147.82 | 92.00 | 95.00 | | 4.000 | -71.50 | 13/09/2011 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162167 | 15/04/2008 | 610730 | 7555327 | 55 | -22.10 | 148.07 | 87.10 | 93.10 | COND 1110 | 0.000 | -67.58 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162178 | 21/05/2008 | 613679 | 7548084 | 55 | -22.17 | 148.10 | 77.00 | 83.00 | | 0.000 | -41.56 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162168 | 17/05/2008 | 608929 | 7554114 | 55 | -22.11 | 148.06 | 115.00 | 118.00 | COND 13630 | 0.000 | -37.60 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162166 | 16/05/2008 | 608920 | 7556710 | 55 | -22.09 | 148.06 | 39.80 | 42.80 | COND 16570 | 0.000 | -31.76 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162170 | 19/05/2008 | 611129 | 7551675 | 55 | -22.14 | 148.08 | 78.00 | 83.00 | COND 1810 | 0.000 | -29.94 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162174 | 17/05/2008 | 611249 | 7549500 | 55 | -22.16 | 148.08 | 61.00 | 62.00 | COND 11380 | 0.000 | -27.05 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162137 | 17/07/2012 | 611503 | 7558187 | 55 | -22.08 | 148.08 | 115.00 | 127.00 | COND 8630 | 0.100 | -25.80 | 17/07/2012 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 141945 | 7/12/2011 | 604812 | 7569884 | 55 | -21.97 | 148.02 | 29.50 | 0.00 | | 0.130 | -24.60 | 7/12/2011 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162142 | 8/07/2012 | 611779 | 7562387 | 55 | -22.04 | 148.08 | 125.00 | 139.00 | COND 7550 | 0.020 | -23.70 | 19/08/2012 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162175 | 23/05/2008 | 614317 | 7548834 | 55 | -22.16 | 148.11 | 71.00 | 77.00 | COND 9790 | 0.000 | -19.68 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162172 | 18/05/2008 | 612441 | 7550671 | 55 | -22.15 | 148.09 | 41.00 | 44.00 | COND 3960 | 0.000 | -14.15 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 162163 | 13/05/2008 | 609752 | 7560149 | 55 | -22.06 | 148.06 | 83.00 | 85.00 | COND 15610 | 0.000 | -8.44 | 8/06/2008 | MORANBAH COAL MEASURES | MORANBAH COAL MEASURES | | |
| 158622 | 18/03/2014 | 652544 | 7488000 | 55 | -22.71 | 148.49 | 45.00 | 51.00 | FRESH-BRACKISH | 0.100 | -44.00 | 18/03/2014 | QUATERNARY - UNDEFINED | QUATERNARY - UNDEFINED | | |
| 162173 | 17/05/2008 | 611249 | 7549500 | 55 | -22.16 | 148.08 | 9.00 | 15.00 | COND 2130 | 0.000 | -14.05 | 8/06/2008 | QUATERNARY - UNDEFINED | QUATERNARY - UNDEFINED | | |
| 162171 | 18/05/2008 | 612441 | 7550671 | 55 | -22.15 | 148.09 | 9.00 | 15.00 | COND 440 | 0.000 | -13.49 | 8/06/2008 | QUATERNARY - UNDEFINED | QUATERNARY - UNDEFINED | | |
| 161240 | 16/09/2014 | 669406 | 7557364 | 55 | -22.08 | 148.64 | 13.00 | 0.00 | BRACKISH | 0.100 | -12.00 | 16/09/2014 | QUATERNARY - UNDEFINED | QUATERNARY - UNDEFINED | | |
| 162369 | 12/02/2015 | 641620 | 7593928 | 55 | -21.75 | 148.37 | 9.00 | 12.00 | POTABLE | 0.000 | -6.10 | 12/02/2015 | QUATERNARY - UNDEFINED | QUATERNARY - UNDEFINED | | |
| 162370 | 14/02/2015 | 639787 | 7598071 | 55 | -21.72 | 148.35 | 4.00 | 0.00 | POTABLE | 0.000 | -4.00 | 14/02/2015 | QUATERNARY - UNDEFINED | QUATERNARY - UNDEFINED | | |
| 162349 | 8/11/2014 | 636535 | 7635795 | 55 | -21.37 | 148.32 | 159.00 | 166.00 | POTABLE | 0.000 | -159.00 | 8/11/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Not considered to be a reliable SWL - SWL matches exactly to the top of the screen | N |
| 162351 | 5/11/2014 | 636535 | 7635795 | 55 | -21.37 | 148.32 | 128.00 | 174.00 | BRACKISH | 0.060 | -128.00 | 5/11/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Not considered to be a reliable SWL - SWL matches exactly to the top of the screen | N |
| 153235 | 14/09/2011 | 595167 | 7646339 | 55 | -21.28 | 147.92 | 112.00 | 120.00 | | 0.100 | -55.80 | 14/09/2011 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 153238 | 18/09/2011 | 594512 | 7668243 | 55 | -21.08 | 147.91 | 33.00 | 52.00 | | 0.500 | -43.00 | 18/09/2011 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 141947 | 3/04/2012 | 620875 | 7595650 | 55 | -21.74 | 148.17 | 130.00 | 135.00 | BRACKISH | 0.700 | -42.00 | 3/04/2012 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 141170 | 7/03/2012 | 620826 | 7595643 | 55 | -21.74 | 148.17 | 128.00 | 132.00 | BRACKISH | 8.200 | -40.00 | 7/03/2012 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 141976 | 17/05/2012 | 632833 | 7558719 | 55 | -22.07 | 148.29 | 54.00 | 0.00 | BRACKISH | 0.500 | -35.00 | 17/05/2012 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 141978 | 14/05/2012 | 632416 | 7558583 | 55 | -22.07 | 148.28 | 84.00 | 0.00 | BRACKISH | 2.040 | -31.00 | 14/05/2012 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162185 | 26/10/2013 | 635149 | 7555403 | 55 | -22.10 | 148.31 | 120.00 | 138.00 | SALTY | 15.400 | -26.00 | 26/10/2013 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162000 | 18/04/2006 | 620779 | 7582851 | 55 | -21.85 | 148.17 | 119.50 | 0.00 | | 1.200 | -25.00 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Duplicated borehole entry and SWL | N |
| 162000 | 18/04/2006 | 620779 | 7582851 | 55 | -21.85 | 148.17 | 124.50 | 0.00 | | 1.410 | -25.00 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Duplicated borehole entry and SWL | N |
| 162000 | 18/04/2006 | 620779 | 7582851 | 55 | -21.85 | 148.17 | 112.00 | 0.00 | | 0.920 | -25.00 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162235 | 1/01/2004 | 629689 | 7559294 | 55 | -22.07 | 148.26 | 56.00 | 59.00 | | 0.000 | -24.42 | 20/07/2004 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162001 | 18/04/2006 | 620709 | 7582972 | 55 | -21.85 | 148.17 | 76.50 | 78.00 | | 10.400 | -24.39 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Duplicated borehole entry and SWL | N |
| 162001 | 18/04/2006 | 620709 | 7582972 | 55 | -21.85 | 148.17 | 102.00 | 113.00 | | 3.800 | -24.39 | 18/04/2003 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Duplicated borehole entry and SWL | N |
| 162001 | 18/04/2006 | 620709 | 7582972 | 55 | -21.85 | 148.17 | 115.00 | 117.00 | | 0.000 | -24.39 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Duplicated borehole entry and SWL | N |
| 162001 | 18/04/2006 | 620709 | 7582972 | 55 | -21.85 | 148.17 | 35.00 | 60.00 | | 1.200 | -24.39 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162234 | 1/01/2004 | 629690 | 7559289 | 55 | -22.07 | 148.26 | 38.30 | 44.00 | | 0.000 | -24.29 | 20/07/2004 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 141975 | 4/05/2012 | 632792 | 7558634 | 55 | -22.07 | 148.29 | 83.00 | 0.00 | | 0.000 | -23.29 | 4/05/2012 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162237 | | 629571 | 7556436 | 55 | -22.09 | 148.26 | 59.00 | 65.00 | | 0.000 | -21.87 | 22/07/2004 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162236 | 1/01/2004 | 629578 | 7556426 | 55 | -22.09 | 148.26 | 29.00 | 34.00 | | 0.000 | -21.85 | 21/07/2004 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162006 | 18/04/2006 | 620784 | 7582835 | 55 | -21.85 | 148.17 | 55.00 | 0.00 | COND 1174 | 0.010 | -21.73 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162007 | 18/04/2006 | 620708 | 7582978 | 55 | -21.85 | 148.17 | 90.00 | 99.00 | COND 1110 | 11.000 | -20.80 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | Duplicated borehole entry and SWL | N |
| 162007 | 18/04/2006 | 620708 | 7582978 | 55 | -21.85 | 148.17 | 45.00 | 55.00 | | 0.500 | -20.80 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162005 | 18/04/2006 | 620860 | 7582690 | 55 | -21.86 | 148.17 | 55.00 | 110.00 | COND 4740 | 13.910 | -19.63 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 63240 | | 598468 | 7637915 | 55 | -21.36 | 147.95 | 26.00 | 29.00 | | 9.000 | -19.60 | 8/09/1982 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 141653 | 2/11/2009 | 659045 | 7556157 | 55 | -22.09 | 148.54 | 34.00 | 76.00 | SALTY | 3.900 | -19.00 | 2/11/2009 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162035 | 18/04/2006 | 620678 | 7582528 | 55 | -21.86 | 148.17 | 49.00 | 50.00 | COND 2460 | 0.020 | -16.60 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |

| RN | DRILLED_DA | EASTING | NORTHING | ZONE | GIS_LAT | GIS_LNG | TOP | BOTTOM | QUALITY | YIELD | SWL | RDATE | FORM_DESC | Aquifer | Comment | Use in summary statistics ? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 162034 | 18/04/2006 | 620705 | 7582520 | 55 | -21.86 | 148.17 | 55.00 | 61.00 | COND 2360 | 0.430 | -16.57 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162009 | 18/04/2006 | 620370 | 7583003 | 55 | -21.85 | 148.16 | 17.00 | 20.00 | COND 1240 | 0.010 | -15.00 | 18/04/2006 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162010 | 18/04/2006 | 620520 | 7582806 | 55 | -21.85 | 148.17 | 17.00 | 31.00 | COND 2900 | 0.010 | -13.60 | 18/04/2005 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162350 | 3/11/2014 | 631621 | 7637688 | 55 | -21.36 | 148.27 | 22.00 | 23.00 | BRACKISH | 1.600 | -12.53 | 3/11/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 153237 | 17/09/2011 | 593438 | 7663430 | 55 | -21.13 | 147.90 | 44.00 | 59.50 | | 0.800 | -11.20 | 17/09/2011 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162238 | 24/02/2014 | 644152 | 7595252 | 55 | -21.74 | 148.39 | 14.00 | 16.00 | COND 1060 | 0.100 | -10.44 | 24/02/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162243 | 1/03/2014 | 640901 | 7597858 | 55 | -21.72 | 148.36 | 127.00 | 133.00 | COND 5700 | 3.500 | -9.50 | 1/03/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162216 | 3/12/2013 | 647192 | 7616082 | 55 | -21.55 | 148.42 | 24.00 | 31.00 | COND 2354 | 0.500 | -9.23 | 3/12/2013 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 153228 | 10/12/2013 | 608396 | 7650987 | 55 | -21.24 | 148.04 | 36.00 | 42.00 | SALTY | 0.200 | -9.00 | 10/12/2013 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 153244 | 13/12/2013 | 599460 | 7660644 | 55 | -21.15 | 147.96 | 39.00 | 0.00 | SALTY | 0.200 | -8.00 | 13/12/2013 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162239 | 25/02/2014 | 642089 | 7596835 | 55 | -21.73 | 148.37 | 12.00 | 0.00 | COND 910 | 0.460 | -7.47 | 25/02/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162217 | 3/12/2013 | 647306 | 7616184 | 55 | -21.55 | 148.42 | 29.00 | 35.00 | COND 2450 | 0.210 | -4.60 | 3/12/2013 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162242 | 27/02/2014 | 640979 | 7597468 | 55 | -21.72 | 148.36 | 6.25 | 8.50 | COND 600 | 0.130 | -1.75 | 27/02/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 162241 | 26/02/2014 | 640975 | 7597479 | 55 | -21.72 | 148.36 | 12.50 | 16.00 | COND 1460 | 0.040 | -1.65 | 26/02/2014 | RANGAL COAL MEASURES | RANGAL COAL MEASURES | | |
| 141947 | 3/04/2012 | 620875 | 7595650 | 55 | -21.74 | 148.17 | 61.00 | 69.00 | BRACKISH | 0.800 | -46.00 | 3/04/2012 | REWAN FORMATION | REWAN GROUP | | |
| 141170 | 7/03/2012 | 620826 | 7595643 | 55 | -21.74 | 148.17 | 56.00 | 0.00 | BRACKISH | 1.800 | -44.00 | 7/03/2012 | REWAN FORMATION | REWAN GROUP | | |
| 105427 | 22/04/2004 | 629841 | 7570637 | 55 | -21.96 | 148.26 | 0.00 | 100.00 | | 3.780 | -33.50 | 26/04/2004 | REWAN GROUP | REWAN GROUP | | |
| 162042 | 4/07/2005 | 621025 | 7580332 | 55 | -21.88 | 148.17 | 83.00 | 0.00 | | 0.170 | -29.00 | 4/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141313 | 2/07/2005 | 623736 | 7577830 | 55 | -21.90 | 148.20 | 35.00 | 0.00 | COND 1690 | 1.280 | -23.80 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141988 | 2/07/2005 | 622551 | 7577806 | 55 | -21.90 | 148.19 | 43.00 | 0.00 | BRACKISH | 0.450 | -17.36 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 81909 | 17/12/1994 | 620090 | 7573318 | 55 | -21.94 | 148.16 | 24.93 | 0.00 | POTABLE | 1.130 | -17.20 | 16/12/1994 | REWAN GROUP | REWAN GROUP | Duplicated borehole entry and SWL | N |
| 81909 | 17/12/1994 | 620090 | 7573318 | 55 | -21.94 | 148.16 | 40.93 | 0.00 | POTABLE | 4.450 | -17.20 | 17/12/1994 | REWAN GROUP | REWAN GROUP | Duplicated borehole entry and SWL | N |
| 81909 | 17/12/1994 | 620090 | 7573318 | 55 | -21.94 | 148.16 | 60.00 | 0.00 | POTABLE | 5.270 | -17.20 | 17/12/1994 | REWAN GROUP | REWAN GROUP | | |
| 141989 | 2/07/2005 | 622597 | 7577809 | 55 | -21.90 | 148.19 | 19.00 | 0.00 | POTABLE | 6.200 | -16.42 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141985 | 2/07/2005 | 623273 | 7577826 | 55 | -21.90 | 148.19 | 115.00 | 0.00 | SALINE | 1.340 | -16.00 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141990 | 2/07/2005 | 622646 | 7577812 | 55 | -21.90 | 148.19 | 18.00 | 0.00 | POTABLE | 3.350 | -15.29 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141982 | 2/07/2005 | 622980 | 7577822 | 55 | -21.90 | 148.19 | 59.00 | 0.00 | SALINE | 39.410 | -15.00 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141984 | 30/06/2005 | 623169 | 7577827 | 55 | -21.90 | 148.19 | 62.00 | 0.00 | SALINE | 3.490 | -14.00 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141984 | 30/06/2005 | 623169 | 7577827 | 55 | -21.90 | 148.19 | 76.00 | 0.00 | SALINE | 3.490 | -14.00 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141991 | 2/07/2005 | 622691 | 7577816 | 55 | -21.90 | 148.19 | 17.00 | 0.00 | BRACKISH | 0.300 | -12.64 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141983 | 2/07/2005 | 623080 | 7577824 | 55 | -21.90 | 148.19 | 64.00 | 0.00 | SALINE | 2.530 | -12.12 | 2/07/2005 | REWAN GROUP | REWAN GROUP | Duplicated borehole entry and SWL | N |
| 141983 | 2/07/2005 | 623080 | 7577824 | 55 | -21.90 | 148.19 | 54.00 | 0.00 | SALINE | 2.530 | -12.12 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141992 | 2/07/2005 | 622744 | 7577820 | 55 | -21.90 | 148.19 | 80.00 | 0.00 | SALINE | 3.400 | -12.00 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141993 | 2/07/2005 | 622846 | 7577824 | 55 | -21.90 | 148.19 | 40.00 | 0.00 | SALINE | 2.200 | -11.48 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141292 | 2/07/2005 | 622798 | 7577839 | 55 | -21.90 | 148.19 | 52.00 | 0.00 | COND 8350 | 4.400 | -10.99 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 141342 | 2/07/2005 | 621885 | 7577758 | 55 | -21.90 | 148.18 | 25.00 | 0.00 | SALINE | 0.100 | -10.68 | 2/07/2005 | REWAN GROUP | REWAN GROUP | | |
| 162255 | 6/06/2008 | 619280 | 7590379 | 55 | -21.79 | 148.15 | 10.50 | 12.00 | | 0.000 | -4.24 | 9/07/2008 | REWAN FORMATION | REWAN GROUP | | |
| 162256 | 4/06/2008 | 623500 | 7591382 | 55 | -21.78 | 148.19 | 2.00 | 4.88 | | 0.000 | -2.74 | 9/07/2008 | TERTIARY - UNDEFINED | REWAN GROUP | Inferred Rewan based on outcrop geology mapping | |
| 151344 | 21/04/2006 | 675288 | 7519813 | 55 | -22.42 | 148.70 | 15.20 | 23.00 | POTABLE | 1.260 | -15.20 | 21/04/2006 | SAND | SAND | | |
| 141956 | 24/09/2011 | 600519 | 7580877 | 55 | -21.87 | 147.97 | 35.00 | 0.00 | SALTY | 0.130 | -35.00 | 24/09/2011 | SUTTOR FORMATION | SUTTOR FORMATION | | |
| 141963 | 10/10/2011 | 599982 | 7581299 | 55 | -21.87 | 147.97 | 17.40 | 0.00 | POTABLE | 0.130 | -17.40 | 10/10/2011 | SUTTOR FORMATION | SUTTOR FORMATION | | |
| 141960 | 28/09/2011 | 599340 | 7581570 | 55 | -21.87 | 147.96 | 30.00 | 0.00 | SALTY | 0.130 | -11.50 | 28/09/2011 | SUTTOR FORMATION | SUTTOR FORMATION | | |
| 141967 | 12/10/2011 | 597151 | 7580326 | 55 | -21.88 | 147.94 | 8.60 | 0.00 | | 0.000 | -8.60 | 12/10/2011 | SUTTOR FORMATION | SUTTOR FORMATION | | |
| 153230 | 9/09/2011 | 587122 | 7656990 | 55 | -21.19 | 147.84 | 61.00 | 69.00 | COND 2020 | 8.500 | -61.00 | 9/09/2011 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 153232 | 11/09/2011 | 587279 | 7643867 | 55 | -21.30 | 147.84 | 55.00 | 59.00 | | 0.700 | -43.30 | 11/09/2011 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 63407 | | 593148 | 7621109 | 55 | -21.51 | 147.90 | 42.00 | 56.00 | | 2.500 | -40.20 | 3/12/1981 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 105677 | 13/06/2005 | 622136 | 7573306 | 55 | -21.94 | 148.18 | 35.00 | 67.00 | 1055 US/CM | 7.290 | -25.14 | 13/06/2005 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 43063 | 1/02/1973 | 672366 | 7487004 | 55 | -22.72 | 148.68 | 24.00 | 26.00 | 890 US/CM | 1.500 | -24.40 | 1/02/1973 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 88528 | 5/02/1992 | 664087 | 7516922 | 55 | -22.45 | 148.59 | 30.00 | 32.40 | BRACKISH | 1.200 | -24.00 | 5/02/1992 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 153231 | 10/09/2011 | 587115 | 7656973 | 55 | -21.19 | 147.84 | 35.00 | 52.00 | | 1.500 | -22.80 | 10/09/2011 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 131000 | 27/11/2005 | 621880 | 7578276 | 55 | -21.90 | 148.18 | 36.00 | 70.00 | 1866 US/CM | 6.200 | -21.00 | 18/11/2005 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 88527 | 1/02/1992 | 665212 | 7516134 | 55 | -22.45 | 148.61 | 32.30 | 34.40 | BRACKISH | 1.000 | -17.00 | 1/02/1992 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 131003 | 18/11/2005 | 621880 | 7578276 | 55 | -21.92 | 148.18 | 53.00 | 61.00 | | 0.400 | -16.00 | 18/11/2005 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | Duplicated borehole entry and SWL | N |
| 131003 | 18/11/2005 | 621880 | 7578276 | 55 | -21.92 | 148.18 | 49.00 | 53.00 | 1362 US/CM | 3.200 | -16.00 | 18/11/2005 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 105676 | 19/06/2005 | 622312 | 7577795 | 55 | -21.90 | 148.18 | 19.00 | 41.16 | 1243 US/CM | 6.000 | -13.92 | 19/06/2005 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 131001 | 18/11/2005 | 622201 | 7577289 | 55 | -21.90 | 148.18 | 24.00 | 34.50 | 1732 US/CM | 11.400 | -13.00 | 18/11/2005 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 85100 | 5/09/1987 | 607014 | 7623268 | 55 | -21.49 | 148.03 | 18.30 | 21.30 | | 1.400 | -11.10 | 5/09/1987 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | |
| 162255 | 6/06/2008 | 619280 | 7590379 | 55 | -21.79 | 148.15 | 8.72 | 10.00 | | 0.000 | -4.24 | 9/07/2008 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | N |
| 162255 | 6/06/2008 | 619280 | 7590379 | 55 | -21.79 | 148.15 | 10.00 | 10.50 | | 0.000 | -4.24 | 9/07/2008 | TERTIARY - UNDEFINED | TERTIARY - UNDEFINED | | N |

Kavita Singh
Groundwater Management Lead
Arrow Energy Pty Ltd
GPO Box 5262
Brisbane QLD 4001

8 November 2016

Dear Kavita

**RE: Peer review of GDE rationalisation to support Condition 21a(iii) for the Arrow Energy Bowen Gas Project**

On 27th October 2014 the Australian Government Minister for the Environment approved the Arrow Bowen Gas Project (EPBC 2012/6377) subject to conditions. Conditions 21(a) to 21(h) require that the proponent submits a Groundwater Monitoring and Management Plan (GMMP) for the approval of the Minister.

Condition 22 specifies that "*The GMMP, including any revised plans, must be peer reviewed by a suitably qualified water resources expert/s approved by the Minister in writing.*"

As the *suitably qualified water resources expert* approved by the Minister for the Environment on 7 July 2015, I have completed a review of work and documentation relating to Condition 21a(iii), as presented in the following Memorandum:

> Coffey Environments (2016). **Bowen Gas Project GMMP – Rationalisation of mapped and known GDEs**. Dated 6th October 2016, document reference ENAUBRIS107043AE-M06_v3.

The Memo details existing information and observations in support of Condition 21a(iii) which requires: "*The GMMP must contain details of a groundwater monitoring network for the measurement of impacts on water resources associated directly or indirectly with the action, including the ability to monitor potential impacts on groundwater dependent ecosystems, including spring based and non-spring based ecosystems, and provide for the early detection of impacts*"

The peer review included:

- Field site reconnaissance to mapped GDEs in the Bowen Basin; and
- Review of the findings presented in report Coffey Environments (2016).

Based on my review, I find that the information and analysis presented in the abovementioned Memorandum forms a sound technical basis on which to address the specific requirements of Condition 21a(iii) and I endorse the findings.

Sincerely,

Dr. Glenn Harrington
Director & Principal Hydrogeologist

# APPENDIX E BASELINE GROUNDWATER MONITORING ASSESSMENT

## Memorandum

| | |
|---|---|
| **Recipient** | Arrow Energy Pty Ltd |
| **Memo date** | 14/03/2019 |
| **Author** | Coffey Services Australia Pty Ltd |
| **Project number** | 754-MELEN213220 |
| **Memo Subject** | Bowen Gas Project Groundwater Monitoring and Management Plan (GMMP) Baseline Groundwater Monitoring Assessment |

# 1. Introduction

The Bowen Gas Project (BGP) EPBC Approval Conditions 21 to 23 (EPBC 2012/6377) set out the requirements for the development of a Groundwater Management and Monitoring Plan (GMMP).

As part of this, a groundwater monitoring assessment has been conducted to enable the background groundwater level and quality of key aquifers, and their trends, to be characterised. This provides a baseline against which any potential impacts from CSG development can be referenced.

In addition, the data has informed the original and 2018-update of the numerical groundwater model that underpins the GMMP.

The baseline assessment relies on monitoring data from the following sources:

- existing and publicly available monitoring data as supplied and interpreted in the BGP EIS (URS 2012) and SREIS (Coffey 2014);
- ongoing monitoring data collected from the UWIR Water Monitoring Strategy (WMS) groundwater monitoring network located in the MGP area (Arrow Energy 2016 & 2018);
- groundwater monitoring data collected from baseline water bore assessments conducted as part of the UWIR; and
- ongoing groundwater level and quality monitoring data collected from BGP GMMP monitoring sites MB2 (RH60) and MB3 (RH51) in the Red Hill Central development area

# 2. Baseline data

A description of the range of data and information sources that have informed the GMMP groundwater baseline assessment are listed in Table 2-1.

Table 2-1 Description of baseline monitoring data

| Data / information source | Description |
|---|---|
| BGP EIS (URS 2012) | Available groundwater level data was compiled and analysed from the Queensland Government groundwater database, Arrow groundwater monitoring program, and private landholder bores. In total, within the Project area, static groundwater level data were available for a total of 64 bores completed within the unconfined Quaternary age and Tertiary age aquifers and the confined Triassic age and Permian age aquifers. Longer term groundwater level monitoring data was available for 6 bores in the Project area.<br>Groundwater quality data was also complied and analysed, however the information and interpretation is considered superseded by the BGP SREIS. |
| BGP SREIS (Coffey 2014) | The SREIS updated the characterisation of groundwater quality in the Project area on the basis of two studies; Ausenco-Norwest (2013) and WorleyParsons (2012). |
| UWIR WMS groundwater monitoring network – MGP area (Arrow 2016 & 2018) | In accordance with the WMS in the approved 2013 and 2016 Bowen UWIRs, a regional aquifer groundwater monitoring network, consisting of 7 deep and 9 shallow bores, in the MGP area was developed by Arrow and is subject to ongoing groundwater level and quality monitoring. The purpose of this monitoring network is to establish baseline groundwater level and quality data and monitor the future effects of CSG production on the groundwater system. The shallow monitoring bores are manually gauged while the deeper monitoring bores are subject to continuous instrumented water level monitoring.<br>Details concerning the groundwater monitoring network are presented in Table 2-2, while the spatial distribution of the monitoring bores is illustrated in Figure 2-1, along with the locations of the active CSG production wells present in the MGP area. |
| UWIR baseline water bore assessments | To date Arrow has undertaken baseline water bore assessments on 167 bores within the BGP, as a requirement of the Queensland Water Act (2000). In total, 99 water supply bores have been subject to groundwater level and quality baseline assessments by Arrow, since 2012. The water supply bores are screened across a range of aquifers (see Table 2-3) and are distributed across the Project area, with a focus on the Red Hill Central development area where CSG development is imminent (Figure 2-2).<br>All the water supply bores listed in Table 2-3 have been monitored once for groundwater level and/or groundwater quality, with the exception of bore AEN1010 which has been monitored for groundwater level and quality on two occasions in 2012 and 2018. |
| BGP GMMP monitoring network – Red Hill Central development area | BGP GMMP monitoring sites MB2 and MB3 were re-purposed from existing CSG appraisal/production testing wells RH60 and RH51, respectively. Both sites (Figure 2-1) are now instrumented and function as monitoring bores for the MCM in the Red Hill Central development area. Groundwater level monitoring data is available for these bores since mid-February 2019.<br>Groundwater quality monitoring data is also available for these two sites from |

| Data / information source | Description |
|---|---|
| | September 2016 (RH60, now MB2) and May 2017 (RH51, now MB3), prior to the sites being re-purposed for monitoring. |

Key details of the UWIR WMS groundwater monitoring network in the MGP area are presented in Table 2-2.

Table 2-2 UWIR WMS groundwater monitoring network – MGP area

| Bore ID | Classification | Total constructed depth (m) | Screen interval (m bgl) | Screened formation | Period of monitoring |
|---|---|---|---|---|---|
| M339W | Shallow | 41.00 | 35.0 – 41.0 | Weathered Tertiary Basalt | Manual and continuous 2012 to 2018 |
| M225W | Shallow | 34.00 | 23.0 – 34.0 | Weathered Tertiary Basalt | Manual and continuous 2012 to 2018 |
| M340W | Shallow | 27.30 | 19.3 – 27.3 | Weathered Tertiary Basalt | Manual and continuous 2012 to 2017 |
| M230W | Shallow | 32.00 | 29.0 – 32.0 | Weathered Tertiary Basalt | Manual and continuous 2012 to 2018 |
| M250W | Shallow | 56.50 | 44.5 – 56.5 | Sand (Tertiary alluvium) | Manual and continuous 2012 to 2018 |
| M224W | Shallow | 17.50 | 6.5 - 15.5 | Sand and clay (Quaternary Alluvium) | Manual and continuous 2012 to 2018 |
| M222W | Shallow | 30.20 | 20.0 – 26.0 | Weathered Fort Cooper Coal | Manual and continuous 2012 to 2018 |
| AN020F | Shallow | 77.00 | 70.0 – 72.0 | Rewan Formation | Manual and continuous 2016 to 2018 |
| AN021F | Shallow | 27.00 | 20.0 – 22.0 | Tertiary Formation | Dry 2012 to 2016 |
| M313W | Deep | 532.4 | 313.0 – 316.5<br>507.0 – 510.0 | Moranbah Coal Measures (QA Seam)<br>Back Creek Group | Continuous 2014 to 2018 |
| M314W | Deep | 560.5 | 210.5 – 213.5<br>551.5 – 553.5 | Moranbah Coal Measures (QA Seam)<br>Back Creek Group | Continuous 2014 to 2018 |
| M324W | Deep | 240.0 | 163.0 – 166.0<br>187.0 – 190.0 | Fort Cooper Coal Measures<br>Moranbah Coal Measures (QA Seam) | Continuous 2014 to 2018 |

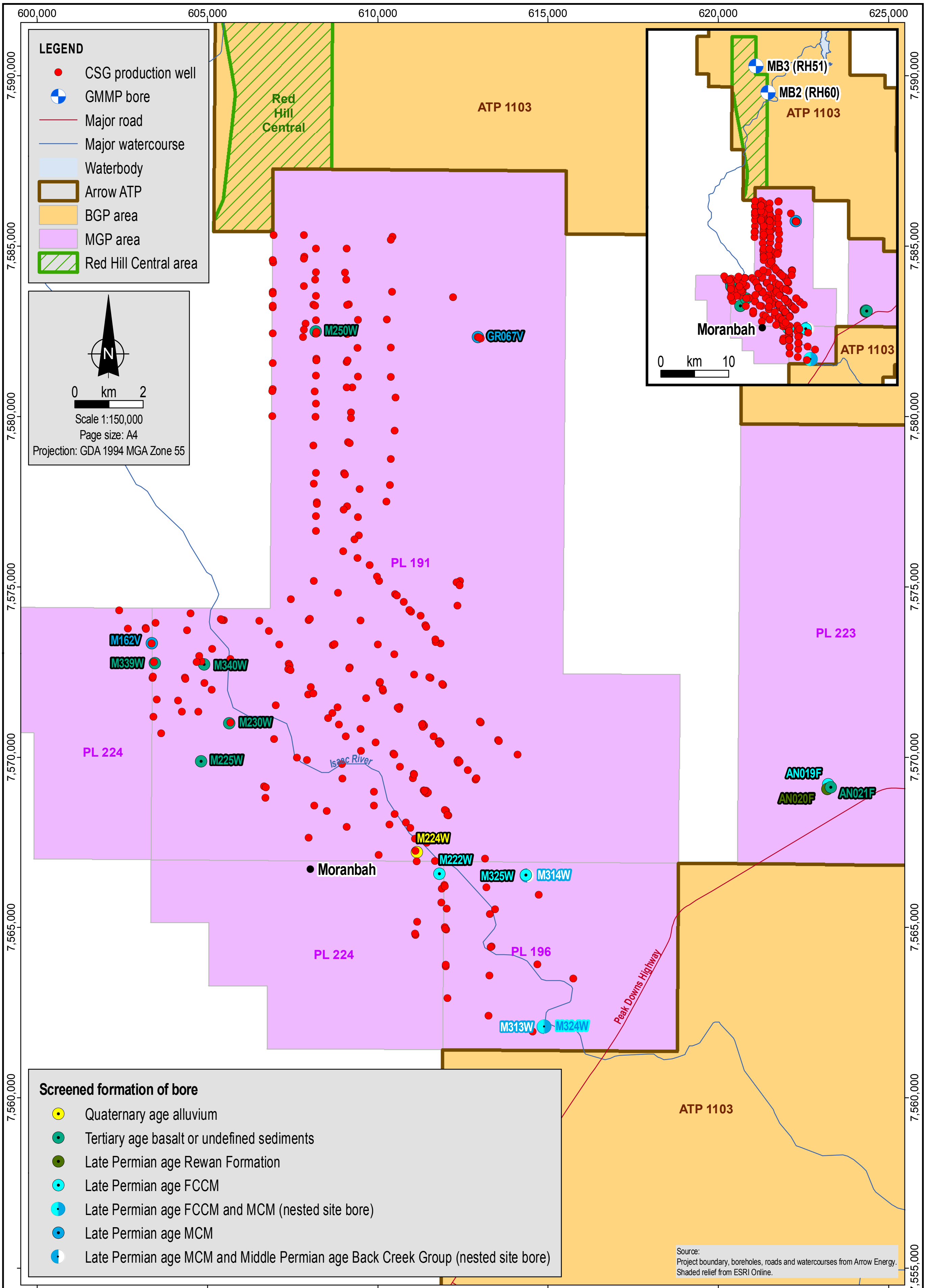
| Bore ID | Classification | Total constructed depth (m) | Screen interval (m bgl) | Screened formation | Period of monitoring |
|---|---|---|---|---|---|
| M325W | Deep | 202.3 | 180.5 – 182.0 | Fort Cooper Coal Measures | Continuous 2015 to 2018 |
| AN019F | Deep | 290.0 | 269.0 – 271.0 | Fort Cooper Coal Measures | Continuous 2015 to 2018 |
| M162V | Deep | 276.0 | 252.0 – 256.0 | Moranbah Coal Measures | Continuous 2015 to 2018 |
| GR067V | Deep | 610.9 | 543.2 – 610.9 | Moranbah Coal Measures | Continuous 2016 to 2018 |

**Note:**
*Bore AN020F commenced groundwater monitoring in 2016 as a replacement for AN021F.*

Key details of the UWIR baseline assessment water bores in the Project area are presented in Table 2-3.

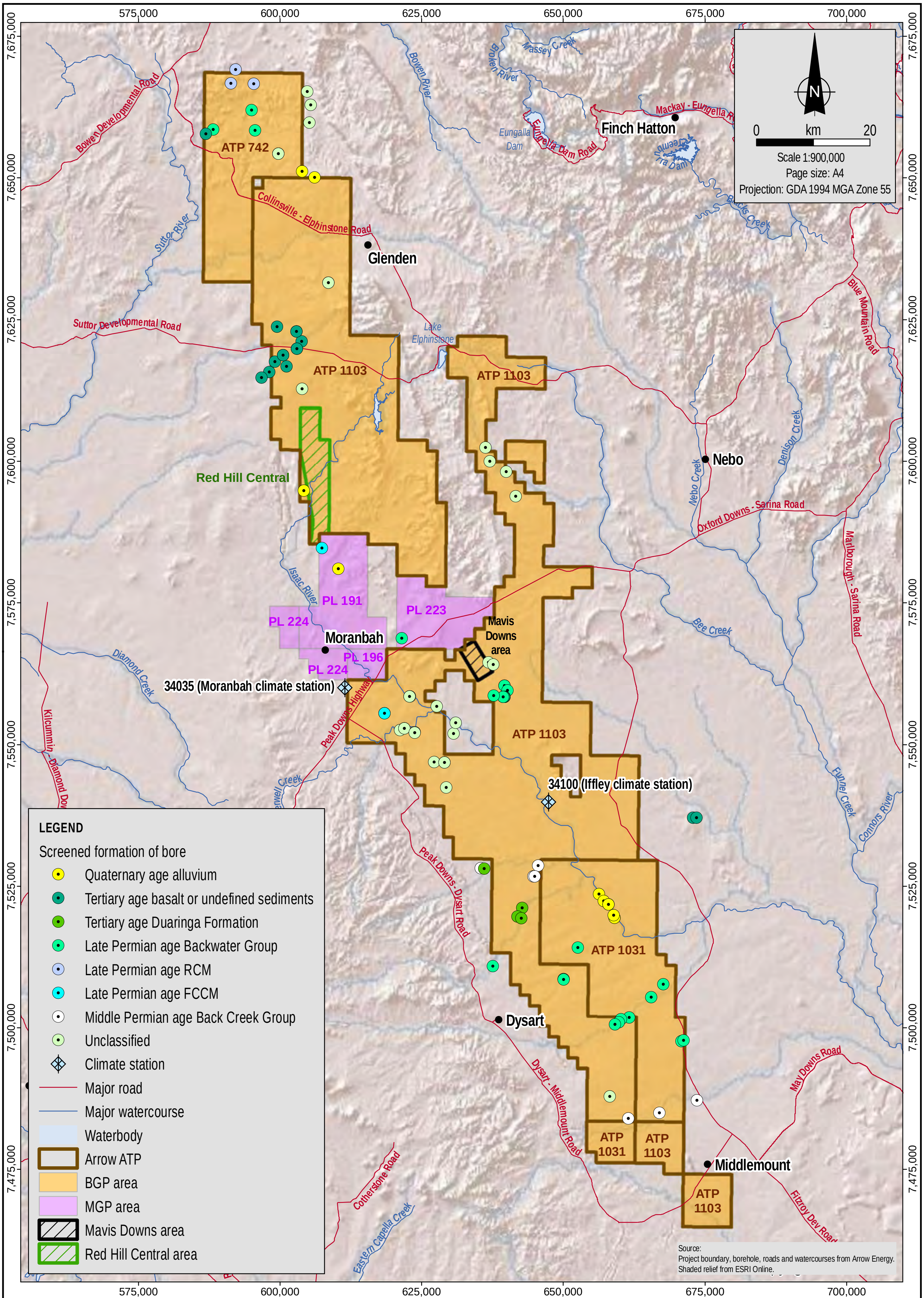
Table 2-3 Summary of UWIR baseline assessment water bores

| Assigned formation | Number of water supply bores monitored | Number of water bores subject to manual water level gauging | Number of water bores subject to groundwater quality sampling and field / laboratory analysis |
|---|---|---|---|
| Quaternary age alluvium | 11 | 11 | 9 |
| Tertiary age basalt or undefined sediments | 15 | 15 | 6 |
| Tertiary age Duaringa Formation | 4 | 2 | 3 |
| Late Permian age Backwater Group | 25 | 21 | 13 |
| Late Permian age FCCM | 3 | 3 | 2 |
| Late Permian age RCM | 3 | 3 | 1 |
| Middle Permian age Back Creek Group | 8 | 6 | 7 |
| Unclassified | 30 | 26 | 17 |
| **Totals** | **99** | **87** | **58** |




| coffey A TETRA TECH COMPANY | Date: 12.03.2019<br>Project: 754-MELEN213220<br>File Name: 213220_M04_F02.1_GIS | Arrow Energy<br>Bowen Gas Project | arrow energy go further | UWIR WMS groundwater monitoring network in the MGP and BGP GMMP current monitoring network | Figure No: 2-1 |
|---|---|---|---|---|---|

MXD Reference: 213220_M04_GIS019_v0_4




MXD Reference: 213220_M04_GIS020_v0_1

coffey
A TETRA TECH COMPANY

Date: 05.03.2019
Project: 754-MELEN213220
File Name: 213220_M04_F02.2_GIS

Arrow Energy

Bowen Gas Project

arrow energy
go further

Bowen Gas Project (BGP)
Distribution of the UWIR baseline assessment bores

Figure No: 2-2

# 3. Rainfall trends

Rainfall records are a useful tool for understanding the groundwater level response to recharge variation, for areas both near to and more distant from outcrop recharge areas.

A rainfall residual mass curve has been prepared from an amalgamation of two weather stations in the BGP area (Figure 2-2); Iffley (Station number 034100) and Moranbah (Station number 034035). The rainfall residual mass curves, presented in Figure 3-1, represent the cumulative sum of differences between the value at any time point and the average, and therefore how individual monthly rainfall compares to average monthly rainfall for the period. A rising slope of the curve indicates a period of excess rainfall compared to the long-term monthly average (e.g. wetter than average conditions). Conversely, where the slope of the curve is falling, a period of deficit rainfall compared to the long-term average has been recorded (e.g. drier than average conditions). Periods of both above and below average monthly rainfall have been observed since the commencement of monitoring at the weather station in 1998.

Historical rainfall patterns and trends, and their influence on groundwater levels in the BGP, have been assessed in the BGP EIS (URS 2012). For the period of record of interest in the current baseline assessment (2012 to 2018), a cyclic pattern is observed whereby from 2012 to the end of 2015, a period of generally below average monthly rainfall was recorded, followed by a period of mostly above average monthly rainfall until mid-2017. Recent records, between mid-2017 to the end of 2018, are characterised by generally below average monthly rainfall (Figure 3-1).

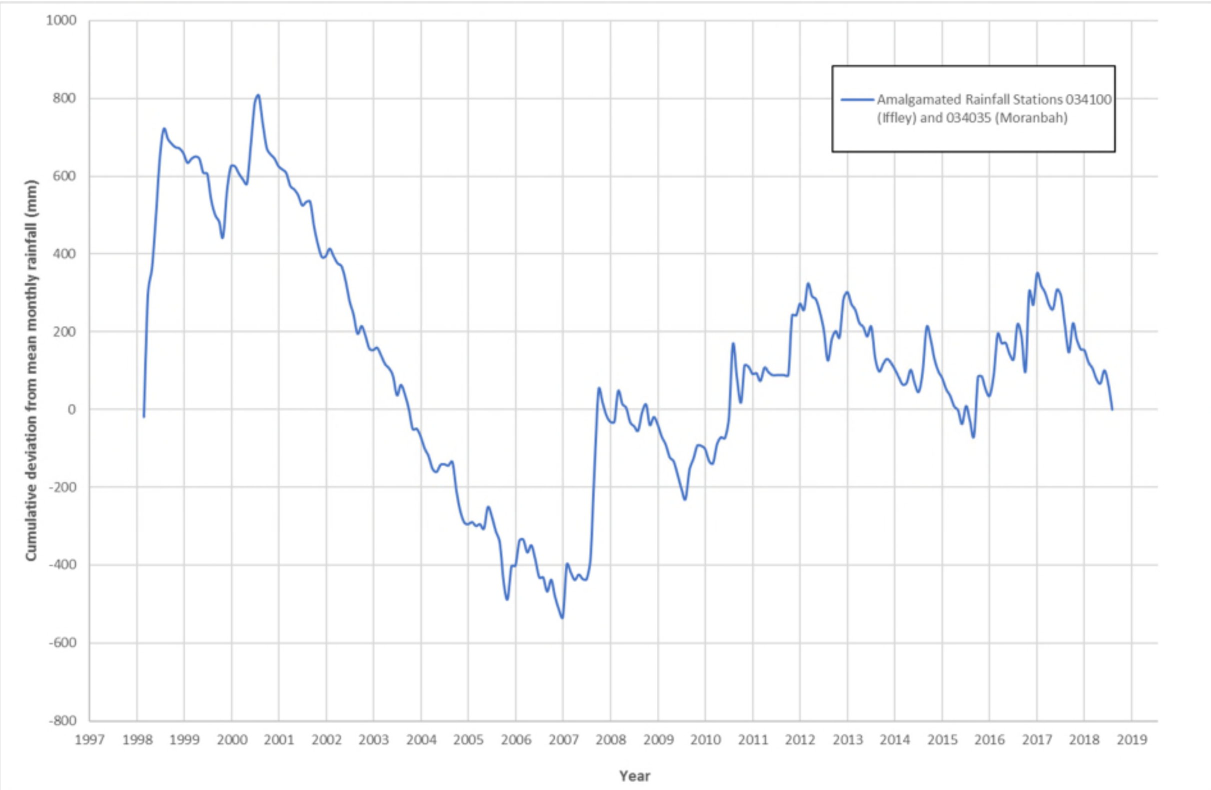



Figure 3-1 Rainfall residual mass curve (amalgamated), Iffley (034100) and Moranbah (034035)

# 4. Groundwater level trend assessment

## 4.1. BGP EIS (URS 2012)

*Quaternary age alluvium and Tertiary age basalt / sediments*

In the EIS study area, the shallow groundwater of the Quaternary age and Tertiary age aquifers was characterised as typically unconfined, with monitored bores in the northern Bowen Basin exhibiting a correlation with rainfall patterns. Challenges in data interpretation were noted due to the relatively short duration of the monitoring record and low gauging frequency. The key conclusions for these shallow aquifers were as follows (URS 2012):

- Decadal-scale variations in groundwater levels were linked to *el Niño* and *la Niña* years and possible groundwater consumptive use;
- Seasonal variations and sudden spikes in groundwater levels were unclear due to infrequent measurements; and
- Groundwater levels were observed to have been influenced by activities such as underground coal mining at limited locations.

Broadly, it was concluded that the regional watertable generally mimics surface topography albeit smoother and more 'subdued'. Most of the shallow bores are typically located in the most favourable groundwater resources, in basalt on the western side of the basin, and in alluvium and sediments on the eastern side of the Basin.

*Permian age Blackwater Group and Back Creek Group*

The EIS concludes that the interpretation of groundwater level trends in the Permian age aquifers is complicated by significant east-west differences in Permian strata depth, thickness of the Rewan Formation aquitard, and degree of confinement.

The Permian strata subcrop along the west and east margins of the Bowen Basin. As a result, groundwater levels in these areas are typically shallow, unconfined, and exposed to potential rainfall recharge.

In contrast, long-term groundwater level data for the confined Permian age aquifers exhibited only minor variations and no discernible rainfall response. The monitoring data for these bores were consistent with previous studies (e.g. WorleyParsons 2010) that the fractured rock aquifers of the Blackwater Group have little or no response to rainfall patterns.

## 4.2. Annual Report for the BGP UWIR (2018)

The Annual Report for the BGP UWIR (2018) presents and discusses the results derived from the UWIR WMS groundwater monitoring network in the MGP area (up to the end of 2017). The BGP GMMP baseline monitoring assessment (see below) relies on the same monitoring data, and for this reason, the outcomes of the 2018 annual report are not repeated here.

## 4.3. UWIR WMS groundwater monitoring network – MGP development area (Arrow 2016 & 2018)

Groundwater level data acquired from the UWIR WMS groundwater monitoring network has been assessed to characterise recent (2012 to 2018) groundwater level trends across the MGP area.

The groundwater level trends are described for each bore in Appendix A and the corresponding hydrographs are presented in Appendix B.

The following are key outcomes of the groundwater level trend assessment for those bores screening the shallower formations:

- Minor fluctuations in groundwater level were observed over the monitoring period.
- No clear correlation with rainfall was observed, with the exception of the Quaternary age alluvium bore M224W where the groundwater level exhibited a subdued correlation.
- Groundwater level trends varied spatially and temporally, between declining trends of 0.35 m/yr (M224W) and rising trends of 0.6 m/yr (M222W).
- Groundwater levels in the monitoring bores completed into the weathered Tertiary age basalt, located in close proximity to the Isaac River (M339W, M225W, M340W and M230W), exhibited no direct hydraulic connection to Isaac River levels. Due to the low frequency of the groundwater gauging data it is not possible to definitively determine the nature of the connectivity between the Quaternary age alluvium aquifer at bore MW224W with the Isaac River.
- There is no evidence that CSG production in the MGP area is currently influencing groundwater levels in the Quaternary age alluvium, weathered Tertiary age basalt, Tertiary age sediment and weathered Late Permian age Fort Cooper Coal Measures (FCCM) aquifers where these bores are installed.
- Groundwater withdrawal associated with underground coal mining has contributed to a groundwater level decline in bore M340W by > 6 m between mid-2015 to mid-2017. Data also indicates M230W has been impacted by underground mining, with a rapid decline of approximately 0.4 m observed in this bore between early 2017 and late 2018 which correlates with the mine plan operations in the vicinity of the bore.

For the deeper formation monitoring bores, groundwater levels in the Permian age MCM are shown to be responding to CSG and associated groundwater production activities in the MGP area. Nested monitoring bores also indicate a level of connectivity with the overlying FCCM and possibly the underlying Middle Permian Back Creek Group. The following were observations from the deeper formation monitoring network:

- No clear correlation of groundwater levels with rainfall was observed.
- Nested monitoring bores M313W and M324W, screening the MCM interval, have responded to CSG production and associated groundwater withdrawals in MCM well GM052V by drawdowns of 60 m and 6 m, respectively. Both wells exhibited a degree of groundwater level recovery following cessation of CSG production in well GM052V. The groundwater level response is less pronounced in M324W (compared with M313W) as the bore is screened at a comparatively shallower level in the MCM, being more removed from the deeper interval of CSG production.
- Nested monitoring bore M324W, screening the overlying FCCM interval, recorded a declining trend of 0.8 m/yr from mid-2016 to late 2017. Thereafter the groundwater level stabilised. The trend exhibited a delayed correlation with the groundwater level response in the underlying MCM interval being affected by CSG production, indicating a level of inter-connectivity between the two coal seam intervals. A similar trend was observed in monitoring bore AN019F, screening the FCCM, separated by 11 km.
- Nested monitoring bore M313W, screening the underlying Middle Permian age Back Creek Group, recorded a declining trend of 0.5 m/yr from late-2016 to late 2018. The trend exhibited a delayed correlation with the groundwater level response in the overlying MCM interval being affected by CSG production. Ongoing monitoring will indicate if the recovery recorded in the overlying MCM at the nested site is also observed in the Back Creek Group interval. This will assist to determining the nature of the connectivity with the overlying unit or whether the observed drawdown is due to another factor(s).
- Monitoring bore M162V exhibited a declining trend of 6.5 m/yr from late 2016 to late 2018 in response to CSG production from MCM well M134GMV, situated 470 m to the northwest.

- Nested monitoring bore M314W, screening the MCM, exhibited a declining groundwater level trend of 0.6 m/yr, in response to nearby CSG production in the MCM. Groundwater levels in the underlying Back Creek Group, at this location, also exhibited declining trends of 0.4 m/yr, possibly indicating a level of inter-connectivity between the two units.
- Groundwater levels are still stabilising in bore M325W, following bore construction and development, and bore GR067V, following its conversion from a CSG well in November 2015. Longer term monitoring is required in these bores to determine baseline conditions.

## 4.4. UWIR baseline water bore assessments

The water supply bores subject to the baseline assessment are typically gauged for water level on one occasion only. There are no temporal datasets from which to characterise groundwater level trends of these bores.

## 4.5. BGP GMMP monitoring network – Red Hill Central development area

BGP GMMP monitoring sites MB2 and MB3 were re-purposed from existing CSG appraisal/production testing wells RH60 and RH51, respectively. Both sites (Figure 2-1) are now instrumented and function as monitoring bores for the MCM in the Red Hill Central development area. Approximately one month of continuous groundwater level monitoring data is available for these bores, since mid-February 2019. Baseline groundwater level data is also available for these monitoring sites prior to CSG development in 2016.

The monitoring data demonstrated that over this one month monitoring period, the groundwater levels at both sites are still recovering and stabilising to pre-CSG development levels of approximately 270 m AHD, following being re-purposed from CSG appraisal/production wells.

Longer term groundwater level monitoring at MB2 and MB3 is required to characterise baseline groundwater levels (post-stabilisation) at these sites.

# 5. Groundwater quality data and trend assessment

## 5.1. BGP SREIS (Coffey 2014)

The assessment of groundwater quality in the BGP SREIS (Coffey 2014) relied on studies completed by Ausenco-Norwest (2013) and WorleyParsons (2012). The spatial distribution of bores with available groundwater quality information from these studies were focused to the east (primarily in the alluvium) and south-west of the Project area, while the majority of the Arrow-sourced data was associated with the MGP. The outcomes presented in the BGP SREIS are therefore considered to provide a regional overview of groundwater quality across geological formations, rather than a more local scale representation of the Project area.

In general, the BGP SREIS made similar conclusions as was presented in the BGP EIS, that is, that groundwater quality across the study area, within each aquifer assessed, was moderately to highly variable. There was no apparent correlation between salinity with respect to depth or location within the basin, within a geological formation, or between formations. Likewise, there appeared to be no trend in the spatial distribution of major-ion data and such data could not be used to definitively characterise an aquifer.

The monitoring data indicated that groundwater quality typically was slightly alkaline, with good quality (i.e. < 1,000 mg/L TDS) groundwater present in areas within the Quaternary age alluvium, Tertiary age basalt and Triassic age Clematis Sandstone aquifers. Groundwater quality is expected to be highly variable and good quality groundwater is likely to be limited in spatial extent. The water type typically varies from sodium-chloride type to sodium-bicarbonate type.

## 5.2. Annual Report for the BGP UWIR (2018)

The Annual Report for the BGP UWIR (2018) presents and discusses the results derived from the UWIR WMS groundwater monitoring network in the MGP area (up to the end of 2017). The BGP GMMP baseline monitoring assessment (see below) relies on the same monitoring data, and for this reason, the outcomes of the 2018 annual report are not repeated here.

## 5.3. UWIR WMS groundwater monitoring network – MGP area (Arrow 2016 & 2018)

Groundwater quality (field and laboratory) data acquired from the UWIR WMS groundwater monitoring network has been assessed to characterise recent (2012 to 2018) groundwater quality trends across the MGP area.

The groundwater level trends are described for each bore in Appendix A.

Groundwater quality, including minimum and maximum ranges and averages in salinity and pH and the dominant water type are summarised in Table 5-1 (in the context of the screened aquifer formation), for bores constituting the UWIR WMS groundwater monitoring network in the MGP area.

The groundwater quality data indicated the Quaternary age alluvium, Tertiary age basalt and Late Permian age MCM have considerable variability temporally and/or spatially. The broad groundwater quality characterisations for the bores in the network are as follows:

- Groundwater salinity in the Quaternary age alluvium varied, at one location (M224W), from brackish to saline and slightly acidic to slightly alkaline, with a dominant sodium-magnesium-chloride water type classification. The lower salinity conditions recorded in the bore correlated with of a period of flow in the Isaac River which may reflect “losing” conditions in the river, resulting in recharge to the more saline groundwater system.

- Groundwater salinity in the Tertiary age sediments varied, at one location (M250W), from fresh to brackish and slightly acidic to slightly alkaline, with a dominant sodium-chloride water type classification.

- Groundwater salinity in the Tertiary age basalts varied, spatially and temporally, from brackish to saline and slightly acidic to alkaline, with a dominant sodium-chloride water type classification.
- Groundwater salinity in the Triassic age Rewan Formation, at one location (AN020F), was brackish and slightly acidic to neutral, with a dominant sodium-calcium-chloride water type classification.
- Groundwater salinity in the Late Permian age weathered FCCM, at one location (M222W), was brackish and slightly acidic to slightly alkaline, with a dominant sodium-magnesium-chloride water type classification.
- Groundwater salinity in the Late Permian age FCCM and MCM varied, spatially and temporally, from fresh to brackish and slightly alkaline to alkaline, with a dominant sodium-chloride-bicarbonate water type to sodium-chloride water type classification.

In general, the results for the water quality parameters between different monitoring locations exhibited a high degree of variability which is likely attributable to the spatial heterogeneity and low permeability of the hydrogeological system. The groundwater quality review did not identify any temporal trends in groundwater quality across the bore network.

Table 5-1 Groundwater quality data summary for the UWIR WMS groundwater monitoring network – MGP area

| Assigned formation | Number of bores monitored | Number of groundwater quality samples | Salinity (TDS mg/L) | | | pH (units) | | | Dominant water type classification |
|---|---|---|---|---|---|---|---|---|---|
| | | | Minimum | Maximum | Average | Minimum | Maximum | Average | |
| Quaternary age alluvium | 1 | 20 | 2,360 | 27,000 | 16,211 | 5.7 | 7.5 | 6.4 | Na-Mg-Cl |
| Tertiary age sediment | 1 | 18 | 1,300 | 1,620 | 1,473 | 5.4 | 7.8 | 6.1 | Na-Cl |
| Tertiary age basalt | 4 | 66 | 3,000 | 29,000 | 13,555 | 6.3 | 8.5 | 7.0 | Na-Cl |
| Triassic age Rewan Formation | 1 | 3 | 6,210 | 7,210 | 6,857 | 6.2 | 7.4 | 6.6 | Na-Ca-Cl |
| Late Permian age weathered FCCM | 1 | 20 | 5,190 | 9,600 | 6,810 | 6.1 | 8.2 | 6.6 | Na-Mg-Cl |
| Late Permian age FCCM | 3 | 12 | 707 | 6,140 | 1,847 | 8.1 | 9.2 | 8.7 | Na-Cl-$HCO_3$ to Na-Cl |
| Late Permian age MCM | 5 | 19 | 1,160 | 9,810 | 4,851 | 7.7 | 9.4 | 8.4 | Na-Cl-$HCO_3$ to Na-Cl |

## 5.4. UWIR baseline water bore assessments

Groundwater quality, including minimum and maximum ranges and averages in salinity and pH and the dominant water type is summarised in Table 5-2 (in the context of the screened aquifer formation), for those water supply bores subject to UWIR baseline water bore assessments.

The groundwater quality data exhibited a high level of spatial variability across most of the formations assessed. A similar level of variability was observed in the UWIR WMS groundwater monitoring network in the MGP area (Section 4.3) and is likely attributable to the spatial heterogeneity and low permeability of the hydrogeological system.

Most of the formations subject to the baseline assessment were classed as either fresh to brackish, except the Quaternary age alluvium and Middle Permian age Back Creek Group, which could be classed as saline. The pH was recorded for the formations between neutral to slightly alkaline and the water type classification was variable but generally dominated by sodium and bicarbonate / chloride. Whilst variable, the characterisation of the different formations is not dissimilar to that identified for the UWIR WMS groundwater monitoring network in the MGP area.

## 5.5. BGP GMMP monitoring network – Red Hill Central development area

Groundwater quality data representing the MCM is available for RH60 (now MB2) in September 2016 and RH51 (now MB3) in May 2017, prior to the sites being re-purposed for pressure monitoring.

The groundwater quality data indicates the MCM at both sites is brackish from 4,860 mg/L TDS (at RH60) to 5,000 mg/L TDS (at RH51). The pH is alkaline varying between 8.0 (at RH60) to 8.7 (at RH51). The groundwater is classified as a Na-Cl water type at both sites. Future monitoring at MB1 (RH28/RH30) will assist in characterising background groundwater quality and any temporal trends in this area.

Table 5-2 Summary of groundwater quality data for the UWIR baseline assessment water bores

| Assigned formation | Number of water bores subject to groundwater sampling and field / laboratory analysis | Salinity (TDS mg/L) | | | pH (units) | | | Dominant water type classification |
|---|---|---|---|---|---|---|---|---|
| | | Minimum | Maximum | Average | Minimum | Maximum | Average | |
| Quaternary age alluvium | 9 | 265 | 13,200 | 1,883 | 7.0 | 8.5 | 7.5 | Na-Ca-Mg-$HCO_3$-Cl |
| Tertiary age basalt or undefined sediments | 6 | 730 | 1,340 | 1,118 | 8.3 | 8.7 | 8.6 | Na-Cl |
| Tertiary age Duaringa Formation | 3 | 728 | 5,060 | 2,249 | 7.0 | 7.7 | 7.5 | Na-$HCO_3$-Cl<br>Na-Mg-Cl<br>Na-Mg-$HCO_3$ |
| Late Permian age Backwater Group | 13 | 582 | 7,330 | 2,225 | 7.3 | 8.1 | 7.7 | Ca-Mg-Na-$HCO_3$-Cl<br>Na-Cl-$HCO_3$<br>Na-Mg-Cl-$HCO_3$<br>Na-Mg-$HCO_3$-Cl |
| Late Permian age FCCM | 2 | 947 | 2,370 | 1,832 | 6.9 | 8.1 | 7.7 | Na-Cl |
| Late Permian age RCM | 1 | 1,070 | 1,070 | 1,070 | 8.2 | 8.2 | 8.2 | Na-$HCO_3$-Cl |
| Middle Permian age Back Creek Group | 7 | 1,470 | 18,300 | 5,504 | 7.0 | 8.1 | 7.6 | Na-Mg-Cl |
| Unclassified | 17 | 304 | 5,790 | 2,164 | 7.2 | 8.6 | 8.3 | Na-Cl-$HCO_3$<br>Na-$HCO_3$-Cl |

# 6. Summary

Groundwater level and quality data collected between 2012 and 2018 as part of the UWIR WMS groundwater monitoring network in the MGP, and the UWIR baseline water bore assessment program, has provided a dataset from which background groundwater conditions in key hydrogeological units including the Quaternary age alluvium, Tertiary age basalt and sediments, Triassic age Rewan Formation, Late Permian age coal seams and the Middle Permian age Back Creek have been characterised in selected areas. The data has informed the original and 2018-update of the numerical groundwater model that underpins the GMMP.

At present, there is no evidence that CSG production in the MGP area is influencing groundwater levels in the Quaternary age alluvium, weathered Tertiary age basalt, Tertiary age sediment or weathered Late Permian age FCCM aquifers where these bores are installed. For the deeper formation monitoring bores, groundwater levels in the Permian age MCM are shown to be responding to CSG and associated groundwater production activities in the MGP area. Nested monitoring bores also indicate a level of connectivity with the overlying FCCM and possibly the underlying Middle Permian Back Creek Group at these locations.

The groundwater quality baseline assessment demonstrated a high degree of variability between monitoring locations which is likely attributable to the spatial heterogeneity and low permeability of the hydrogeological system. A similar conclusion was derived from the studies supporting the BGP SREIS. The groundwater quality review did not identify any temporal trends in groundwater quality across the bore network.

The outcomes of the baseline groundwater monitoring assessment have assisted, together with the risk assessment (Coffey 2019a), in identifying monitoring locations for the BGP GMMP monitoring network, presented in the Groundwater monitoring network memorandum (Coffey 2019a). On the basis of the baseline assessment, monitoring locations have been selected to capture the range of variability expected at the local scale, and importantly, will provide useful water level data for the checking of model outputs and for future model calibrations, as part of the implementation of the Early Warning System (EWS) for the GMMP (Coffey 2019b).

Longer term groundwater level and quality monitoring across the network will assist in further characterising background groundwater level and quality trends and any potential for deviations.

# 7. References

Arrow Energy 2016, *Underground Water Impact Report for Petroleum Leases 191, 196, 223, 224 and Authority to Prospect 1103, 742, 831 and 1031*, August 2016.

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Ausenco-Norwest 2013, *Collation and Assessment of Groundwater Geochemical Data, Northern Bowen Basin, Queensland Australia*, Report prepared for Arrow Energy Pty Ltd.

Coffey 2014*, Supplementary Groundwater Assessment - Arrow Energy Bowen Gas Project.* Supplementary Report to the EIS, Document ENAUBRIS107043AC, April 2014.

Coffey 2019a, *Bowen Gas Project (BGP) Groundwater Management and Monitoring Plan (GMMP) - Groundwater monitoring network memorandum*, 7 March 2019.

Coffey 2019b, *Bowen Gas Project (BGP) Groundwater Management and Monitoring Plan (GMMP) - Groundwater monitoring program and EWS*, 7 March 2019.

URS 2012, *Groundwater Impact Assessment Bowen Gas Project, Appendix L Groundwater and Geology Technical Report*, November 2012, Prepared for Arrow Energy Pty Ltd.

WorleyParsons 2010, *Spatial Analysis of Coal Seam Water Chemistry, Task 1: Literature Review*, prepared for the Department of Environment and Resource Management, December 2010, pp. 57.

WorleyParsons 2012, *Activity 2.1: Spatial Analysis of Coal Seam Gas Water Chemistry*, Final Report. Healthy Headwaters, Coal Seam Gas Water Feasibility Study, prepared for the Department of Environments and Resource Management.

# 8. Appendices

## Appendix A Description of groundwater level and quality trends – MGP area

| Bore ID | Target aquifer | Description of groundwater level and quality trends |
|---|---|---|
| M339W<br>Figure 1 | Weathered Tertiary age basalt | During the 2012 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a minor rising trend of 0.01 m/yr. No clear correlation with rainfall was observed. |
| | | During the monitoring period salinity was recorded at between 21,200 and 29,000 mg/L TDS. The pH varies between slightly acidic to alkaline (6.3 to 8.4). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed. |
| M225W<br>Figure 2 | Weathered Tertiary age basalt | During the 2012 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a rising trend of 0.13 m/yr. No clear correlation with rainfall was observed. |
| | | During the monitoring period salinity was recorded at between 17,000 and 20,100 mg/L TDS. The pH varies between slightly acidic to slightly alkaline (6.4 to 7.7). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed. |
| M340W<br>Figure 3 | Weathered Tertiary age basalt | Between mid-2012 to mid-2015, the groundwater level exhibited minor fluctuations and a rising trend of 0.4 m/yr. Thereafter, until the last reading in mid-2017, the groundwater level recorded a decline of close to 6 m. From mid-2017 until present, the groundwater level has declined below the completed depth of the bore; a consequence of groundwater withdrawal associated with underground mining directly below the area.<br>No clear correlation with rainfall or fluctuations with the Isaac River were evident. |
| | | During the monitoring period salinity was recorded at between 5,000 and 7,430 mg/L TDS. The pH varies between slightly acidic to alkaline (6.3 to 8.5). The groundwater is generally classified as a Na-Cl water type. There was a general trend over the monitoring period of the groundwater becoming more saline and alkaline. Such trends may be associated with the effects of dewatering and the possible intra-aquifer and inter-aquifer mixing of groundwater. |
| M230W<br>Figure 4 | Weathered Tertiary age basalt | Between mid-2012 to March-2015, the groundwater level exhibited minor fluctuations and a rising trend of 0.2 m/yr. Thereafter, until the last reading in mid-2017, the groundwater level declined by a rate of 0.3 m/yr. Data indicates M230W has been impacted by underground mining, with a rapid decline of approximately 0.4 m observed in this bore between early 2017 and late 2018 which correlates with the mine plan operations in the vicinity of the bore.<br>No clear correlation with rainfall or fluctuations with the Isaac River was evident. |

| Bore ID | Target aquifer | Description of groundwater level and quality trends |
|---|---|---|
| | | During the monitoring period salinity was recorded at between 3,000 and 3,910 mg/L TDS. The pH varies between slightly acidic to slightly alkaline (6.6 to 7.8). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed. |
| M250W<br>Figure 5 | Tertiary age sand (alluvium) | During the 2012 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a stable trend. No clear correlation with rainfall was observed. |
| | | During the monitoring period salinity was recorded at between 1,300 and 1,620 mg/L TDS. The pH varies between acidic to slightly alkaline (5.4 to 7.8). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed. |
| M224W<br>Figure 6a and Figure 6b (Isaac River water levels) | Quaternary age alluvium | During the 2012 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a declining trend of 0.35 m/yr. The bore is installed in the Quaternary age alluvium within 300 m of the Isaac River. A subdued correlation with rainfall exists. Due to the low frequency of the groundwater gauging data it is not possible to definitively determine the potential connectivity of the aquifer with the Isaac River. |
| | | During the monitoring period salinity was highly variable, being recorded at between 2,360 and 27,000 mg/L TDS. The pH varies between acidic to slightly alkaline (5.7 to 7.5). The groundwater is generally classified as a Na-Mg-Cl water type with some variability. The lower salinity conditions recorded in the bore correlate with of a period of flow in the Isaac River and may be a consequence of “losing” conditions in the Isaac River recharging the more saline groundwater system. |
| M222W<br>Figure 7 | Weathered Fort Cooper Coal Measures | During the 2012 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a rising trend of 0.6 m/yr. No clear correlation with rainfall or fluctuations with the Isaac River were evident. |
| | | During the monitoring period salinity was recorded at between 5,190 and 9,600 mg/L TDS. The pH varies between slightly acidic to alkaline (6.1 to 8.2). The groundwater is generally classified as a Na-Mg-Cl water type with some variability. No temporal trends in groundwater quality was observed, nor does the rising groundwater level trend correlate with recorded salinity levels. |
| AN020F<br>Figure 8 | Triassic age Rewan Formation | Six groundwater level monitoring points are available for this bore since March 2016. No clear trend can be determined from the data available. Longer-term monitoring data is required to establish any definitive groundwater level trends. |
| | | During the monitoring period, salinity was recorded at between |

| Bore ID | Target aquifer | Description of groundwater level and quality trends |
|---|---|---|
| | | 6,210 and 7,200 mg/L TDS. The pH varies between slightly acidic to slightly alkaline (6.2 to 7.4). The groundwater is generally classified as a Na-Ca-Cl water type. |
| AN021F | Tertiary age Formation | AN021F, installed in the Tertiary age Formation, has been dry since installation and has been replaced by bore AN020F screened in the Triassic age Rewan Formation. |
| M313W<br>Figure 9 | Late Permian age MCM | During the 2014 to 2018 monitoring period, the groundwater level exhibited a rapid decline of up to 60 m in May 2016, followed by a recovery of 50 m commencing April 2017. No correlation with rainfall was evident. The declining groundwater levels in the bore was due to CSG production and associated groundwater extraction in production well GM052V, located 300 m to the southwest and within the MCM. Groundwater production ceased in April 2017 and the response in M313W was observed in the groundwater level recovery. |
| | | During the monitoring period salinity was recorded at between 2,420 and 4,110 mg/L TDS. The pH is slightly alkaline to alkaline (7.8 to 8.2). The groundwater is generally classified as a Na-Cl-$HCO_3$ water type with some variability. No temporal trends in groundwater quality was observed. |
| | Middle Permian age Back Creek Group | During the 2014 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a declining trend from September-2016 onwards of 0.5 m/yr. No correlation with rainfall is evident. Upwards vertical hydraulic gradients were maintained throughout the monitoring period between the Back Creek Group and MCM.<br>The reduction in the pressure occurs approximately 5 months after the drawdown response in the overlying MCM, indicating possible hydraulic connectivity between the two units. Ongoing monitoring will indicate if the recovery recorded in the overlying MCM at the nested site is also observed in the Back Creek Group interval. This will assist to determining the nature of the connectivity with the overlying unit or whether the observed drawdown is due to another factor(s). |
| M314W<br>Figure 10 | Late Permian age MCM | During the 2014 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a declining trend of 0.6 m/yr. No correlation with rainfall was evident.<br>The declining groundwater level trend was in response to nearby ongoing groundwater withdrawal associated with CSG production in the MCM. |
| | | During the monitoring period salinity was recorded at between 4,790 and 5,470 mg/L TDS. The pH is alkaline (8.0 to 8.9). The groundwater is generally classified as a Na-Cl-$HCO_3$ water type with some variability. No temporal trends in groundwater quality |

| Bore ID | Target aquifer | Description of groundwater level and quality trends |
|---|---|---|
| | | was observed. |
| | Middle Permian age Back Creek Group | During the 2014 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a declining trend averaging 0.4 m/yr (noting that the gradient slightly steepens from August-2016 onwards). No correlation with rainfall was evident. Upwards vertical hydraulic gradients were maintained throughout the monitoring period between the Back Creek Group and MCM.<br>The declining groundwater level trends are considered to be in response to overlying groundwater level declines in the MCM; a consequence of groundwater withdrawal associated with nearby CSG production. The groundwater level trends at this nested site location indicates a level of inter-connectivity between the MCM and Back Creek Group units. |
| M324W<br>Figure 11 | Late Permian age FCCM | During the 2014 to 2018 monitoring period, the groundwater level exhibited minor fluctuations and a declining trend from August-2016 to late 2017 at a rate of 0.8 m/yr. No correlation with rainfall was evident.<br>Downwards vertical hydraulic gradients were maintained throughout the monitoring period between the FCCM and MCM.<br>The declining levels commencing August 2016 correlate with groundwater production in nearby CSG well GM052V and consequential drawdown in the underlying MCM indicating a level of inter-connectivity between the two coal seam intervals. The transition of the drawdown impact manifests in the FCCM approximately 4 months following drawdown occurred in the MCM. Groundwater production in GM052V ceased in April 2017 and the drawdown in M324W started to stabilise. |
| | | During the monitoring period salinity was recorded at between 1,300 and 1,540 mg/L TDS. The pH is alkaline (8.6 to 8.9). The groundwater is generally classified as a Na-Cl-$HCO_3$ water type with some variability. No temporal trends in groundwater quality was observed. |
| | Late Permian age MCM | During the 2014 to 2018 monitoring period, the groundwater level exhibited a moderate decline of up to 6 m in May 2015, followed by a recovery of 3 m (commencing early 2017). No correlation with rainfall was evident.<br>As for M313W, the declining groundwater levels in the bore was due to CSG production and groundwater extraction in production well GM052V, located 300 m to the southwest and within the MCM. Groundwater production ceased in April 2017 and the response in M324W was observed in the groundwater level recovery.<br>The drawdown and recovery of the groundwater level is less pronounced than for M313W, as M324W is screened at a comparatively shallower level in the MCM, being more removed |

| Bore ID | Target aquifer | Description of groundwater level and quality trends |
|---|---|---|
| | | from the deeper interval of CSG production. Arrow reports an approximate 2 day time lag before the response manifests in the shallower MCM unit in M324W. |
| M325W<br>Figure 12 | Late Permian age FCCM | From the beginning of the monitoring period in February 2015 until the close of the monitoring period, the groundwater level was marked by a series of sharp recovery and drawdown cycles of varying magnitudes, up to 25 m. No correlation with rainfall was evident.<br>Groundwater levels are still stabilising in the bore following bore construction and development. The series of recovery and drawdown cycles correspond to groundwater sampling dates of the bore and indicate the groundwater level was slow to recover following these events. |
| | | During the monitoring period salinity was recorded at between 2,260 and 3,310 mg/L TDS. The pH is alkaline (8.2 to 8.7). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed. |
| AN019F<br>Figure 13 | Late Permian age FCCM | Following groundwater level recovery in the bore post-drilling and completion, the groundwater level exhibited a declining trend from early 2016 to late 2017 of 0.5 m/yr. The groundwater level has since stabilised. No correlation with rainfall was evident.<br>The groundwater level trend was similar to that recorded in M324W, screening the FCCM. The groundwater levels in both bores, 11 km apart, were responding to groundwater withdrawal associated with CSG production from the underlying MCM in CSG well GM052V. |
| | | During the monitoring period salinity was recorded at between 5,430 and 6,140 mg/L TDS. The pH is recorded at between 11.1 to 11.8, indicating the water may be impacted by bore construction processes (e.g. grouting). Longer term monitoring is required to establish baseline conditions in this bore. |
| M162V<br>Figure 14 | Late Permian age MCM | Following groundwater level recovery in the bore post-drilling and completion, the groundwater level exhibited a declining trend of 6.5 m/yr from late 2016 to the end of the monitoring period. No correlation with rainfall was evident.<br>The groundwater level decline was in response to groundwater withdrawal associated with CSG production from MCM well M134GMV, situated 470 m to the northwest. |
| | | During the monitoring period salinity was recorded at between 6,970 and 7,250 mg/L TDS. The pH is slightly alkaline to alkaline (7.7 to 8.4). The groundwater is generally classified as a Na-Cl water type. No temporal trends in groundwater quality was observed. |

| Bore ID | Target aquifer | Description of groundwater level and quality trends |
|---|---|---|
| GR067V<br>Figure 15 | Late Permian age MCM | From the beginning of the monitoring period in February 2015 until the close of the monitoring period, the groundwater level was marked by a series of sharp recovery and drawdown cycles of varying magnitudes, up to 120 m. No correlation with rainfall was evident.<br>These groundwater levels are not considered representative of the MCM. The monitoring well was converted from a CSG production well in November 2015 and fitted with a low flow sampling pump in August 2016. The pressure trends presented in Figure 17 for GR067V are a result the well being converted from pumping to monitoring, the build-up of gas and regional pressure recovery which resulted in multiple attempts to set the low flow pump.<br>Longer term monitoring of this bore is required to establish baseline groundwater levels and trends for the MCM in this area. |
| | | During the monitoring period salinity was recorded at between 4,000 and 4,910 mg/L TDS. The pH is alkaline to strongly alkaline (8.1 to 9.1). The groundwater is generally classified as a Na-$HCO_3$-Cl water type with some variability. No temporal trends in groundwater quality was observed. |

# Appendix B Hydrographs and other time series graphs of MGP and Red Hill Central monitoring bores

Figure 1 M339W (Tertiary age weathered basalt)

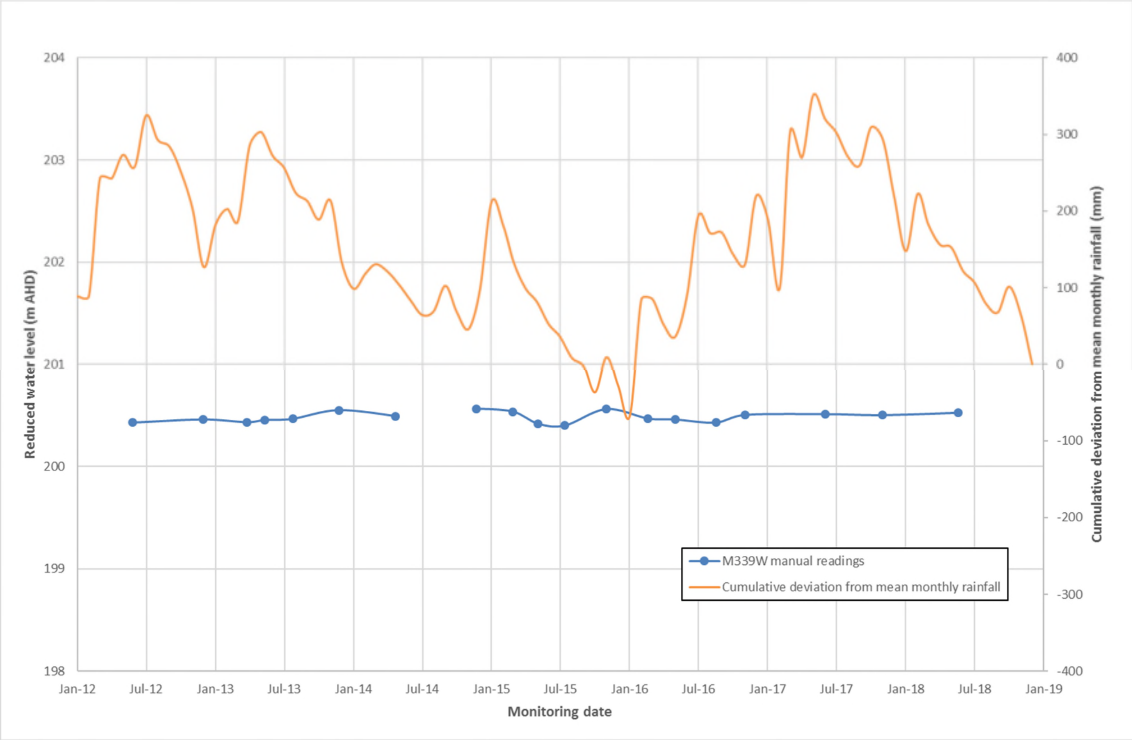



Figure 2 M225W (Tertiary age weathered basalt)

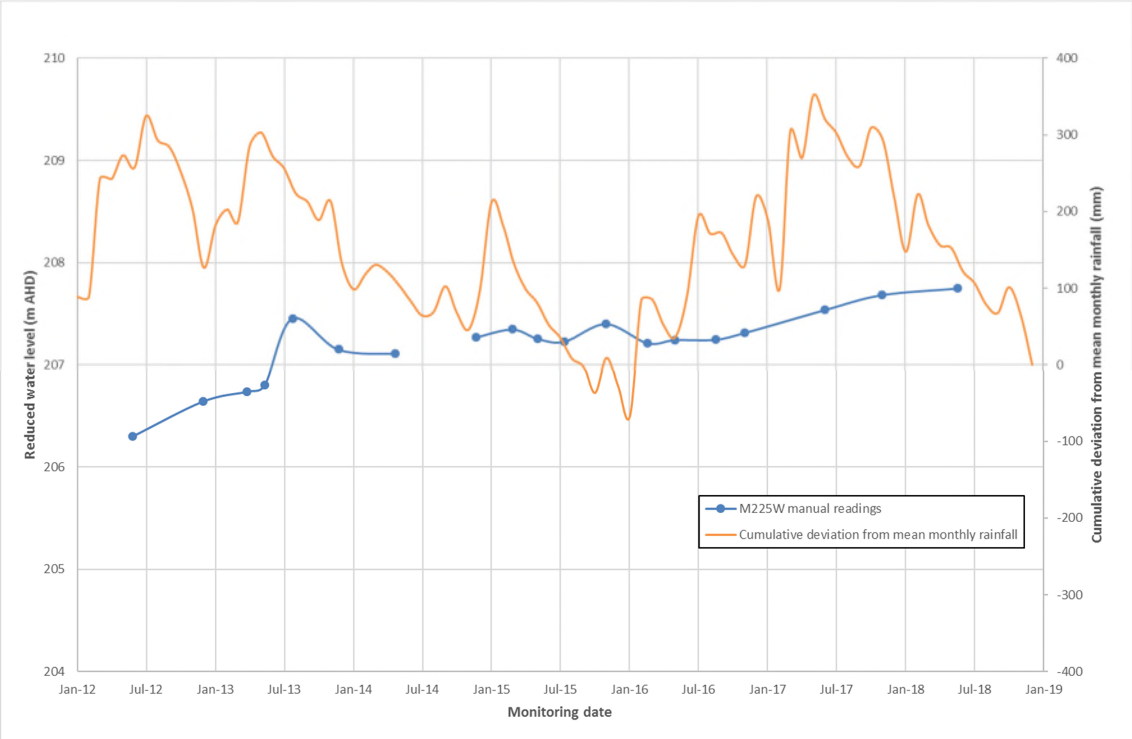


Figure 3 M340W (Tertiary age weathered basalt)

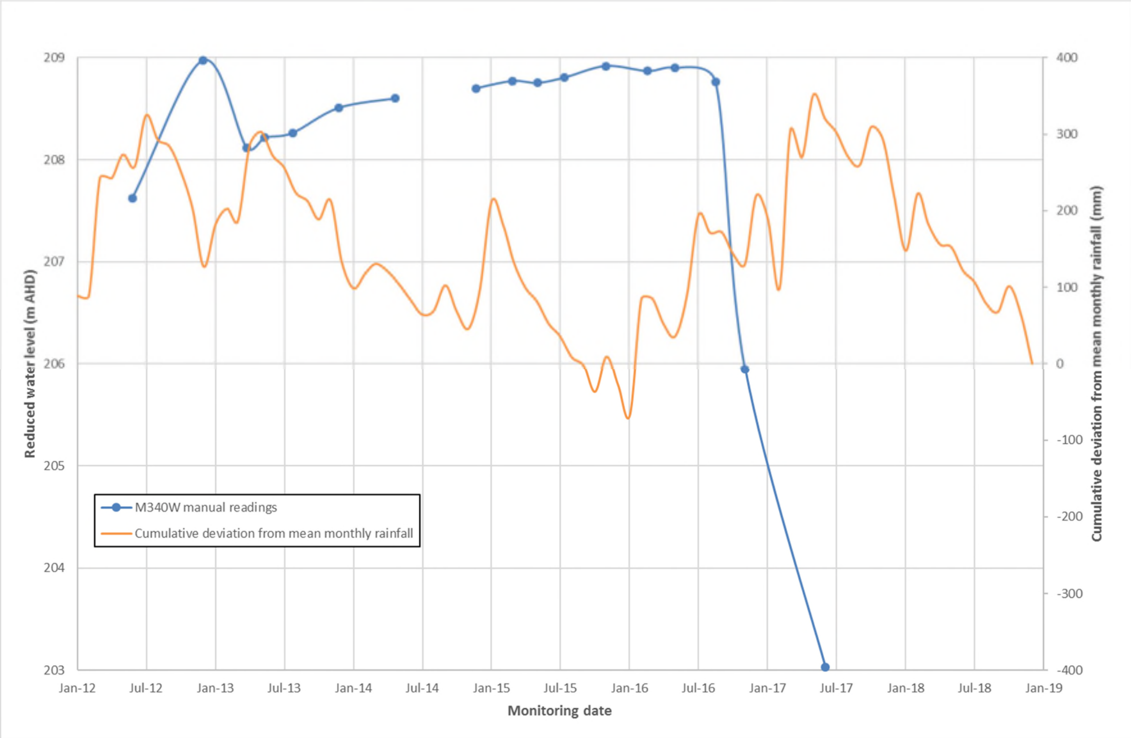



Figure 4 M230W (Tertiary age weathered basalt)

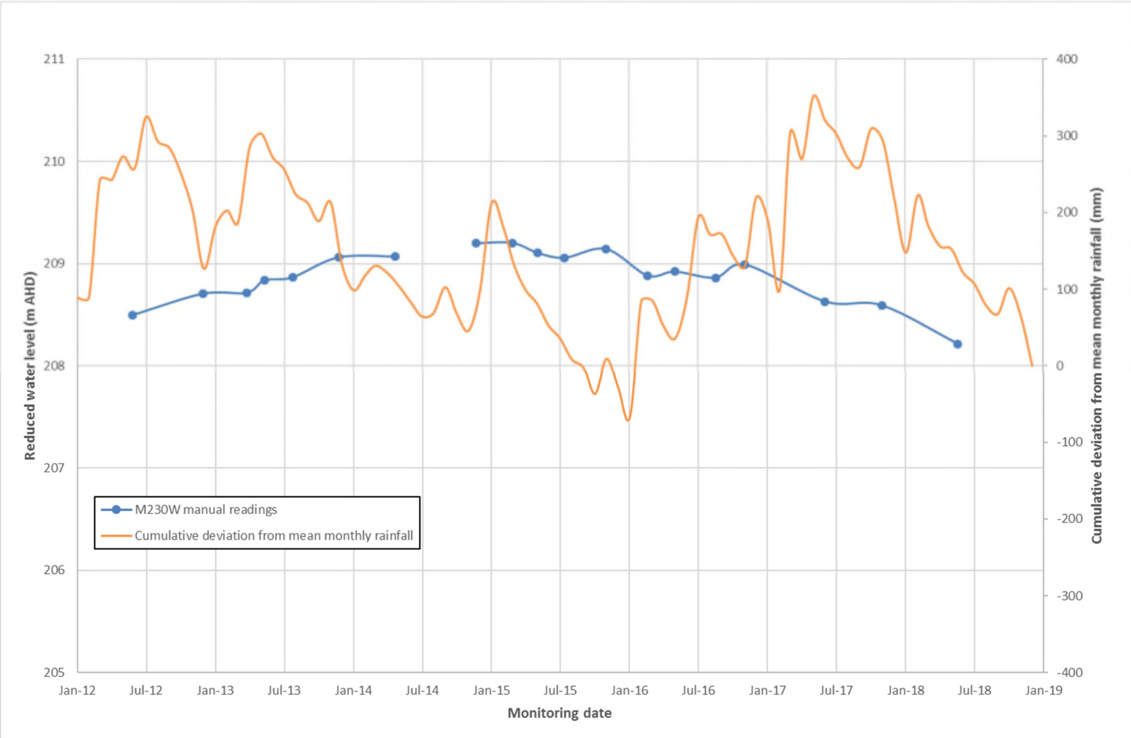


Figure 5 M250W (Tertiary age sand (alluvium)

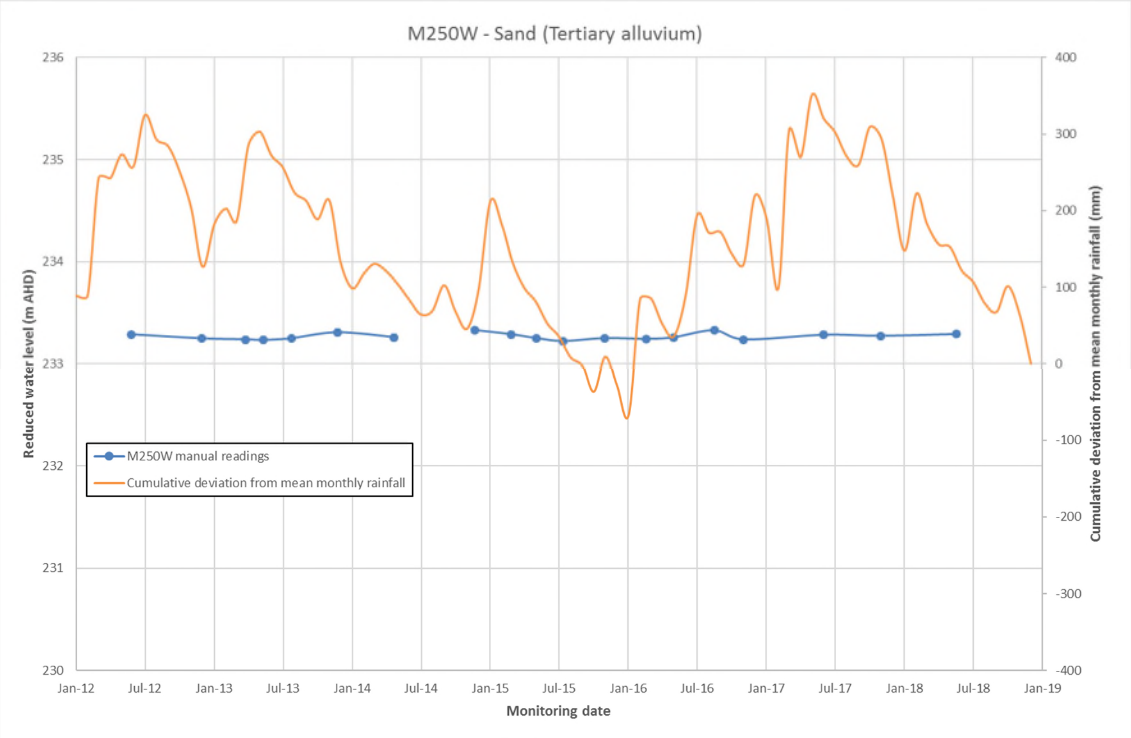


Figure 6a M224W (Quaternary age alluvium)

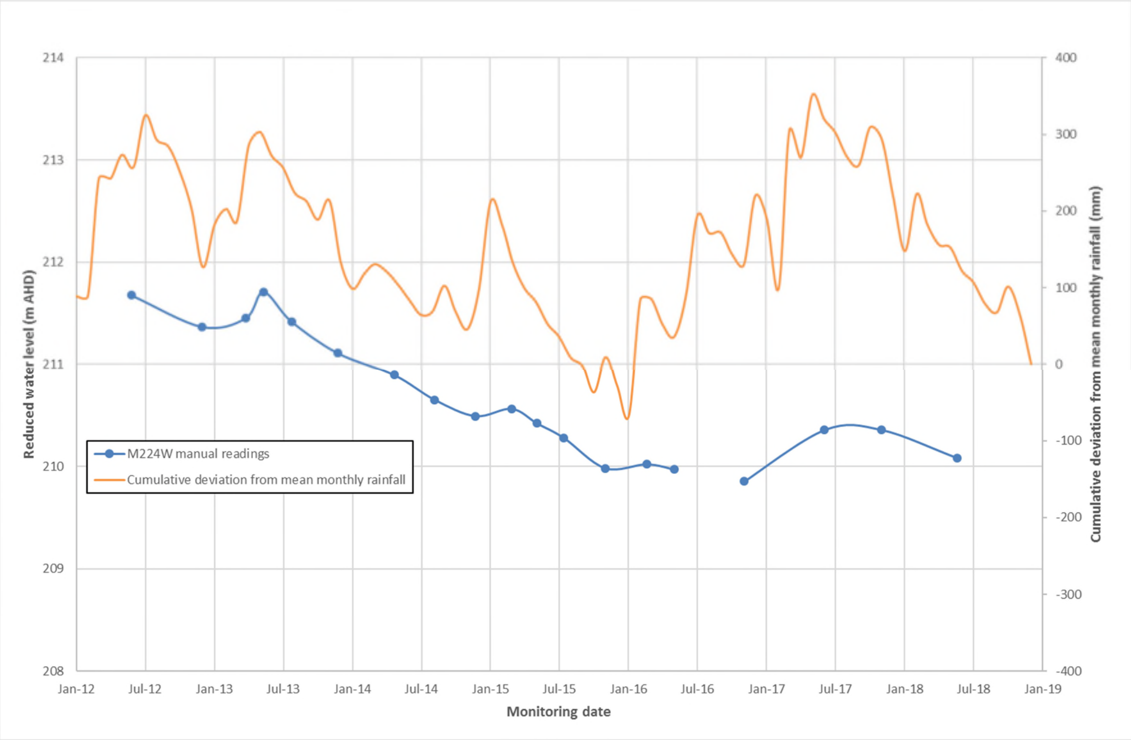



Figure 6b M224W (Quaternary age alluvium) with Isaac River water levels

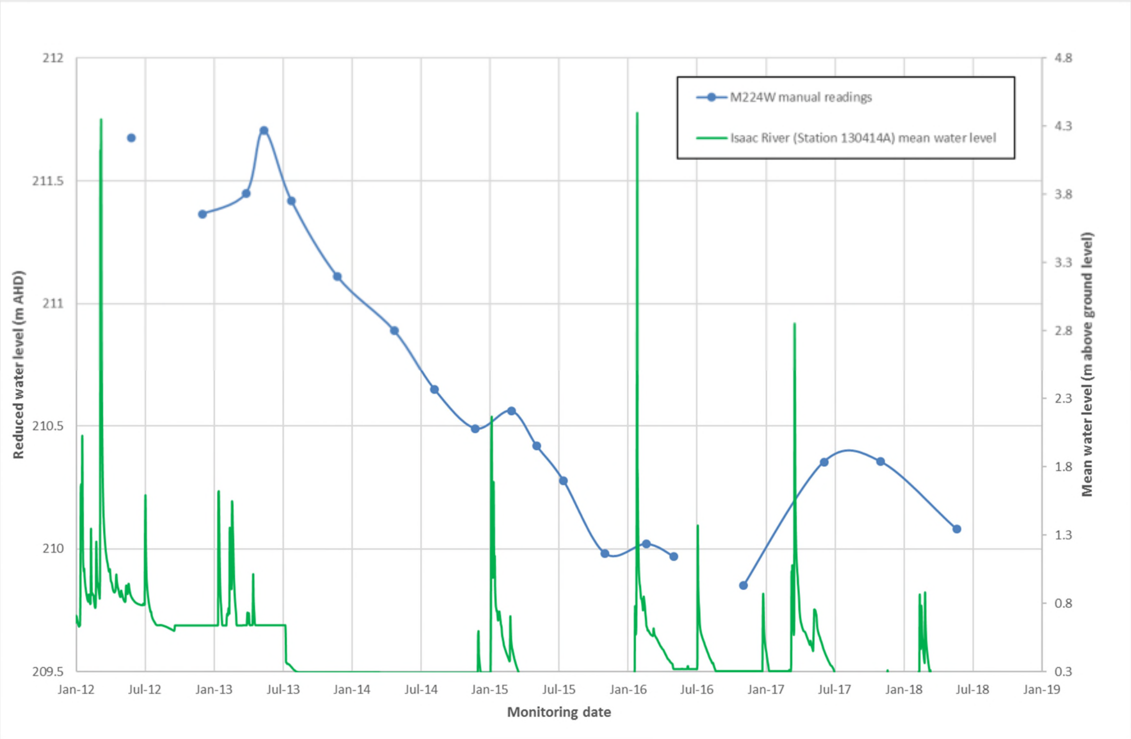


Figure 7 M222W (Late Permian age weathered FCCM)

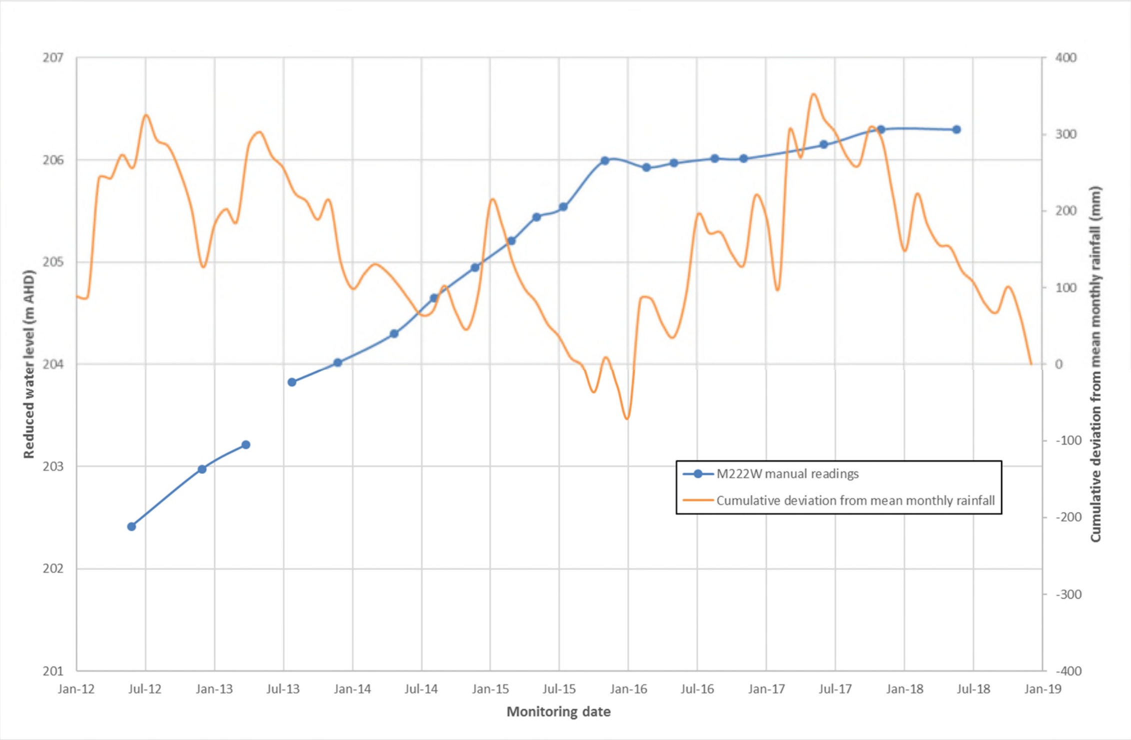



Figure 8 AN020F (Triassic age Rewan Formation)

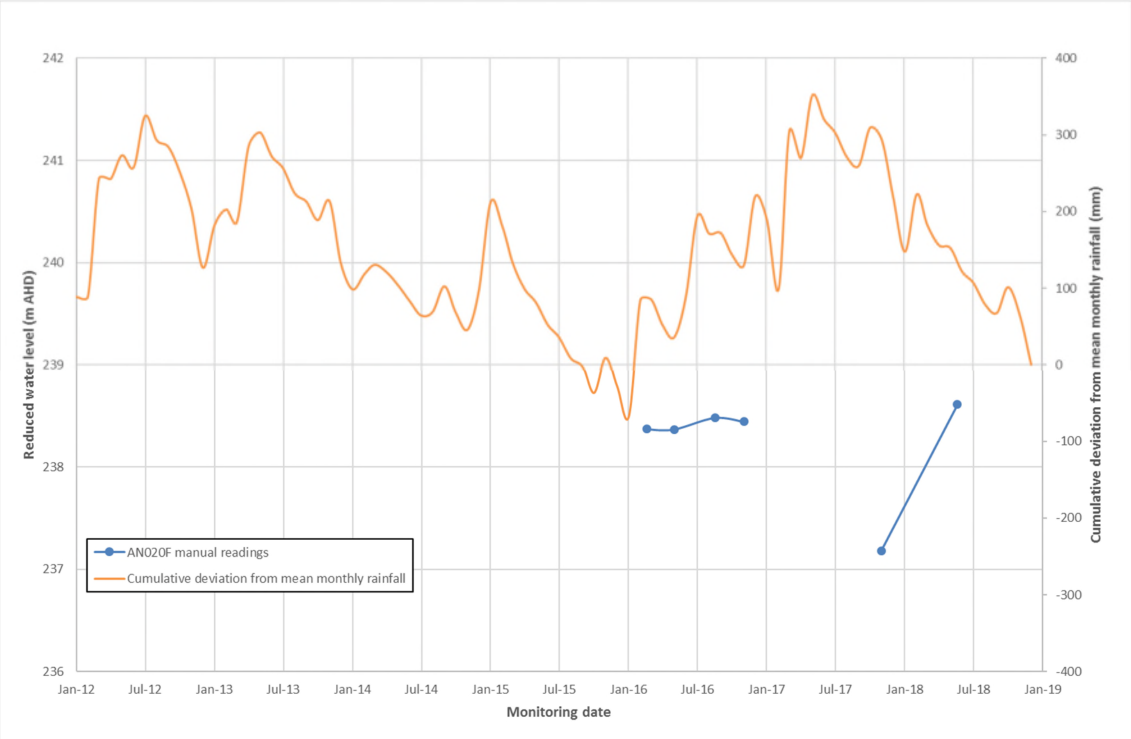


Figure 9 M313W (Permian age MCM and Back Creek Group)

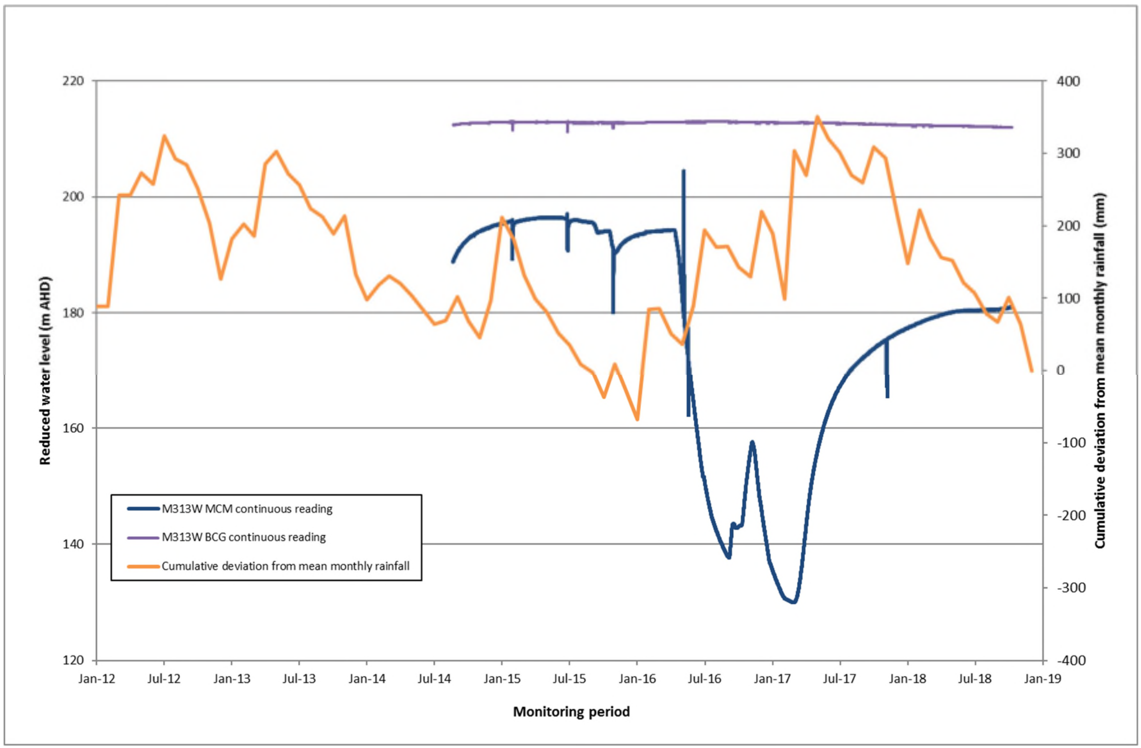



Figure 10 M314W (Permian age MCM and Back Creek Group)

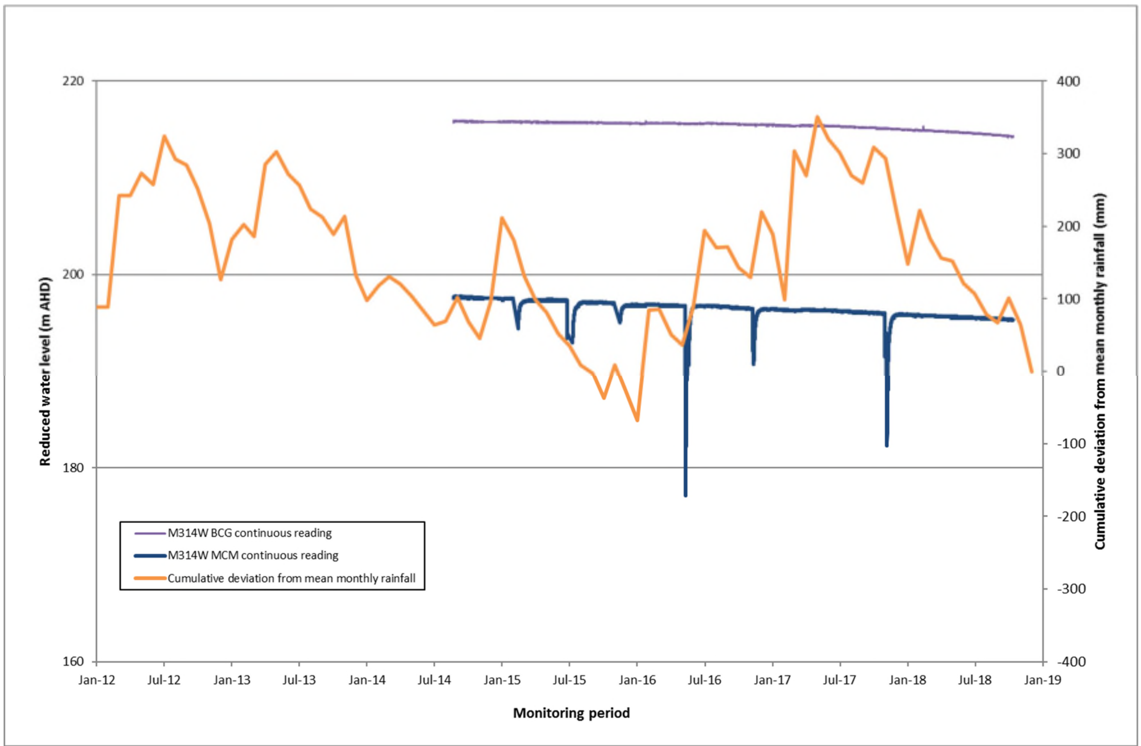


Figure 11 M324W (Late Permian age FCCM and MCM)

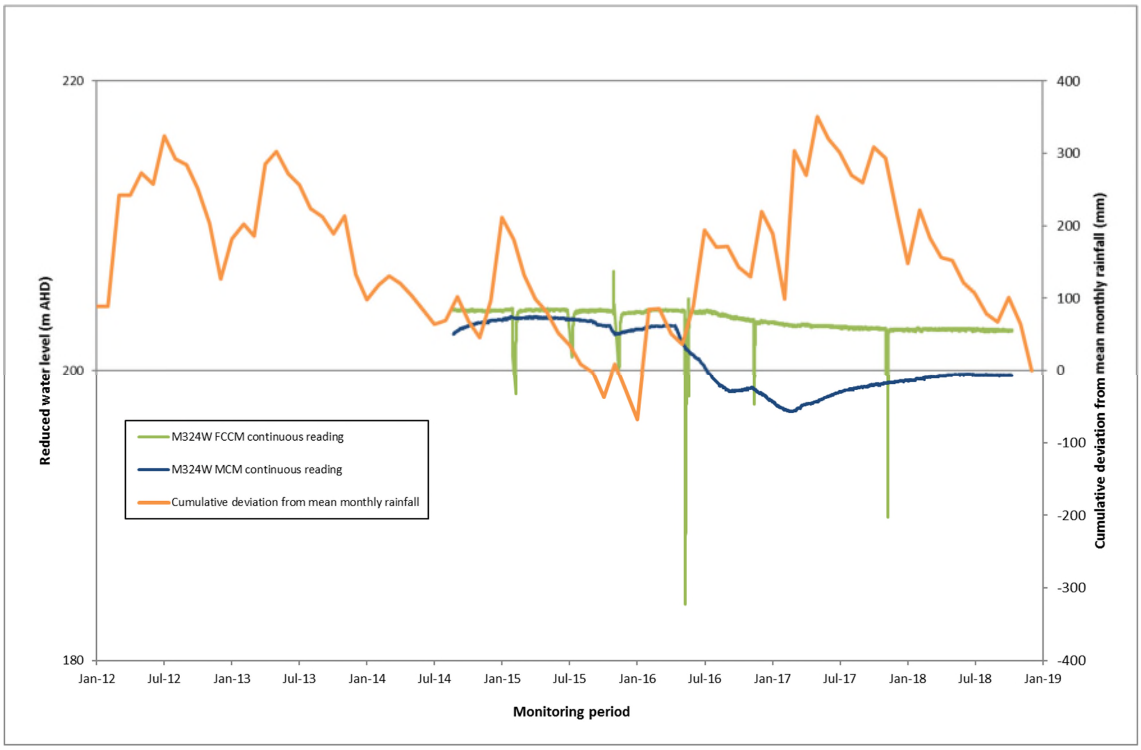



Figure 12 M325W (Late Permian age FCCM)

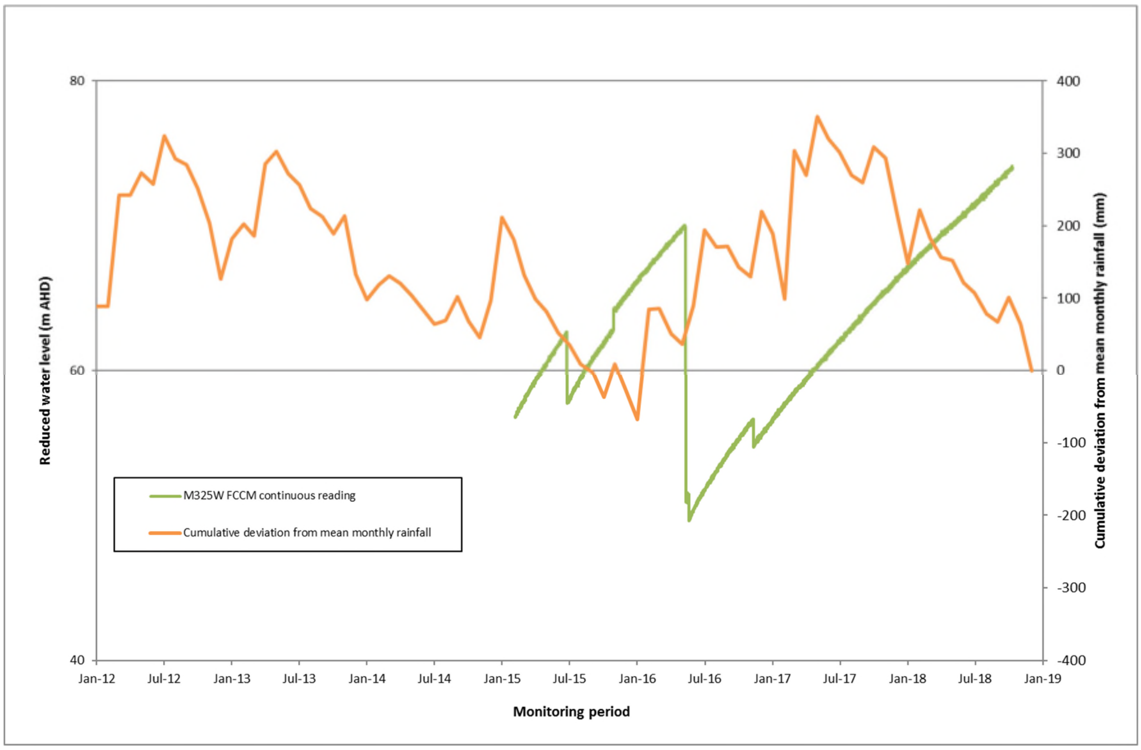


Figure 13 AN019F (Late Permian age FCCM)

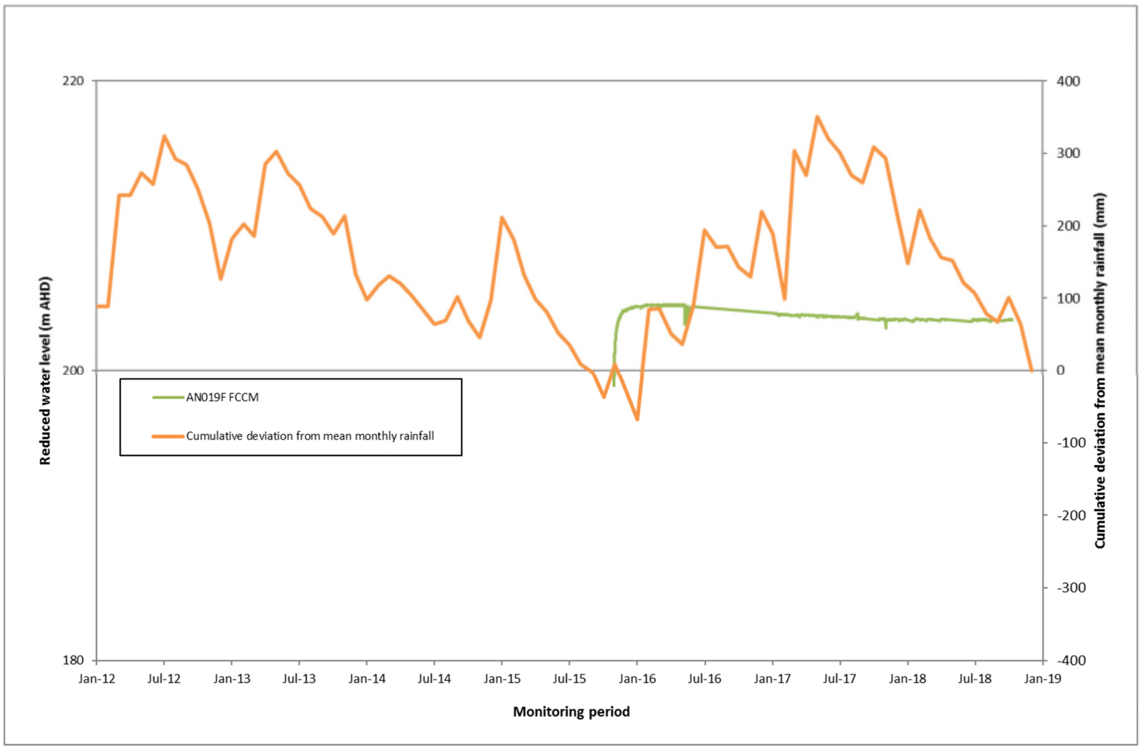



Figure 14 M162V (Late Permian age MCM)

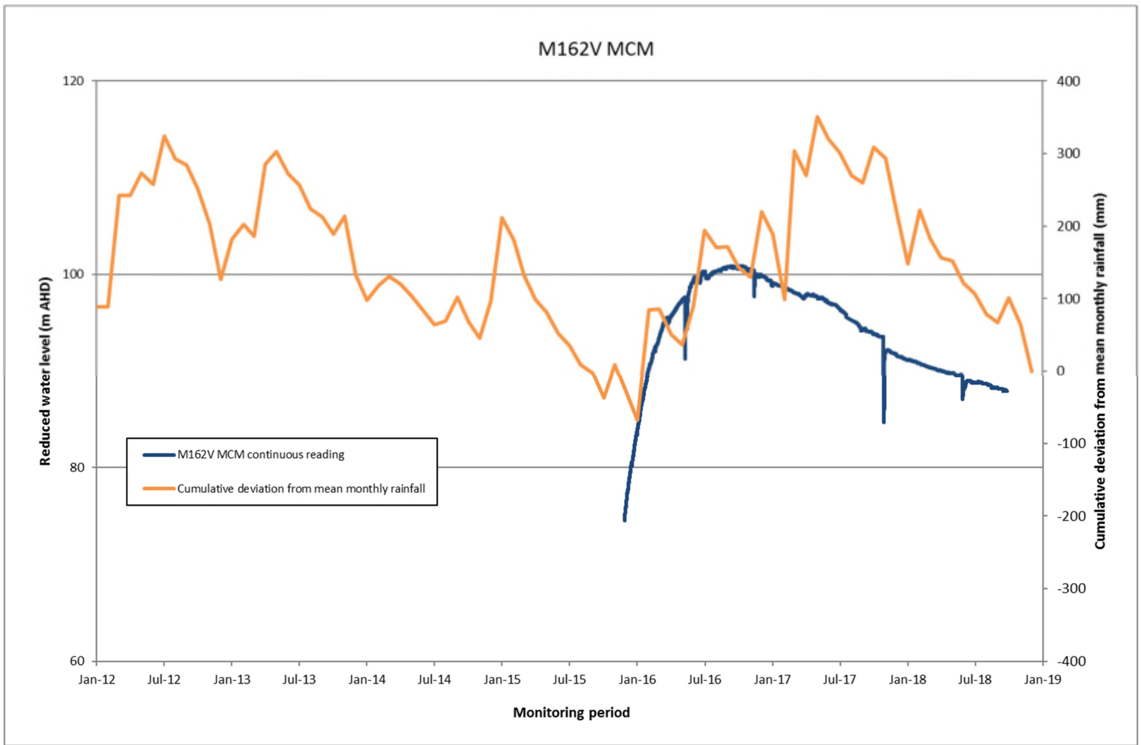


Figure 15 GR067V (Late Permian age MCM)

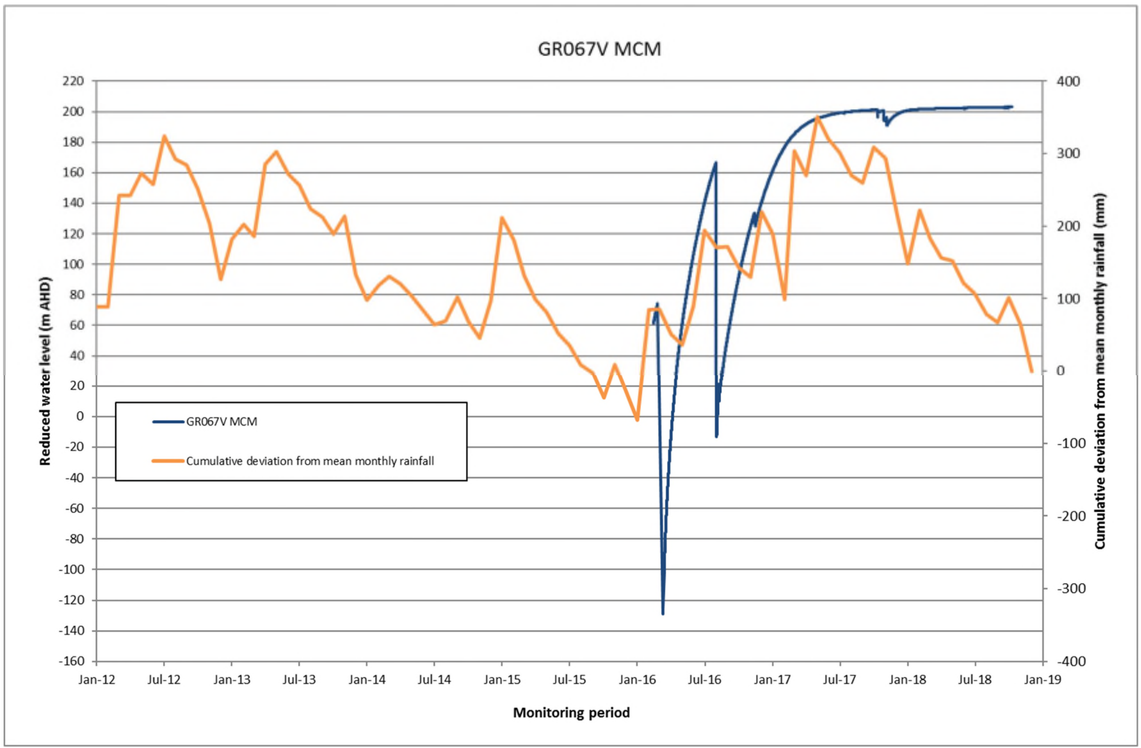
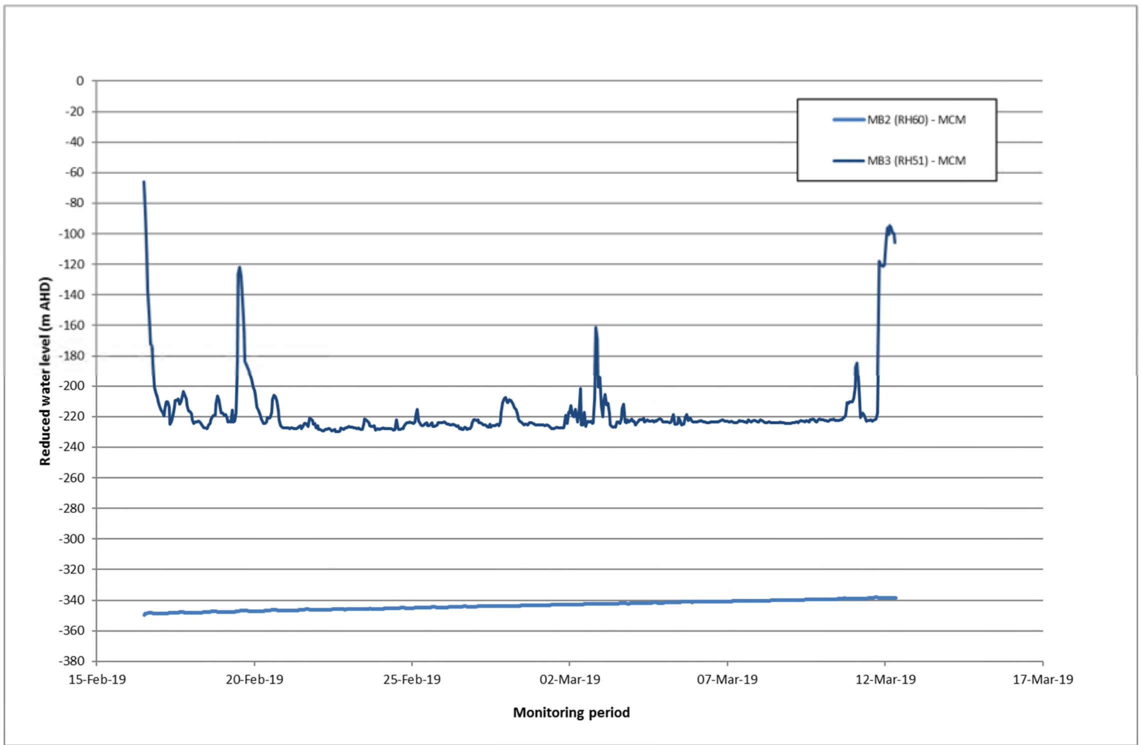



Figure 16 MB2 (RH60) and MB3 (RH51) (Late Permian age MCM)



# APPENDIX F GROUNDWATER MONITORING PROGRAM AND EWS MEMORANDUM

## Memorandum

| | |
|---|---|
| **Recipient** | Arrow Energy Pty Ltd |
| **Memo date** | 14/03/2019 |
| **Author** | Coffey Services Australia Pty Ltd |
| **Project number** | 754-MELEN213220 |
| **Memo Subject** | Bowen Gas Project Groundwater Management and Monitoring Plan (GMMP) Groundwater Early Warning System |

# 1. Introduction

The Arrow Bowen Gas Project (BGP) EPBC Approval Conditions (EPBC 2012/6377) require the development of a Groundwater Management and Monitoring Plan (GMMP). The requirements of the GMMP are set out in Conditions 21 to 23.

This memorandum has been prepared to document the development of a groundwater monitoring program and an Early Warning System (EWS) for the BGP GMMP. It addresses Approval Conditions 21(b), 21(d) and 21(e), specifically:

**Approval Condition 21**

*The approval holder must submit a Groundwater Management and Monitoring Plan (GMMP) for the written approval of the Minister who may seek the advice of an expert panel. The GMMP must contain:*

> **Approval Condition 21(b)**: *Details of a baseline monitoring data acquisition program for the approved action.*
>
> **Approval Condition 21(d)**: *Details of proposed early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels and a description of how and when these measures will be finalised and subsequently reviewed in accordance with the requirements of an Underground Water Impact Report.*
>
> **Approval Condition 21(e)**: *Details of a risk based exceedance response for the actions the approval holder will take, and the timeframes in which these actions will be undertaken, if early warning indicators and trigger threshold values are exceeded.*

The endorsed groundwater monitoring program and EWS memorandum has been incorporated into the GMMP document.

Section 4 of the memorandum also addresses General Approval Conditions 29, 30, 31 and 32 which outline the requirements for record keeping, reporting and non-compliance notification.

## 1.1. Approval Conditions and related documents

In addition to the Environmental Impact Statement (EIS) and Supplementary Report to the EIS (SREIS), further supporting information for the approval conditions is presented in separate memoranda, as summarised in Table 1.1.

Table 1-1 Summary of BGP GMMP supporting assessments

| Memoranda | Approval Conditions addressed | Document ID |
|---|---|---|
| GMMP Review schedule | 21(f), (g), (h) | 754-MELEN213220-M02 |
| Groundwater modelling | 21(a), (b), (c) (part) | 754-MELEN213220-M03 |
| Groundwater monitoring network | 21(a)(i),(ii),(iii),(iv),(v)<br>21(b)<br>21(c) | 754-MELEN213220-M04 |
| Groundwater monitoring program and Early Warning System | 21(b), (d), (e)<br>29, 30, 31 and 32 | 754-MELEN213220-M05<br>(this document) |
| Bowen Gas Project CSG Groundwater Management and Monitoring Plan | 21, 22 and 23<br>29, 30, 31 and 32 | 754-MELEN213220-R01 |

## 1.2. Definitions

Definitions of terms are presented in Table 1-2.

Table 1-2 Definitions

| Term | Definition |
|---|---|
| Background level | Non-Action CSG influenced existing conditions (levels or quality). |
| Bore trigger threshold | Bore trigger threshold has the meaning given in section 362 of the Water Act and means a decline in water level in an aquifer prescribed by regulation, or otherwise 5 metres for consolidated aquifers and 2 metres for unconsolidated aquifers. |
| Consolidated aquifer | Aquifer in a consolidated formation consisting of predominantly consolidated sediment with confined groundwater conditions. |
| Early warning indicator (EWI) | A first-tier groundwater level drawdown level that provides early indication of potential for an impact. |
| Groundwater drawdown due to the Action | Change in hydraulic head relative to the background levels arising from the Action. |
| Limit | A groundwater level based limit for an aquifer not to be exceeded. |
| Immediately affected area (IAA) | Immediately affected area has the meaning given in section 387 of the Water Act and means the area of an aquifer where the water level is predicted to decline, because of the exercise of underground water rights, by more than the bore trigger threshold within three years after the consultation day for the Underground Water Information Report. |
| Long term affected area (LAA) | Long term affected area has the meaning given in section 387 of the Water Act and means the area of an aquifer where the water level is predicted to decline, |

| Term | Definition |
|---|---|
| | because of the exercise of underground water rights, by more than the bore trigger threshold at any time.<br>It is noted that the UWIR guidelines DES (2018), reference the Long term affected area as LTAA. In this memorandum, LAA and LTAA have the same meaning. |
| Make good obligations | Make good obligations has the meaning given in section 409 of the Water Act and means the obligations of resource tenure holder for an immediately affected area bore, which are:<br>• Undertaking a bore assessment of the bore;<br>• Entering into a make good agreement with the bore owner;<br>• Complying with the make good agreement; and<br>• If asked to vary the make good agreement, negotiating a variation of the make good agreement. |
| SREIS drawdown | Groundwater level drawdown predicted in the Arrow SREIS. |
| The Action | The Arrow BGP. |
| Trigger threshold (EWS) | A second-tier groundwater level drawdown level that triggers response actions. |
| Unconsolidated aquifer | An aquifer other than a consolidated aquifer. |

# 2. Groundwater monitoring program

## 2.1. Rationale

Specification of the groundwater monitoring program to address Approval Condition 21(b) is founded on the collection of sufficient groundwater level / pressure and groundwater quality data to:

- Fulfil knowledge gaps and characterise the groundwater system;
- Establish baseline conditions;
- Provide for the early detection of impacts;
- Provide data for the periodic calibration of the BGP groundwater model; and
- Underpin the development of risk-based exceedance response plans if trigger levels and thresholds are exceeded.

## 2.2. Groundwater pressure and level

The GMMP monitoring network locations specified in Coffey (2019b) are presented in Figure 1 (Red Hill Central and Mavis Downs), Figure 2 (Northern remainder of BGP FDP) and Figure 3 (Southern remainder of BGP FDP). Included in the figures are the four contingent monitoring sites (consisting of five monitoring intervals):

- MB4, which will be installed if: (i) ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or (ii) monitoring at MB1-S indicates the potential or likelihood of watertable level impacts as a consequence of the BGP.
- MB6, which will be installed if: (i) ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or (ii) monitoring of other sites in the northern development area indicate the potential or likelihood of preferential groundwater flow occurring across formations by way of geological faults.
- MB13-D, which will be installed if: (i) ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location; or (ii) monitoring of MB13-S and/or other bores in the southern development area indicate the potential or likelihood of preferential groundwater flow occurring across formations by way of geological faults.
- MB17-S/I, which will be installed should the early detection of impacts be identified at MB11, or revised modelling indicates a risk of depressurisation impacts to Lake Elphinstone.

All functional GMMP monitoring locations will be monitored for groundwater level / pressure.[1] Table 2-1 presents the groundwater pressure and level monitoring program for monitoring locations with a primary purpose of baseline data collection (11 monitoring locations) and those with other primary purposes (3 monitoring locations), excluding contingent locations.

Following the first twelve months of data collection at each monitoring site, the data will be reviewed to characterise temporal and spatial variation in groundwater levels. Where there is confidence that the observed trends are understood, the monitoring frequency will be reduced in accordance with the program specified in Table 2-1. In some instances, there may be a need to continue monitoring at the initial higher frequency to advance the conceptual understanding of the local and regional scale hydrogeological regime.

[1] The terms 'monitoring locations' and 'monitoring sites' are used interchangeably throughout this GMMP, and are used to describe a location where one or more groundwater monitoring bores are installed.

Table 2-1 Groundwater pressure and level monitoring program

| Monitoring location purpose | Monitoring Location ID (1,2) | Minimum monitoring frequency | |
|---|---|---|---|
| | | Initial 12 months following installation | Remainder of CSG production |
| Baseline monitoring | MB1-S, MB1-I, MB1-D<br>MB2<br>MB3<br>MB5<br>MB7-S, MB7-D<br>MB9-S, MB9-I, MB9-D<br>MB11-S, MB11-D<br>MB12<br>MB14-S, MB14-I, MB14-D<br>MB15-S, MB15-D<br>MB16 | Twice daily (via data logger) and 6-monthly manual readings | 6-monthly manual readings (3) |
| Other | MB8<br>MB10<br>MB13-S | Twice daily (via data logger) and 6-monthly manual readings | 6-monthly manual readings (3) |

***Note:***
*(1) S: shallow monitoring point, I: intermediate monitoring point, D: deep monitoring point (monitoring points and monitoring intervals have the same meaning).*
*(2) MB4, MB6, MB13-D, MB17-S and MB17-D are contingent locations and not included in the table above (Coffey 2019b).*
*(3) Timing for 6-monthly readings will be informed by the peaks and troughs identified during initial 12-month continuous (twice daily) data logger measurements.*

## 2.3. Groundwater quality

Groundwater quality monitoring will be undertaken at eleven groundwater monitoring locations (Coffey 2019b), excluding contingent locations. All monitoring intervals at nested monitoring sites will be sampled and analysed for groundwater quality. The exception is MB1 which will be re-purposed from RH28/RH30. Due to well completion constraints, it will not be possible to sample from the intermediate and shallow intervals at this site. Should pressure data indicate the potential for inter-connectivity between the MCM and overlying units at this site, a shallow groundwater quality monitoring point will be established.

Table 2-2 below lists the monitoring locations and intervals subject to groundwater quality monitoring.[2]

Table 2-2 Groundwater quality monitoring locations and intervals

| Monitoring location | Development area | Target formation (1) |
|---|---|---|
| MB1-D | Red Hill Central | MCM |
| MB5 | Mavis Downs | Tertiary / Triassic |
| MB7-S<br>MB7-D | Northern remainder of BGP FDP | Tertiary<br>RCM |

[2] The terms 'monitoring interval' and 'monitoring point' are used interchangeably throughout this GMMP, and are used to describe the screened interval of the monitoring site.

| Monitoring location | Development area | Target formation (1) |
|---|---|---|
| MB8 | | Quaternary / Tertiary |
| MB9-S<br>MB9-I<br>MB9-D | | Quaternary / Tertiary<br>RCM<br>MCM |
| MB10 | | Tertiary |
| MB11-S<br>MB11-D | | Quaternary / Tertiary or Rewan Formation<br>RCM |
| MB13-S | Southern remainder of BGP FDP | Quaternary / Tertiary (if present) |
| MB14-S<br>MB14-I<br>MB14-D | | Quaternary / Tertiary<br>RCM<br>MCM |
| MB15-S<br>MB15-I | | Unconfined alluvials<br>Tertiary / Triassic |
| MB16 | | Tertiary |

***Notes:***
*(1) Surficial aquifer assumed based on outcrop geology mapping. Refinement of surficial target aquifer may require refinement at the local scale.*
*(2) Should contingent nested locations (MB13-D and MB17-S/I) be required, groundwater quality monitoring will be initiated at these sites across all intervals.*
*S: shallow nested bore screen interval*
*I: intermediate nested bore screen interval*

During the initial twelve months following monitoring point installation, groundwater quality monitoring will be conducted on a six-monthly basis and include the physical parameter and full analytical suites presented in Table 2-3. Following the initial monitoring, groundwater quality monitoring will be conducted annually. A reduced laboratory analytical suite may be selected for monitoring locations, if supported by a review of the initial monitoring data.

Table 2-3 Groundwater quality monitoring program

| Suite | Selected parameters / analytes | Comment |
|---|---|---|
| Physical parameters | Electrical conductivity (EC)<br>pH<br>Redox potential (Eh)<br>Dissolved oxygen (DO)<br>Temperature | The selected parameters will be measured in the field during every sampling event. |
| Full laboratory analytical suite | Total dissolved solids (TDS)<br>Major cations and anions (calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate, carbonate and total alkalinity)<br>Speciated nitrogen (nitrite, nitrate, ammonia)<br>Fluoride<br>Strontium<br>Dissolved metals (arsenic, barium, boron, | The full analytical suite will be reviewed on a site-by-site basis following the first year of monitoring. The analysis suite may subsequently be rationalised if supported by a review of the initial monitoring data. |

| Suite | Selected parameters / analytes | Comment |
| --- | --- | --- |
| | chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, zinc)<br>Total and dissolved organic carbon (TOC/DOC)<br>Total phosphorus | |
| Discretionary analyses | Dissolved methane<br>Stable isotopes | Laboratory analysis where field observations indicate a requirement (e.g. groundwater sample is de-gassing or methane is measured at borehead). |

## 2.4. Data management and analysis

Implementation of the GMMP will generate considerable data including field records and observations, electronically logged water levels / pressure and laboratory water quality analysis. All data generated will be collated electronically and stored in dedicated databases.

At a minimum, the databases will contain details of:

- GMMP monitoring locations, construction details and monitored aquifer;
- Monitoring point drilling records, survey records, geophysical logs and interpreted stratigraphy;
- Any permanent monitoring location infrastructure or instrumentation;
- Groundwater level and pressure records; and
- Groundwater quality records (field records and observations, and laboratory analysis).

Following upload to the databases, data will be reviewed for transcription errors and consistency with historical data. Where anomalies are identified, or trends that markedly deviate from model drawdowns, further data assessment and/or analysis will be triggered.

For each monitoring site, at the end of the first year of monitoring, groundwater level/pressure and quality data will be reviewed in detail to determine whether it is appropriate to reduce the monitoring frequency as described in Sections 2.2 and 2.3.

Should changes to monitoring frequencies be warranted (specifically reduced monitoring frequency), in accordance with Approval Condition 22, these changes would be implemented only following endorsement by suitably qualified water expert/s approved by the Minister in writing.

# 3. Early Warning System

This section presents the Early Warning System (EWS) for the BGP GMMP to address Approval Condition 21(d) which requires that proposed early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels in accordance with the requirements of the UWIR be described.

Section 3.1 provides an overview and rationale for the EWS, while Section 3.2 presents a description of the EWS, including specification of the limits, trigger thresholds and early warning indicators. The exceedance response actions, accompanying the EWS, are described in Section 3.3.

## 3.1. Overview

### 3.1.1. Target systems

**Consolidated and unconsolidated aquifers**

UWIRs must include, amongst other things, predictions of groundwater level change in affected aquifers, as a consequence of groundwater extraction undertaken as part of CSG production. The EWS therefore applies to aquifers that have the potential to be depressurised by CSG water extraction from the Late Permian age coal measures and include:

- Quaternary age Alluvium;
- Tertiary age sediments and basalts; and
- Triassic age Clematis Sandstone.

These formations are treated as unconsolidated where they present as the watertable aquifer (Coffey 2019b). Affected geological formations do not include units formally recognised as aquitards/confining units.

The late Permian age coal measures being developed for CSG have been specifically excluded from the EWS because depressurisation of these coal seams is an essential and unavoidable component of the Action as described in the BGP SREIS (Coffey 2014). Water levels in any water bores within the coal seam units, affected by depressurisation activities associated with the Action, will be managed through the BGP UWIR, in accordance with the Queensland Water Act (2000).

**Groundwater Dependent Ecosystems**

The basis for identifying GDEs that may be impacted by the Action is presented in the BGP EIS/SREIS, which identified a range of known and potential GDEs using existing information sources. This included known and potential GDEs as mapped in the Atlas of Groundwater Dependent Ecosystems (GDE Atlas), a publicly available data set developed under the National Water Commission's Raising National Water Standards Program (BOM 2018).

In addition, field work was carried out in November 2015 to assess areas within the project area that were mapped in the GDE Atlas as having potential GDEs. This field work, conducted by specialist hydrogeologists and an ecologist, identified the limited likelihood for ecosystem groundwater dependence across most of the areas observed, including those mapped as being potential GDEs in the GDE Atlas.

The assessment and findings were updated with the current field development plan (FDP) and the 2018 BGP GMMP groundwater model (AGE 2018) in the monitoring network memorandum (Coffey 2019b). The assessment did not identify any potential spring GDEs or non-spring GDEs at risk of impact from the Action and accordingly, there are no current monitoring requirements for GDEs in the BGP GMMP.

Two watertable bores (MB4 (contingent) and MB15-S) have been sited to fulfil multiple monitoring purposes in proximity to the upper Isaac River which is associated with field verified riparian vegetation (Coffey 2019b).

The EWS described herein will be applied to spring and non-spring GDEs should such features be identified in the future that are assessed as being at risk of impact from the Action, or if monitoring indicates a potential for the field verified riparian vegetation to be affected by groundwater drawdown in connected underlying aquifers, as additional information becomes available, or changes to the FDP are proposed.

### 3.1.2. Investigation levels

Approval Condition 21(d) requires the proposal of early warning indicators, trigger thresholds, and limits for detecting impacts on groundwater levels. In addition to these requirements, periodic data review and analysis is a commitment under the BGP EIS/SREIS and an ongoing requirement under the Queensland Water Act (2000) obligations.

Table 3-1 provides a summary of the condition requirements for the EWS.

Table 3-1 EWS requirements

| System | Early warning indicator | Trigger threshold | Limit |
|---|---|---|---|
| Consolidated aquifers | ✓ | ✓ | ✓ |
| Unconsolidated aquifers | ✓ | ✓ | ✓ |

In accordance with Approval Condition 21(d), the EWS for the BGP includes tiered investigation levels with escalating responses:

1. **Early warning indicators**, for early identification of potential groundwater drawdown issues to enable additional baseline monitoring data to be collected.
2. **Trigger thresholds**, for identifying the potential for groundwater drawdown (as a consequence of the Action) to affect groundwater users and enable monitoring and management measures to be implemented to mitigate the potential for impact.
3. **Limits**, that define groundwater levels of drawdowns not to be exceeded.

Commensurate with Approval Condition 21(d), the proposed EWS for the BGP GMMP is aligned with the requirements for the preparation of UWIRs (DES 2018).

While the UWIR guideline (DES 2018) does not specify a requirement for an EWS, it does require groundwater level declines to be predicted for affected aquifers due to the Action and an accompanying water monitoring strategy to be developed. The predictions for affected aquifers are made for:

- Water level declines, by more than the applicable bore trigger threshold, within three years following the report consultation day (immediately affected area, or IAA); and
- Water level declines, by more than the applicable bore trigger threshold, at any time (long-term affected area, or LAA).

In the UWIR guidelines (DES 2018), the bore trigger threshold has the following meaning under Section 362 of the Water Act (2000):

- A decline in water level in an aquifer prescribed by regulation, or otherwise 5 m for consolidated aquifers and 2 m for unconsolidated aquifers.

These principals are integrated into the proposed EWS for the BGP GMMP in the form of the adopted tiered investigation levels (Table 3-1 and further elaborated on in Section 3.2) together with exceedance response actions (Section 3.3).

### 3.1.3. Approach and inputs

Groundwater level model drawdown predictions will serve to identify, on a periodic basis, whether any of the assigned early warning indicators, triggers and limits in the EWS are predicted to be reached or exceeded.

For consistency with the BGP UWIR, and as a conservative measure to serve as an early warning indicator, the $P_{95}$ groundwater level model drawdown predictions, sourced from the BGP GMMP numerical groundwater model (AGE 2018), will be utilised in identifying potential exceedances in EWS.[3]

The BGP GMMP numerical groundwater model (AGE 2018) does not simulate cumulative drawdown, due to coal mining activities (Coffey 2019a). A direct comparison of observed groundwater level data and assigned EWS levels derived from predictive modelling, is therefore not a viable approach for identifying potential exceedances in the EWS.

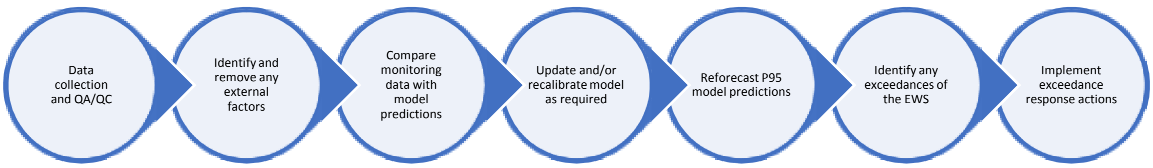
The first step in the EWS is the collection of groundwater monitoring data and the implementation of QA/QC procedures:

- Reviewing and checking data and field documents to identify transcription errors.
- Reviewing and checking the calibration of measurement equipment (e.g. pressure gauges, water quality meter).
- Correlation of logged data against manually gauged data.

Following data collection, any external physical factors that may affect the monitoring data will be identified and removed. Some of these influences relate to actual changes in storage, such as pumping from the aquifer, whilst other influences may cause apparent groundwater level changes, with no actual resource volumetric changes, for example, barometric pressure changes. Data may require the removal of confounding influences, such as barometric effects and earth tides, to provide corrected data that does not lead to misinterpretation of trends. Software available for this purpose includes proprietary software provided by data logger manufacturers.

Groundwater level and quality monitoring data collected from the GMMP monitoring network (defined in Coffey 2019b) will be used to help consolidate the understanding of groundwater systems across the BGP. Importantly, a comparison of monitoring data and model predictions, in consideration of cumulative scale effects on the groundwater resource, will guide any updates and/or requirements for model recalibration. In turn, potential $P_{95}$ groundwater drawdown and impacts will be re-forecast for ongoing implementation of the EWS.

The periodic approach to identifying potential exceedances in the EWS is illustrated below. The last two stages of the EWS are further explained in Section 3.2 and 3.3, respectively.




[3] The same numerical model has been used (and it is proposed to continue to be used) in making predictions for the BGP UWIR and future iterations of the BGP GMMP.

## 3.2. Limits, trigger thresholds and early warning indicators

Approval Condition 21(d) requires that the BGP GMMP specify early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels as a consequence of the Action.

The EWS is based on comparing modelled groundwater drawdowns derived from the BGP GMMP groundwater model (AGE 2018) with staged early warning indicator levels, trigger threshold levels, and drawdown limits, to inform escalating response actions.

As reported in the Review Schedule Memorandum (Coffey 2018), the revised GMMP will be prepared and delivered concurrently with three-yearly updates to the UWIR for the purposes of aligning and achieving consistency between the two documents, to the extent practicable.

Events triggering an EWS level initiate prescribed investigation and actions to mitigate potential impacts, as described in Section 3.3. Figure 4 illustrates operation of the EWS.

### 3.2.1. Early warning indicator

An early warning indicator is considered exceeded if an existing water supply bore is identified within a predicted $P_{95}$ LAA for the BGP in any of the target systems. Identification of LAAs for affected aquifers is a requirement of the UWIR (DES 2018).

The $P_{95}$ model predictions conducted as part of the BGP GMMP (Coffey 2019b) did not identify any predicted LAAs in the consolidated or unconsolidated aquifers, outside of the coal measures targeted for CSG development.

### 3.2.2. Trigger thresholds

A trigger threshold is considered exceeded if an existing water supply bore is identified within a predicted $P_{95}$ IAA for the BGP in any of the target systems. Identification of IAAs for affected aquifers is a requirement of the UWIR (DES 2018).

The $P_{95}$ model predictions conducted as part of the BGP GMMP (Coffey 2019b) did not identify any predicted IAAs in the consolidated or unconsolidated aquifers, outside of the coal measures targeted for CSG development.

### 3.2.3. Limits

A limit is considered exceeded if an existing water supply bore is identified within a predicted $P_{95}$ IAA for the BGP, with predicted drawdown of more than double the UWIR guideline (DES 2018) of the bore trigger threshold (10 m for consolidated aquifers and 4 m for unconsolidated aquifers), at an existing water supply bore.

As per Section 3.1.1, the coal measures subject to CSG development are excluded from the target systems.

## 3.3. Exceedance response actions

Approval Condition 21(e) requires the BGP GMMP to include a risk based exceedance response plan that details the actions to be taken and timeframes if early warning indicators or trigger threshold values are exceeded. According to the Approval Conditions, while a risk based exceedance response plan is not required to consider responses for exceeding limits, the BGP GMMP has been prepared to include such measures.

EWS response actions are risk-based in that escalating actions apply to exceedances due to the Action, depending on the level of the exceedance. The response actions (identified in Table 3-2) have been developed with the aim of achieving consistency with the requirements of the UWIR (DES 2018).

The levels of exceedance are described in the sections above.

An evaluation of potential exceedances of the EWS will be undertaken, on a three-yearly basis, as part of the review and update of the BGP GMMP and BGP UWIR.

The next version of the BGP UWIR is scheduled for submission on 4 April 2019. The document will report on the revised IAAs and LAAs for the BGP (as per Section 5.2 of the BGP GMMP) and any implications or exceedances of the EWS, together with any corresponding revisions to the Bore Assessment Plan (BAP) and obligations concerning bore assessments. The forecast impacts in the BGP UWIR and BGM GMMP will therefore be consistent. To maintain this consistency, future revisions of the BGP GMMP will be prepared on the basis of the BGP UWIR (current at the time of development of the updated BGP GMMP).

Table 3-2 Risk-based exceedance response actions

| Risk based exceedance level | Response action |
|---|---|
| Early warning indicator | Within 12 months of exceeding an early warning indicator, conduct a baseline assessment of water bores potentially affected by the Action. (1)<br><br>Baseline assessments will be undertaken in accordance with the updated (if necessary) and approved Baseline Assessment Plans (BAPs) for tenures in the Project Area. The information collected in baseline assessments establishes benchmark data prior to the bore experiencing any impact from the resource tenure holder exercising their underground water rights. The results of baseline assessments will be summarised in each annual review.<br><br>Within 30 days of completing the revised baseline assessments, submit these to the relevant Queensland state agencies (OGIA or their successor) and the bore owner.<br><br>Within 15 months of exceeding an early warning indicator, prepare and submit to the Department an Early Warning Indicator Exceedance Report which includes:<br><br>a) The results of an evaluation of the reasons for the predicted EWI exceedance, and the likelihood of a future exceedance of a trigger threshold or limit.<br><br>b) The outcomes of the baseline assessment program. |
| Trigger threshold | Arrow will comply with the requirements of the Queensland Water Act (2000) including by using best endeavours to enter into a make good agreements with the bore owner (after a bore assessment has been undertaken) and comply with the agreement.<br><br>Within 1 month of exceeding a trigger threshold, advise the Department of the exceedance, and of the obligation to conduct bore assessments of those water bores within the new IAA.<br><br>Within 60 business days of exceeding a trigger threshold (or a later date if agreed with the chief executive of DES), conduct bore assessment(s) for those water bores within the IAA. (2)<br><br>The bore assessment aims to establish whether a bore has, or is likely to have, an impaired capacity as a result of CSG groundwater extraction, and in turn, to determine whether make good measures are required as part of a make good agreement between the tenure holder and the bore owner. Make good agreements ensure that the bore owner is not disadvantaged if their bore is, or is likely to be, impaired as a result of resource activities.<br><br>Within 15 months of exceeding a trigger threshold, prepare and submit to the Department a Trigger Threshold Exceedance Report which includes: |

| Risk based exceedance level | Response action |
| --- | --- |
| | a) The results of an evaluation of the reasons for the predicted trigger threshold exceedance, and the likelihood of a future exceedance of a limit.<br>b) Details of compliance with any make good obligations arising because of the trigger threshold exceedance including the outcomes of the bore assessment program.<br>c) The outcomes of the bore assessment program and any make good obligations. |
| Limit | Within 120 days, prepare and submit to the Department a limit exceedance report that includes:<br>a) The results of an evaluation of the reasons for the limit exceedance, and an evaluation of any impacts that may arise due to the exceedance.<br>b) An evaluation of the risk to groundwater environmental values.<br>c) Corrective actions to mitigate against any impacts, including demonstration that make good obligations of impacted water supply bores have been entered in to. |

***Notes:***

*(1) The underground water impact management framework under Chapter 3 of the Water Act (2000), requires resource tenure holders to undertake Baseline Assessments on all authorised water bores potentially affected by the Action. A baseline assessment (defined in section 394 of the Water Act 2000) is an assessment of a water bore, undertaken by a resource tenure holder, to obtain information about the bore, including: level and quality of water, construction and pumping infrastructure.*

*(2) Undertaking a bore assessment is a key element of a resource tenure holder's make good obligations under Chapter 3 of the Water Act (2000). The 2016 UWIR also sets out Arrow's commitment to bore assessments for any landholder bore intersected by the IAA.*

# 4. Compliance reporting and notification

## 4.1. Introduction

Approval Conditions 29, 30, 31 and 32 require record keeping, reporting and non-compliance notification. Arrow will meet the requirements of these conditions, with respect to the BGP GMMP, as set out in this Chapter, and in conjunction with Arrow's EIS/SREIS reporting, updating and review commitments. In particular:

**Approval Condition 29** requires that the annual report (Approval Condition 30) must state all confirmed cases of non-compliance along with details of any remedial actions.

**Approval Condition 30** requires that the approval holder must publish an annual report on its website outlining how they have been compliant with the conditions of the approval over the previous 12 months, including the implementation of any management plans, strategies or programs as specified in the conditions.

**Approval Condition 31** requires that the approval holder must provide documentary evidence to the Department [4] (at the same time as the compliance report, Approval Condition 30, is published) with proof of the date of publication of any non-compliance with any of the conditions of the approval.

**Approval Condition 32** requires that the approval holder must notify the Department [4] in writing of potential non-compliance with any condition of this approval as soon as practical and within no later than ten business days of becoming aware of the potential non-compliance. Under Approval Condition 32, the notice provided to the Department must specify:

a) The condition which the approval holder has potentially breached;

b) The nature of the potential non-compliance;

c) When and how the approval holder became aware of the non-compliance;

d) How the non-compliance will affect the anticipated impacts of the approved action, in particular how the non-compliance will affect the impacts on the matters of national environmental significance (MNES);

e) The measures the approval holder will take to address the impacts of the non-compliance on the MNES and rectify the non-compliance; and

f) The time by when the approval holder will rectify the non-compliance.

Arrow's reporting compliance relating to the EWS is provided in the following sections.

## 4.2. Department notification

Arrow will comply with the reporting and notification requirements of the Approval Conditions, including non-compliance reports. Reporting provided to the Department will be in compliance with the conditions.

## 4.3. Potential non-compliance reports

The Department will be notified in writing no later than ten business days after becoming aware of any potential non-compliance with any Approval Condition.

Potential non-compliance notification will occur if:

[4] Department is defined in the conditions to mean the Australian Government Department administering the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth.)

- Arrow fail to meet any of the requirements of Approval Condition 21 (i.e. Arrow do not develop or carry out any of the activities required under approval conditions 21(a) to 21(h)).

The notification will include:

- The Approval Condition that has been potentially breached;
- The nature of the potential non-compliance;
- When and how the approval holder became aware of the potential non-compliance;
- How the potential non-compliance may affect the approved action;
- How the potential non-compliance may affect the anticipated impacts of the approved action, in particular any impacts on MNES, and the measures to be taken to address the impacts of the potential non-compliance on MNES and to rectify the potential non-compliance; and
- The time by when the approval holder will rectify the potential non-compliance.

# 5. References

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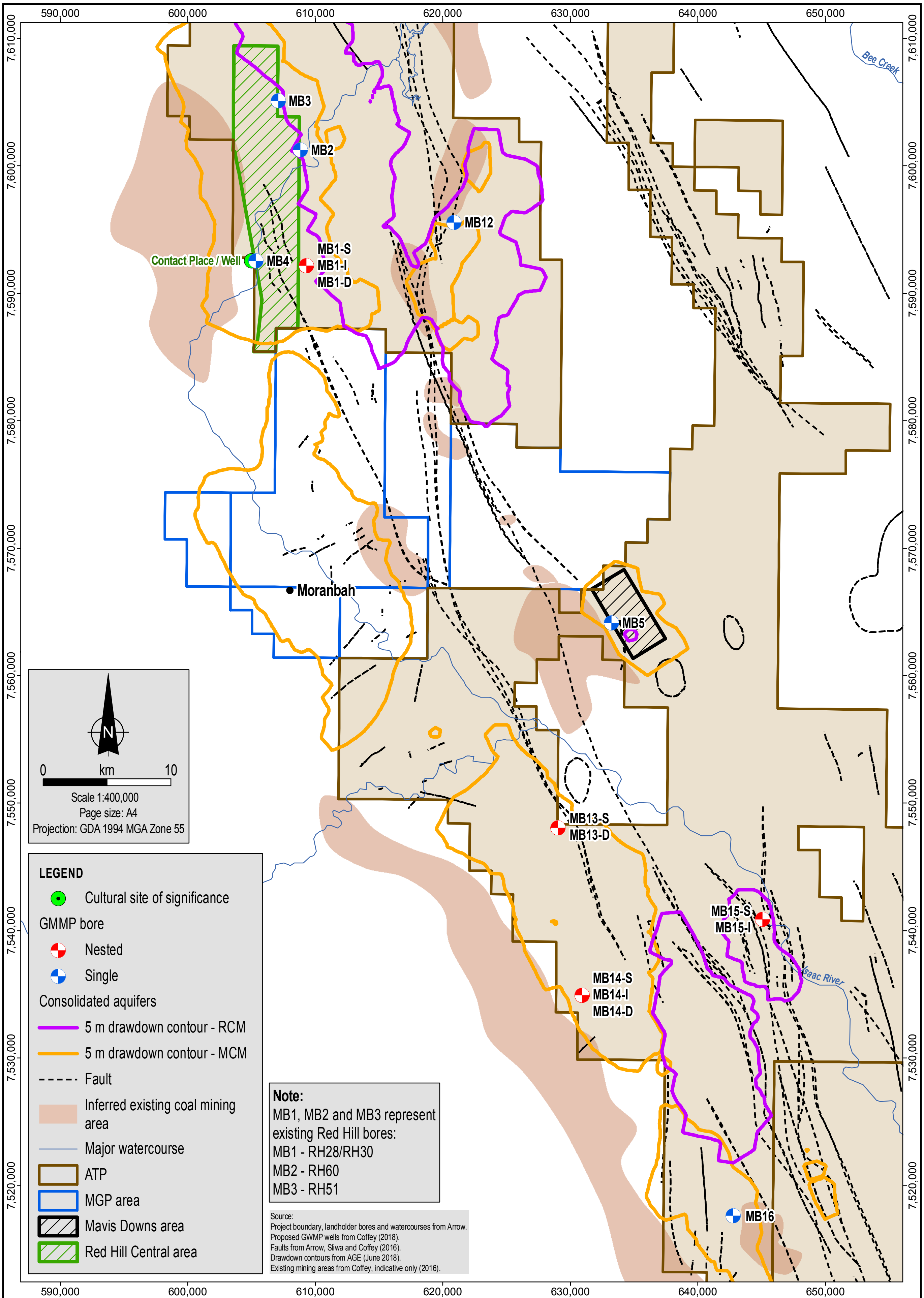
# Figures

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Date: 12.03.2019
Project: 754-MELEN213220
File Name: 213220_M05_F001_GIS

Arrow Energy

Bowen Gas Project

arrow energy
go further

Red Hill Central and Mavis Downs development areas - BGP GMMP monitoring bore network

Figure No: 1

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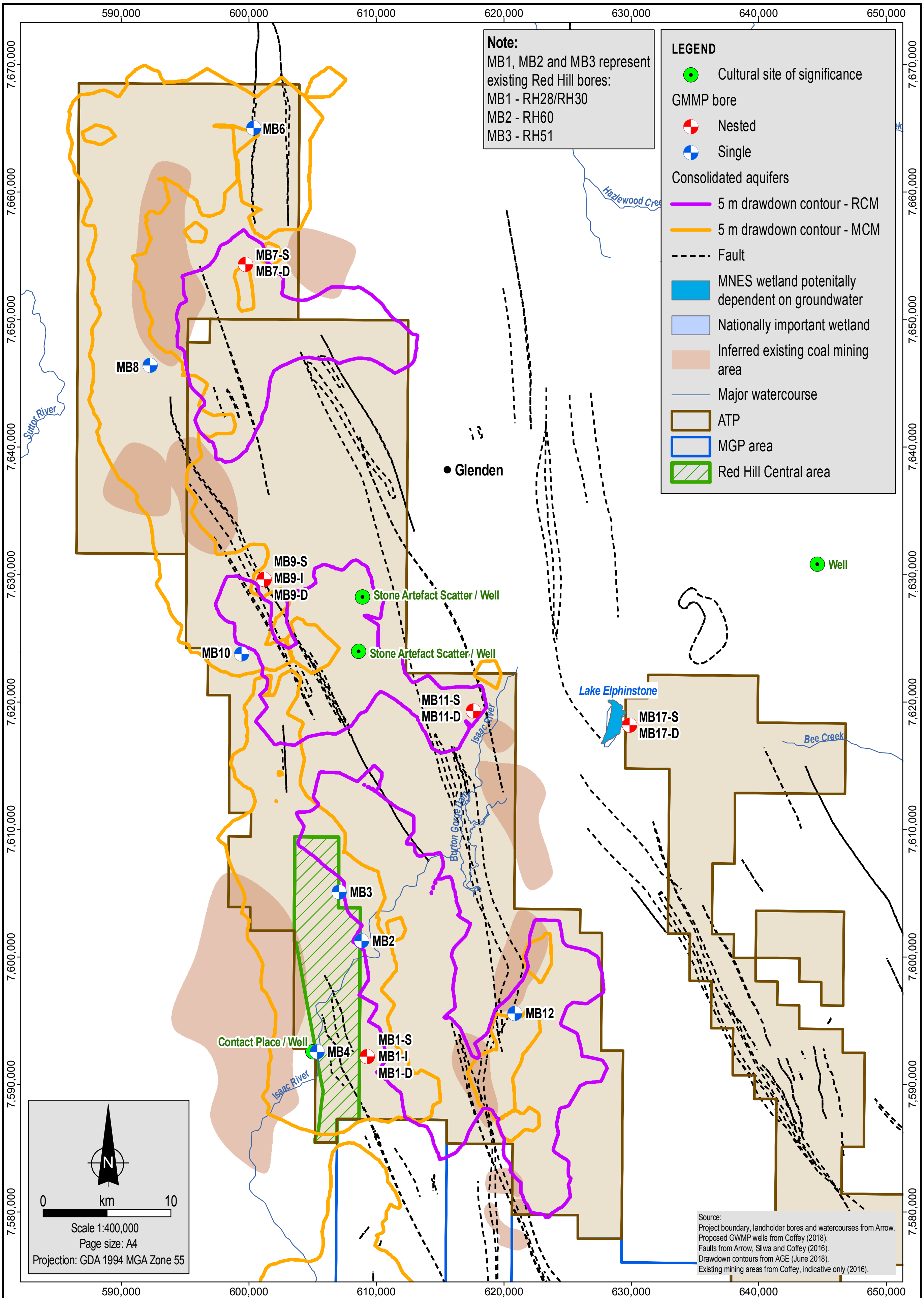



MXD Reference: 213220_M05_GIS006_v0_5

coffey
A TETRA TECH COMPANY

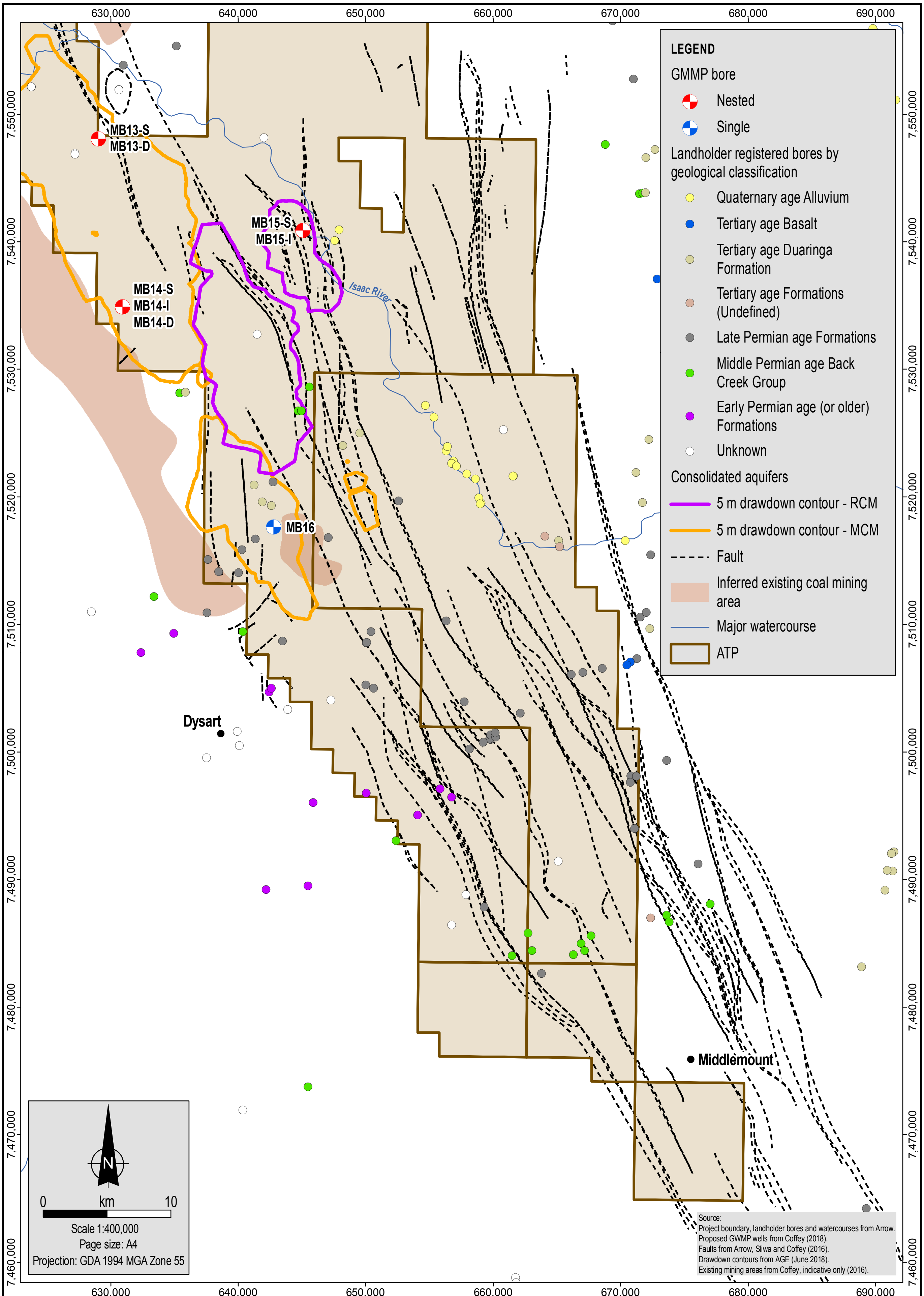
Date: 12.03.2019
Project: 754-MELEN213220
File Name: 213220_M05_F002_GIS

Arrow Energy
Bowen Gas Project

arrow energy
go further

BGP FDP northern development area - BGP GMMP monitoring bore network

Figure No: 2
DRAFT




MXD Reference: 213220_M05_GIS007_v0_3

coffey
A TETRA TECH COMPANY

Date: 25.02.2019
Project: 754-MELEN213220
File Name: 213220_M05_F003_GIS

Arrow Energy

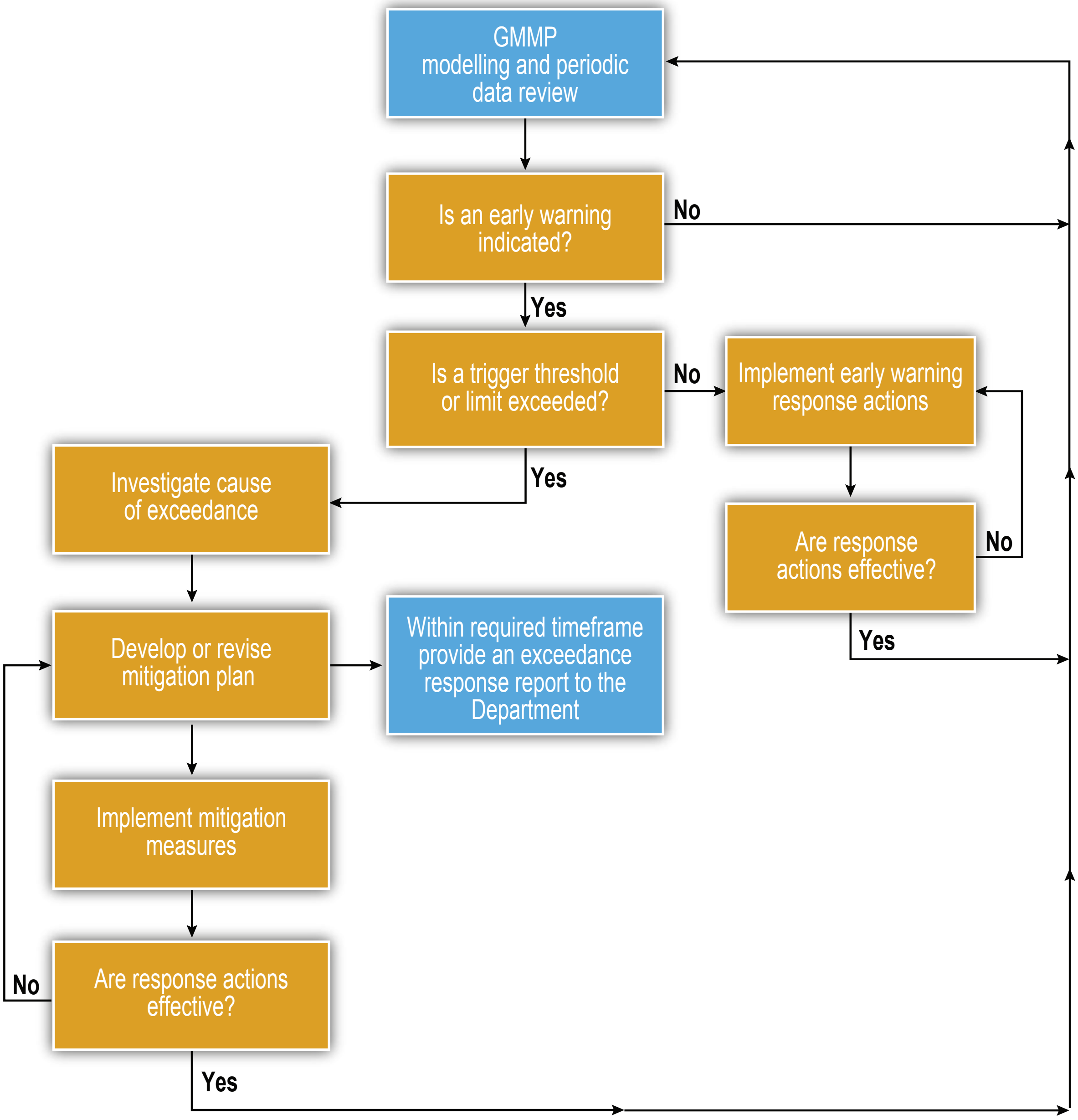
Bowen Gas Project

arrow energy
go further

**BGP FDP southern development area - BGP GMMP monitoring bore network**

Figure No: **3**

DRAFT




| | | | | |
|---|---|---|---|---|
| coffey<br>A TETRA TECH COMPANY | Date: 20.12.2018<br>Project: 754-MELEN213220<br>File Name: 213220_M05_F004_GRA | Arrow Energy<br>Bowen Gas Project | arrow energy<br>go further | EWS process and actions | Figure No: 4 |

# APPENDIX G REVIEW SCHEDULE MEMORANDUM

## Memorandum

| | |
|---|---|
| **Recipient** | Arrow Energy Pty Ltd |
| **Memo date** | 11/02/2019 |
| **Author** | Coffey Services Australia Pty Ltd |
| **Project number** | 754-MELEN213220 |
| **Memo Subject** | Bowen Gas Project Groundwater Management and Monitoring Plan (GMMP) Review schedule memorandum |

# 1. Introduction

The Arrow Bowen Gas Project (BGP) EPBC Approval Conditions (EPBC 2012/6377) require the development of a Groundwater Management and Monitoring Plan (GMMP). The requirements of the GMMP are set out in Conditions 21 to 23.

A number of the Conditions relate to administrative commitments including defining a timeframe for regular review and updates of the GMMP, public dissemination of the monitoring results and provision of monitoring data to Federal and State Government authorities, if requested. These non-technical requirements are addressed in the current memorandum.

The Conditions addressed in this memorandum include:

**Approval Condition 21f**: *details of the timeframe for a regular review of the GMMP in accordance with the requirements of the Underground Water Impact Report and subsequent updates of the GMMP, including to incorporate the outcomes of updates to the numerical groundwater model and water balance calculations.*

**Approval Condition 21g**: *provisions to make monitoring results publicly available on the approval holder's website for the life of the project.*

**Approval Condition 21h**: *provisions to make monitoring data available to the Department and Queensland Government authorities (if requested) for inclusion in any cumulative impact assessment, regional water balance model, bioregional assessment or relevant research.*

# 2. Approach to Addressing Conditions

## 2.1. Approval Condition 21f

In accordance with the requirements of Approval Condition 21(f), and consistent with the UWIR, the GMMP will be reviewed and updated at three-yearly intervals. The revised GMMP will be prepared and delivered concurrently with three-yearly updates to the UWIR for the purposes of aligning and achieving consistency between the two documents, to the extent practicable. Updates to the GMMP will ensure any revisions to the numerical groundwater model and water balance calculations (for example, in response to significant operational changes, new knowledge becoming available that informs predicted impacts, and/or upon review and consideration of monitoring outcomes) are captured and addressed in the updated document. In accordance with Approval Condition 22, any revised GMMP will be peer reviewed by a suitably qualified water resources expert/s approved by the Minister.

Annual review reports will also be prepared that detail whether there has been material change in the information or predictions used to determine the impacted areas. As for the three-yearly updates, the annual review reports for the GMMP and UWIR will be prepared concurrently to ensure alignment and consistency between the two outputs is achieved, to the extent practicable. There is no requirement under the BGP EPBC Approval Conditions for the annual review reports to be peer reviewed.

Opportunities will be explored to rationalise the three-yearly updates to the UWIR and GMMP by addressing the requirements of each review and consolidating their documentation into a single report. A similar approach may be adopted for the annual review reports of the UWIR and GMMP.

If any amendments to the UWIR are required, for example a material change or error in the information or predictions is identified, then any amendments to the UWIR (for example, an update to the modelling that has implications for the impact assessment) will be reflected and submitted in an updated GMMP, outside of the 3-yearly delivery schedule.

The intended objectives, components and delivery schedule of the three-yearly update to the GMMP and annual review reporting is presented in Table 1.

Table 1 Objectives, components and delivery schedule of the GMMP update and annual review reporting

| | Three-yearly GMMP review / update | Annual review reporting |
|---|---|---|
| **Objective** | A comprehensive review of the GMMP which will include determination of ongoing suitability of the GMMP, and if necessary to recommend where the GMMP requires revision. | A factual annual review report that presents monitoring results and new hydrogeological data. This will include a summary of whether there has been a material change in the information or predictions used to inform the impacted areas. |
| **Components** | The GMMP will be appraised to determine its ongoing suitability, adequacy and effectiveness. Outcomes of any review will be incorporated into an updated GMMP where required, consistent with the commitment to continual improvement.<br>In particular, any revisions to the numerical groundwater model and water balance calculations (e.g. in response to significant operational changes, new knowledge and data, or upon review and consideration of monitoring outcomes) will be addressed and captured in the updated document including any implications to assigned early warning indicators, trigger thresholds and limits. | The annual review report will:<br>• Present new hydrogeological data that significantly alters the conceptual model.<br>• Detail any updates to the Field Development Plan and whether the taking of water for CSG production varied materially from that forecast.<br>• Review available data to determine whether predictions made have changed materially.<br>• Provide update on the implementation of the groundwater monitoring network and baseline monitoring.<br>• Present analysis of water level and water quality data to understand impacts and trends.<br>• Review compliance with bore trigger thresholds. |
| **Delivery** | The updated GMMP, accompanied by the peer review, will be issued directly to the Department of Environment and Energy within 10 business days following each third anniversary day of when the first UWIR took effect on 21 March 2016. | The annual review report issued directly to the Department of Environment and Energy within 20 business days following the anniversary day of when the first UWIR took effect on 21 March 2016. |

| | Three-yearly GMMP review / update | Annual review reporting |
|---|---|---|
| | Relevant electronic data will be provided to the Department upon request. The three-yearly GMMP and UWIR reviews will be published on Arrow's website. | Relevant electronic data will be provided to the Department upon request. |

## 2.2. Approval Condition 21g

Arrow will make public the results of data obtained from the water-related aspects of their monitoring network for the life of the project via two mechanisms:

1. Publication of the BGP GMMP and UWIR (and subsequent revisions) on Arrow's website, which will include monitoring results from associated investigations undertaken as a requirement of the GMMP.

2. Supply of data collected by Arrow, including bore and baseline data, will be reported to the Office of Groundwater Impact Assessment (OGIA) associated with obligations under the UWIR, and baseline and bore assessment obligations.

## 2.3. Approval Condition 21h

Arrow will make provisions for the availability of monitoring data to the Department of the Environment and Energy and Queensland Government authorities, as requested, for inclusion in cumulative impact assessments, regional water balance modelling, bioregional assessments or other relevant research. Arrow will store monitoring data in an internal database which can easily be exported and provided as part of any such information requests. This approach is consistent with groundwater monitoring results currently being provided to the OGIA.

# 3. References

Department of Environment and Science (DES) 2018, *Underground water impact reports and final reports*, Version 3.02, effective 21 May 2018.

Queensland Government 2000, *Water Act 2000*, as revised 1 March 2017.

# APPENDIX H PEER REVIEW AND MINISTERIAL ENDORSEMENT

Innovative Groundwater Solutions

Mr. Greg Manning
Assistant Secretary
Assessments (WA, SA, NT) and Post Approvals
Department of the Environment and Energy
GPO Box 787
CANBERRA ACT 2600

14 March 2019

Dear Mr. Manning

**RE: Letter of endorsement for the Bowen Gas Project Coal Seam Gas Groundwater Management and Monitoring Plan**

**Introduction**
On 27th October 2014 the Australian Government Minister for the Environment approved the Arrow Bowen Gas Project (EPBC 2012/6377) subject to conditions. Approval condition 21 requires that the proponent (Arrow Energy) submit a Groundwater Management and Monitoring Plan (GMMP) for the approval of the Minister.

Condition 22 specifies "*The GMMP, including any revised plans, must be peer reviewed by a suitably qualified water resources expert/s approved by the Minister in writing. A peer review must be submitted to the Minister together with the GMMP and a statement from the suitably qualified water resources experts stating that they carried out the peer review and endorse the findings and the content of the GMMP.*"

**Compliance with Approval Condition 21**
As the *suitably qualified water resources expert* approved by the Minister for the Environment on 7 July 2015, I have been actively involved in regular reviews of the methodologies, results, interpretation and reporting of the assessments of potential impacts caused by the Action. These assessments have been documented in three technical memoranda, one non-technical review schedule memorandum, and several supporting technical reports, in order to specifically address the approval conditions (see Table 1 below).

I have progressively reviewed and endorsed these four memoranda and supporting technical reports. Briefly, I consider the most significant contributions of my peer review role over the last four years to be:

1. Participation in the November 2015 field survey with Arrow, Coffey and 3D Environmental to identify and rationalise potential groundwater-dependent ecosystems (GDE), which in-turn informed the groundwater monitoring network.
2. Requesting greater transparency and improved reporting on the rationale for both the modelling scenarios and uncertainty analysis realisations adopted for the assessment of drawdown impacts.
3. Requesting additional monitoring bores along the northern boundary of the Red Hill Central area (MB1 and MB2) and a highly faulted region of the southern development area (MB15-S and MB15-I).
4. Improved reporting on the rationale for using an indirect modelling-based methodology rather than a direct monitoring-based methodology for establishing triggers, thresholds and limits for the Early Warning System (EWS).

**Table 1. Summary of memoranda, the Approval Conditions they address, and reference to the Appendix in which they are provided in the GMMP.**

| Memorandum Title | Conditions Addressed | Appendix |
|---|---|---|
| **Groundwater modelling** | 21(a) (part)<br>21(b) (part)<br>21(c) (part) | C |
| **Groundwater monitoring network** | 21(a)<br>21(b)<br>21(c) | D |
| **Groundwater monitoring program and Early Warning System** | 21(a) (part)<br>21(d)<br>21(e) | F |
| **GMMP review schedule** | 21(f)<br>21(g)<br>21(h) | G |

**Summary**
Based on my iterative peer review of the scientific assessments undertaken and the technical memoranda prepared over the last four years, my overall assessment is that every one of Approval Conditions 21(a) to 21(h) has been adequately addressed in the Groundwater Management & Monitoring Plan (see Table 2 below).

Accordingly, I hereby provide my professional endorsement of the findings and content of the GMMP.

Sincerely,

Dr. Glenn Harrington
Director & Principal Hydrogeologist

Innovative Groundwater Solutions Pty Ltd. | PO Box 2123 Victor Harbor SA 5211
**P** 0458 636 988 | **W** www.innovativegroundwater.com.au | ABN 17 164 365 495 | ACN 164 365 495

**Table 2. Suitably qualified water resource expert peer reviewer's assessment of whether Approval Condition 21 and sub-conditions have been adequately addressed in the GMMP.**

| Approval Condition | Condition Description | Condition Addressed |
|---|---|---|
| **21** | The approval holder must submit a Groundwater Management and Monitoring Plan (GMMP) for the written approval of the Minister who may seek the advice of an expert panel. The GMMP must contain: | - |
| **21a** | Details of a groundwater monitoring network for the measurement of impacts on water resources associated directly or indirectly with the action, including the ability to:<br>(i) provide for the early detection of any changes in the groundwater regime in terms of amplitude and frequency of fluctuations in water pressure, water level and water quality in groundwater systems and changes in connectivity with surface water;<br>(ii) monitor relevant formations to determine hydraulic connectivity and provide for early detection of impacts prior to reaching migration pathways to other formations (e.g. faults and areas of unconformities known to connect two or more formations);<br>(iii) monitor potential impacts on groundwater dependent ecosystems, including spring based and non-spring based ecosystems, and provide for the early detection of impacts;<br>(iv) monitor changes to the project area groundwater balance; and<br>(v) monitor changes to water availability for water users and the environment. | Yes |
| **21b** | Details of a baseline monitoring data acquisition program for the approved action. | Yes |
| **21c** | A rationale for the design of the monitoring network with respect to the nature of potential impacts and the location and occurrence of matters of national environmental significance. | Yes |
| **21d** | Details of proposed early warning indicators, trigger thresholds and limits for detecting impacts on groundwater levels and a description of how and when these measures will be finalised and subsequently reviewed in accordance with the requirements of an Underground Water Impact Report. | Yes |
| **21e** | Details of a risk based exceedance response for the actions the approval holder will take, and the timeframes in which these actions will be undertaken, if early warning indicators and trigger threshold values are exceeded. | Yes |
| **21f** | Details of the timeframe for a regular review of the GMMP in accordance with the requirements of the Underground Water Impact Report and subsequent updates of the GMMP, including to incorporate the outcomes of updates to the numerical groundwater model and water balance calculations. | Yes |
| **21g** | Provisions to make monitoring results publicly available on the approval holder's website for the life of the project. | Yes |
| **21h** | Provisions to make monitoring data available to the Department and Queensland Government authorities (if requested) for inclusion in any cumulative impact assessment, regional water balance model, bioregional assessment or relevant research. | Yes |