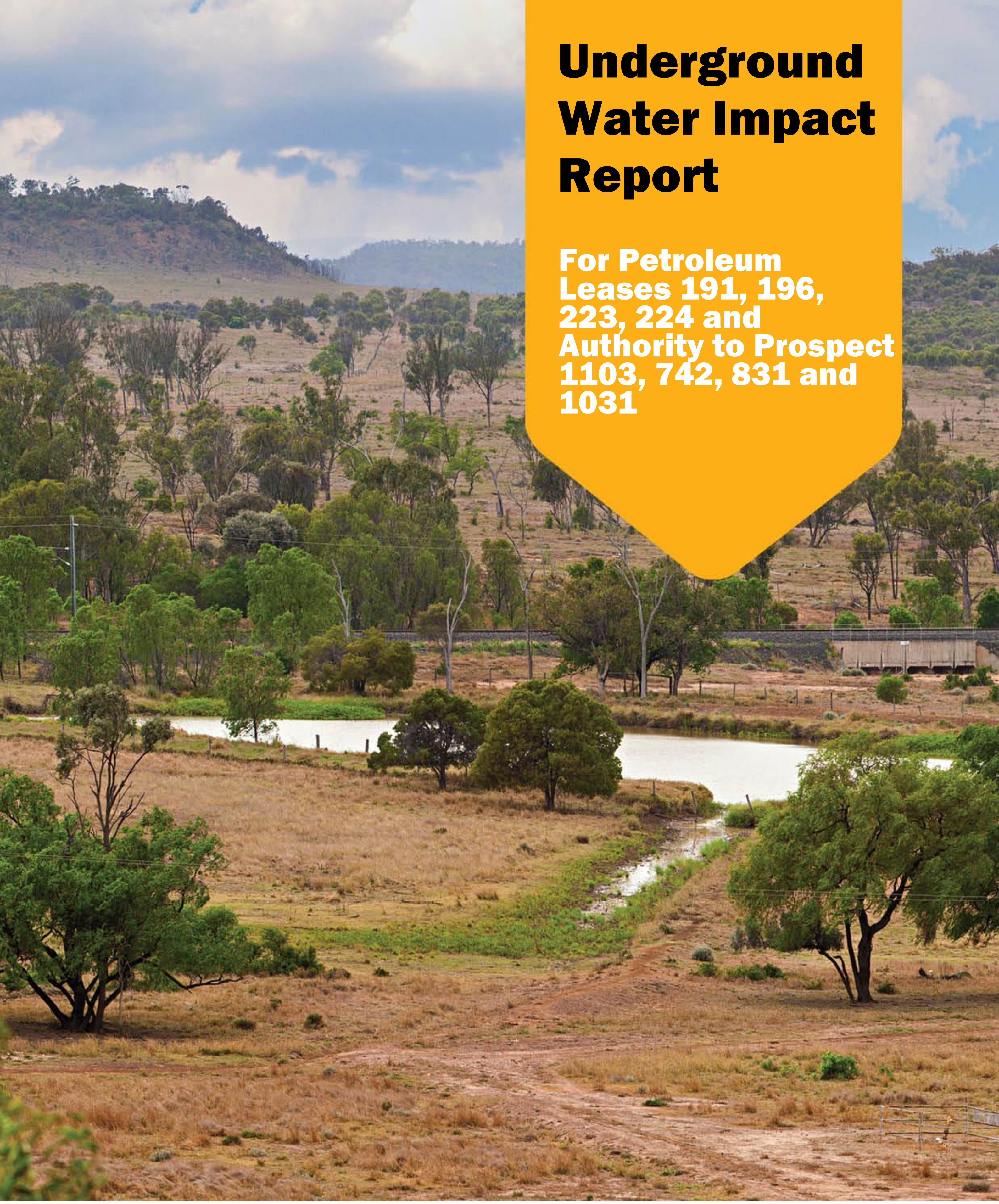

Underground Water Impact Report

For Petroleum Leases 191, 196, 223, 224 and Authority to Prospect 1103, 742, 831 and 1031

arrow energy
go further

August 2016

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EXECUTIVE SUMMARY

This Underground Water Impact Report (UWIR) provides information on the potential decline in water levels in aquifers within the Project Area as a result of the taking of water during production of coal seam gas (CSG) and production testing. The Project Area comprises Petroleum Leases (PLs) 191, 196, 223, 224 and Authorities to Prospect (ATPs) 1103, 1031, 742, 831.

Three separate UWIRs were previously prepared for tenures within the Project Area:

- PLs 191, 196, 223 and 224 (approved 6 March 2013);
- ATP 1031 (approved 6 March 2013); and
- ATP 1103 (approved 21 March 2014).

A conceptual hydrogeological model was developed as part of these UWIRs. The UWIRs also included predictions of potential depressurisation impacts on groundwater resources as a result of CSG production. These predictions were made using a numerical groundwater model (the 2012 UWIR Model).

The conceptual hydrogeological model was updated as part of the Bowen Gas Project Environmental Impact Statement (EIS) and Supplementary Report to the EIS (SREIS). A new numerical model, the EIS Model, was then developed to support the EIS.

This UWIR includes:

- the quantity of water taken because of the exercise of any previous relevant underground water rights;
- the quantity of water estimated to be taken because of the exercise of any relevant underground water rights over the next three years;
- an updated description of aquifers potentially affected (informed by information collected since the publication of the previous UWIRs) including how the aquifer interacts with other aquifers;
- the predicted water level decline as a result of the taking of water and a description of the methods and techniques used to make the prediction;
- information on water bores that may be impacted by a water level decline in excess of the bore trigger threshold; and
- a program for conducting an annual review of the predictions.

Historical water production from the Project Area is 4,957ML. In the next 3 years an additional 762ML is forecast to be produced from PLs 191, 196, 223 and 224.

The validity of the existing conceptual hydrogeological model was reviewed in light of new data from site (including from implementation of the Water Monitoring Strategies described in the previous UWIRs). It was concluded that:

- Data obtained to date is in support of the existing conceptual hydrogeological model, and
- The EIS Model is considered to be suitable for predicting depressurisation impacts as a result of CSG operations for the Project Area as part of this UWIR.

The EIS Model has been updated as part of the development of this UWIR so that the wells simulated in the model reflect historical and forecast production and historical production testing. An analytical groundwater model was also developed for part of the Project Area.

The aforementioned groundwater models have been utilised to predict water level decline in aquifers as a result of the taking of water during production of coal seam gas (CSG) and production testing. This includes identification of Immediately Affected Areas (IAAs; where the predicted drawdown within the next three years exceeds the bore trigger threshold). Key findings are:

- Within PLs 191, 196, and 224 an IAA exists for the Moranbah Coal Measures. This is associated with production of CSG in these tenures. There are no existing or useable bores in this IAA.
- Within ATPs 1103, 1031 and 831 there are small areas of IAA for the Moranbah Coal Measures, Rangal Coal Measures and Baralaba Coal Measures. These are associated with proposed production testing in these tenures. There are no existing or useable bores located within these IAAs.
- There are no IAAs in any of the other aquifers (including alluvial and Tertiary aquifers) modelled within the project area.

A water monitoring strategy has been prepared. The strategy proposes the installation and monitoring of a total of 45 groundwater monitoring bores. The installation of 16 of these groundwater monitoring bores, located on PLs 191, 196, 223 and 224 has been completed. Groundwater monitoring has commenced in these bores. The remaining 29 bores are proposed for groundwater monitoring of potential future impacts associated with the proposed Bowen Gas Project.

This report will be reviewed annually. The review will consider:

- new hydrogeological data that significantly alters the conceptual model;
- whether new production testing or production has been undertaken or is planned; and
- whether the predictions made have materially changed.

1 INTRODUCTION

1.1 Preamble

Pursuant to s. 370(3)(b) of the Water Act 2000, the chief executive of the Department of the Environment and Heritage Protection (DEHP) has directed Arrow Energy Pty. Ltd (Arrow) to submit a single Underground Water Impact Report (UWIR) for Petroleum Leases (PL) 191, 196, 223 and 224 and Authority to Prospect (ATP) 1103, 1031, 831, and 742.

Three separate UWIRs were previously prepared for:

- PLs 191, 196, 223 and 224 (DEHP Reference 46623) which was approved with conditions on the 6 March 2013;
- ATP 1031 (DEHP Reference 101/0004991) which was approved with conditions on the 6 March 2013; and
- ATP 1103 (DEHP Reference 46622) which was approved with conditions on 21 March 2014.

No previous UWIRs have been prepared for ATPs 831 and 742. This report represents a single UWIR for PLs 191, 196, 223, 224 and ATPs 1103, 1031, 742 and 831.

The due date for submitting the single UWIR was set at 21 March 2016.

On this basis, this report provides information on the potential decline in water levels in aquifers due to the taking of water during coal seam gas (CSG) production and CSG production testing activities in Arrow's Bowen Basin tenure (detailed above), as required by the Water Act 2000.

The Registered holders of the tenure covered in this report are presented in the table below.

Table 1: ***Arrow's Tenements, Registered Holder details***

Tenure	Registered Holder
PL 191, PL196, PL223 and PL224	AGL Energy Limited ACN 115 061 375 (50%), CH4 Pty Ltd ACN 092 501 016 (35%) and Arrow CSG (ATP 364) Pty Ltd ACN 092 970 557 (15%)
ATP 742	CH4 Pty Ltd ACN 092 501 016 (100%)
ATP 831	Pure Energy Resources Pty Limited ACN 115 514 880 (50%), Arrow Energy Pty Ltd ACN 078 521 936 (35%), and Arrow CSG (Australia) Pty Ltd ACN 054 260 650 (15%)
ATP 1031	Bow CSG Pty Ltd ACN 117156742 (100%)
ATP 1103	AGL Energy Limited ACN 115 061 375 (99%), CH4 Pty Ltd ACN 092 501 016 (0.7%) and Arrow CSG (ATP 364) Pty Ltd ACN 092 970 557 (0.3%)

1.2 Project Area

Arrow's Bowen Basin tenure is the subject of both production wells (in PLs) and production testing activities (in ATPs) for CSG. The spatial distribution of Arrow's tenure in the Bowen Basin is shown in **Figure 1** and spans the area, from north to south, around the towns of Glenden, Moranbah, Dysart, Middlemount, Saraji, Norwich, Essex, Dingo and Baralaba. The Project Area includes:

- The Moranbah Gas Project (MGP) Area (Arrow's existing production field) comprising PLs 191, 196, 223 and 224 and the following production between 2003 and 2015:
    - approximately 689 production and production testing wells distributed over 49,225 hectares,

- an existing gathering system consisting of approximately 188 kilometres of easements containing gas and water gathering lines from the well heads to relevant gas compression and water storage facilities, and
- 5 approved compressor facilities including the Moranbah Gas Processing Facility (MGPF) and the Node 1, 2, 3 and 4 compressor stations.

- The Arrow Bowen Tenement (ABT) Area (within which exploration and production testing has been undertaken) comprising ATPs 1103, 1031, 831, and 742 and including:
  - Exploration and Testing:
    - ATP 742 - including 3 production testing wells used for production tests in 2015;
    - ATP 1031 - including 6 wells used for production tests between 2012 and 2015;
    - ATP 831 - including 4 wells used for production tests between 2012 and 2015;
    - ATP1103 - including 95 production testing wells between 2008 and 2015.
  - Bowen Gas Project (BGP):
    - Future proposed development that lies within the ATPs 1103, 742, 1031 tenements.

The MGP Area, ABT Area and the BGP are collectively referred to as the Project Area. This is shown in **Figure 1**.

ARROW ENERGY - BOWEN BASIN GAS PROJECT

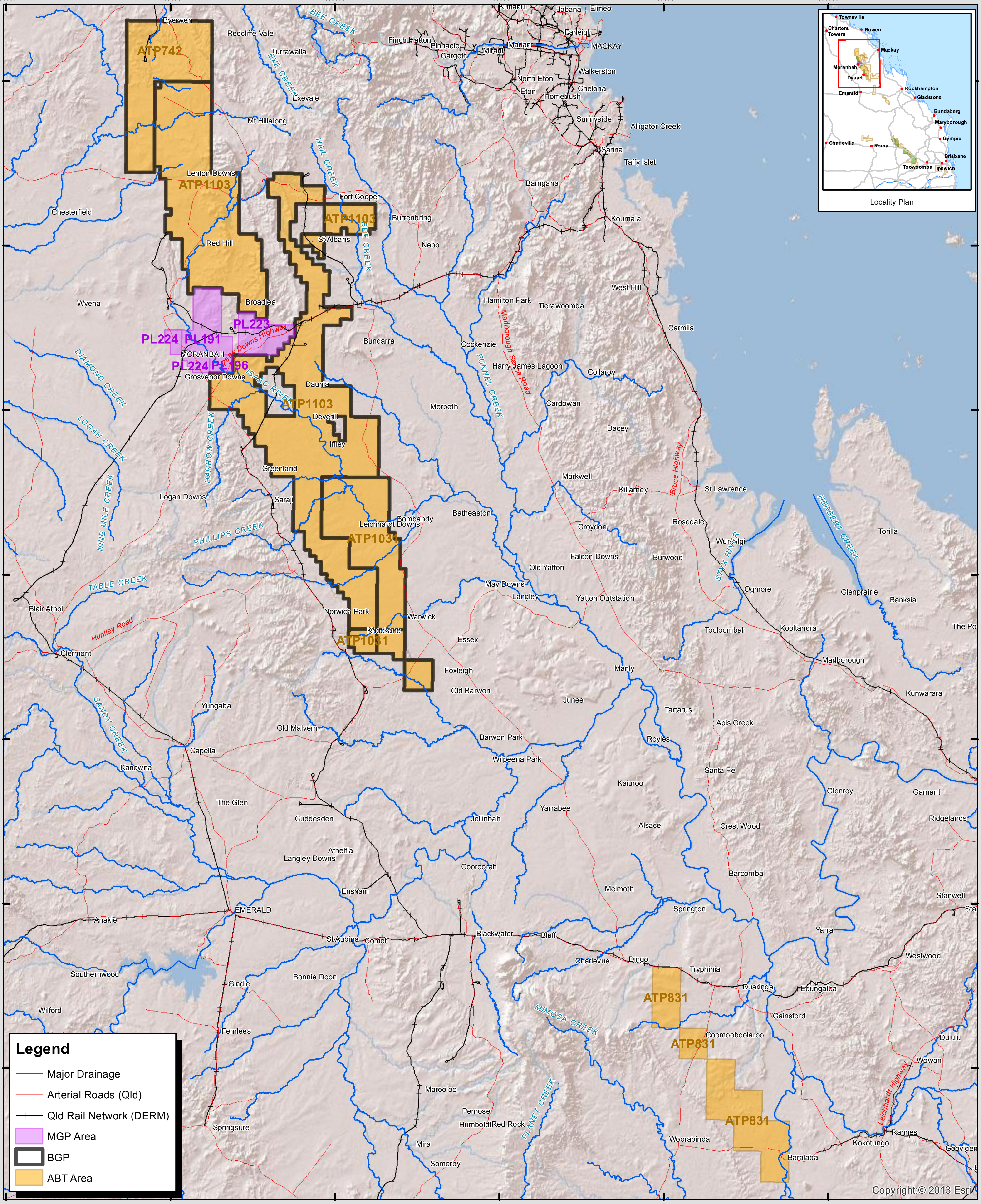

Figure 1. Arrow Energy's Tenements in the Bowen Basin

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 4/01/2016
Issued To: K Singh
Author: tstringer

0 25 50 100
Kilometres
Scale: 1:1,093,000@ A3
Coordinate System: GDA 1994 MGA Zone 55

N

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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

1.3 Requirement for a UWIR

1.3.1 Cumulative Management Areas

The state government may declare cumulative management areas (CMAs) in areas of concentrated CSG development where the impacts on water levels caused by individual petroleum and gas projects can overlap. In Queensland, the area of planned concentrated CSG development has been declared as the Surat CMA.

With the exception of ATP 831, Arrow's operations/project in the Bowen Basin falls outside of the Surat CMA, and under the Water Act (QLD) 2000, there is a requirement to prepare an UWIR.

In the case of ATP 831, which straddles the Surat CMA boundary, the DEHP has instructed Arrow that it must prepare a UWIR for ATP 831 on the basis that:

- the hydrogeology of ATP 831 is generally more similar to the that of the Bowen Basin than the Surat Basin;
- limited production testing has been undertaken to date on ATP831; and
- there is no future production testing planned in ATP831.

This requirement is addressed by this report.

1.3.2 This UWIR

This report forms the UWIR for Arrow's CSG activities in the Bowen Basin, including production and production testing wells, contained within the bounds of the combined tenure.

The purpose of this report is to address Chapter 3, and in particular, s376 of the Water Act (Qld) 2000 which stipulates that the UWIR must include:

a) For the area to which the report relates –

   i. The quantity of water produced or taken from the area because of the exercise of any previous relevant underground water rights; and
   ii. An estimate of the quantity of water to be produced or taken because of the exercise of the relevant underground water rights for a 3 year period starting on the consultation day for the report;

b) For each aquifer affected, or likely to be affected, by the exercise of the relevant underground water rights–

   i. A description of the aquifer; and
   ii. An analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and
   iii. An analysis of the trends in water level change for the aquifer because of the exercise of the rights mentioned in paragraph (a)(i); and
   iv. A map showing the area of the aquifer where the water level is predicted to decline, because of the taking of the quantities of water mentioned in paragraph (a), by more than the bore trigger threshold within 3 years after the consultation day for the report; and
   v. A map showing the area of the aquifer where the water level is predicted to decline, because of the exercise of relevant underground water rights, by more than the bore trigger threshold at any time;

c) A description of the methods and techniques used to obtain the information and predictions under paragraph (b);

d) A summary of information about all water bores in the area shown on a map mentioned in paragraph (b)(iv), including the number of bores, and the location and authorised use or purpose of each bore;

e) A program for –

f) Conducting an annual review of the accuracy of each map prepared under paragraph (b)(iv) and (v); and

g) Giving the chief executive a summary of the outcome of each review, including statement of whether there has been a material change in the information or predictions used to prepare the maps;

h) A water monitoring strategy;

i) A spring impact management strategy;

j) Other information or matters prescribed under a regulation.

1.4 Legislation

The primary legislative requirements for the management and development of groundwater for Arrow's Bowen Basin activities are summarised below.

1.4.1 Petroleum and Gas (Production and Safety) Act 2004 and Petroleum Act 1923

The *Petroleum and Gas (Production and Safety) Act 2004* (P&G Act, 2004) and the *Petroleum Act 1923* regulate coal seam gas activities and also govern groundwater management in relation to CSG development. Under the P&G Act, the petroleum tenure holder may take or interfere with water if taking or interference happens during the course of, or results from, the carrying out of another authorised activity for the tenure. These rights are subject to the tenure holder complying with the holder's underground water obligations (defined in the *Water Act 2000*).

1.4.2 Water Act 2000

Chapter 3 of the *Water Act 2000* provides for the management of impacts on underground water caused by the exercise of underground water rights by petroleum tenure holders. This is achieved primarily by:

- providing a regulatory framework to:
    - require petroleum tenure holders to monitor and assess the impact of the exercise of underground water rights on water bores and to enter into 'make good' agreements with the owners of the bores;
    - requires the preparation of UWIRs that establish underground water obligations, including obligations to monitor and manage impacts on aquifers and springs;
    - manage the cumulative impacts from 2 or more petroleum tenure holders' underground water rights on underground water; and
- giving the chief executive and the office functions and powers for managing underground water.

If a water bore has an impaired capacity as a result of CSG activities, an agreement will be negotiated with the owner of the bore about the following:

- The reason for the bore's impaired capacity.
- The measures the holder will take to ensure the bore owner has access to a reasonable quantity and quality of water for the authorised use and purpose of the bore;
- Any monetary or non-monetary compensation payable to the bore owner for impact on the bore.

If an agreement relating to a water bore is made the agreement is taken to be a 'make good' agreement for the bore.

An UWIR will identify whether an 'immediately affected area' will result from CSG activities. An immediately affected area is defined as an area where the predicted decline in water levels within 3 years is at least:

- 5 m for a consolidated aquifer.
- 2 m for an unconsolidated aquifer.
- 0.2 m for a spring.

UWIRs are published to enable comments from bore owners within the area. Submissions made by bore owners will be summarised by Arrow, addressed as appropriate and provided to the Department of Environment and Heritage Protection (DEHP). UWIRs are submitted for approval by DEHP. The OGIA may also advise DEHP about the adequacy of these reports.

The DEHP will maintain a database of information collected under monitoring plans carried out by petroleum tenure holders in accordance with approved UWIRs. The database will also incorporate bore baseline data collected by petroleum tenure holders.

1.5 Summary of Methods

This UWIR builds on information presented in the:

- UWIR for PLs 191, 196, 223, 224 (Arrow Energy, 2012a);
- UWIR for ATP 1103 (Arrow Energy, 2012b);
- Bowen Gas Project Environmental Impact Statement (EIS) (Arrow Energy, 2012c);
- UWIR for ATP 1031 (Arrow Energy, 2014a); and
- Bowen Gas Project Supplementary Report to the EIS (Arrow Energy, 2014b).

Since the development of the previous UWIRs for PLs 191, 196, 223, 224 and ATPs 1103 and 1031, the conceptual understanding of groundwater occurrence and processes in the Project Area has been updated as part of the Bowen Gas Project Environmental Impact Statement (EIS) and the Supplementary Report to the EIS (SREIS).

Following on from the above mentioned groundwater assessments, additional investigations have been undertaken. Collection of new data from site has been presented in this UWIR to provide an update of the previously developed conceptual models. This has formed the basis for the development of an analytical groundwater model and validation of the numerical groundwater model developed as part of the EIS (the EIS Model).

An assessment of impacts to groundwater from the production and production testing activities has been undertaken based on the following tasks:

- Task 1: Review and analysis of site specific monitoring and assessment data
- Task 2: Hydrogeological assessment and conceptualisation
- Task 3: Numerical and Analytical groundwater model development for making predictions of groundwater impacts
- Task 4: Identification of potential impacts on groundwater
- Task 5: Development and review of the Water Monitoring Strategy (WMS) and Spring Impact Management Strategy (SIMP)

This UWIR presents updated analytical and numerical modelling based on updated production and production testing data. The EIS Model was utilised to predict the potential impacts to groundwater and underpin the development of the management strategies presented in this report.

A summary of the reporting requirements as stipulated in the *Water Act 2000* for this UWIR and relevant sections of this report in which they have been addressed is included in **Table 2** below.

Table 2: *Water Act 2000* reporting requirements for this UWIR

UWIR reporting requirement	Report Section
a) For the area to which the report relates – i. The quantity of water produced or taken from the area because of the exercise of any previous relevant underground water rights; and	Section 2
ii. An estimate of the quantity of water to be produced or taken because of the exercise of the relevant underground water rights for a 3 year period starting on the consultation day for the report;	Section 2
b) For each aquifer affected, or likely to be affected, by the exercise of the relevant underground water rights– i. A description of the aquifer; and	Section 3
ii. An analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and	Section 3, Section 5
iii. A description of the aquifer; and	Section 3, Section 7
iv. An analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and	Section 3, Section 5
v. An analysis of the trends in water level change for the aquifer because of the exercise of the rights mentioned in paragraph (a)(i); and	Section 5
vi. A map showing the area of the aquifer where the water level is predicted to decline, because of the taking of the quantities of water mentioned in paragraph (a), by more than the bore trigger threshold within 3 years after the consultation day for the report; and	Section 9
vii. A map showing the area of the aquifer where the water level is predicted to decline, because of the exercise of relevant underground water rights, by more than the bore trigger threshold at any time;	Section 9
c) A description of the methods and techniques used to obtain the information and predictions under paragraph (b);	Section 1, Section 4, Section 8
d) A summary of information about all water bores in the area shown on a map mentioned in paragraph (b)(iv), including the number of bores, and the location and authorised use or purpose of each bore;	Section 9
e) A program for –	Section 11

UWIR reporting requirement	Report Section
i. Conducting an annual review of the accuracy of each map prepared under paragraph (b)(iv) and (v); and	
ii. Giving the chief executive a summary of the outcome of each review, including statement of whether there has been a material change in the information or predictions used to prepare the maps;	Section 7, Section 8
f) A water monitoring strategy;	Section 10
g) A spring impact management strategy;	Not applicable to the Project Area. Refer to Section 6
h) If the responsible entity is the commission – i. A proposed responsible tenure holder for each report obligation mentioned in the report; and	Not applicable to the Project Area
ii. For each immediately affected area – the proposed responsible tenure holder or holders who must comply with any make good obligations for water bores within the immediately affected area;	Not applicable to the Project Area
i) Other information or matters prescribed under a regulation.	No matters identified
S378 1(a) (i) Water Monitoring Strategy	Section 10, Section 5
(i)Strategy for monitoring the quantity of water produced	
(ii) Strategy for monitoring changes in water level	
(b) Rationale for the strategy	
(c) Timetable for implementing the strategy	
(d) Program for reporting the implementation of the strategy	
2 Strategy must include:	
(a) The parameters to be measured	
(b) Locations for taking the measurements	
(c) Frequency of the measurements	
3 A program for a baseline assessment for each bore that is:	
(a) Outside the tenure, within an immediately or long term affected area	

2 EXISTING AND FORECAST WATER PRODUCTION

Historical water production data since the last UWIR has been compiled for the production and production testing wells to provide an indication of the quantity of water taken for the Project Area.

The volumes of water produced in the wells are measured using various methods. Progressive cavity pumps (PCPs) are used in the gas production and production testing (appraisal) wells. These pumps work by rotating an eccentric screw which pushes the water upwards as the screw moves eccentrically within the pump housing. This results in the flow rate being proportional to the rate of rotation of the pump. These pumps are rated for a given flow rate at a given number of revolutions per minute (rpm) rating.

To calculate the volume of water produced from the PCPs, a flow test is undertaken whereby the pump rate and time for a known volume of water to be pumped is used to calculate an efficiency factor. This is applied to a record of the pumps operating rpm to calculate the volume of water pumped. This flow test is undertaken regularly to maintain the accuracy of the flow calculation.

In addition, the total volume of water pumped into the dam constructed to hold the pilot test water is used as a check on this calculation.

Available forecasts of water production have been compiled for the MGP Area as well as the BGP. Production data are provided for each tenure in the following sections.

2.1 Water Production Summary – MGP Area

The total volume of water taken from each PL, since the last UWIR, in the MGP Area during production and production testing is presented in **Table 3**. It should be noted that whilst PLs 191, 196, 223 and 224 make up the MGP, production has only been undertaken in PLs 191, 196 and 224.

Table 3: Historical water production and production testing data

Tenure	Formation	Production 2003 – 2011	Production 2012 – 2015*	Production Testing 2003 – 2011	Production Testing 2012 – 2015*
		Volume (ML)	Volume (ML)	Volume (ML)	Volume (ML)
PL191	GM Seam	1439.4	697.9	0	0
	P Seam	1038.5	421.2	0	0
	Q Seam	22.2	0	0	0
	Moranbah Coal Measures (GM, P, GML, Q Seams)	105.4	99.5	4.5	30.2
	Fort Cooper Coal Measures and Moranbah Coal Measures	0	0	29.0	0
PL196	GM Seam	77.9	73.1	0	0
	P Seam	127.0	14.4	0	0
	Moranbah Coal Measures (GM, P, GML, Q Seams)	132.3	124.1	0	0
PL223	FG1 Seam	0	0	2.8	0

Tenure	Formation	Production 2003 – 2011	Production 2012 – 2015*	Production Testing 2003 – 2011	Production Testing 2012 – 2015*
		Volume (ML)	Volume (ML)	Volume (ML)	Volume (ML)
	Rangal Coal Measures	0	0	0	0.4
PL224	GM Seam	55.9	42.8	0	0
	P Seam	6.6	12.1	0	0
	Moranbah Coal Measures (GM, P, GML, Q Seams)	42.2	42.9	0	0
CUMULATIVE TOTAL		**3047.4**	**1528.0**	**36.3**	**30.6**

*Note 2015 production volumes are to 20 November 2015

In summary, historical water production data for the production and production testing wells in MGP PLs 191, 223, 196, and 224 for period 2012-2015 indicates a total of 1528 ML and 31 ML respectively.

The water production data has been plotted in **Figure 2** to illustrate the proportion of water extracted historically from the petroleum leases that make up the MGP.

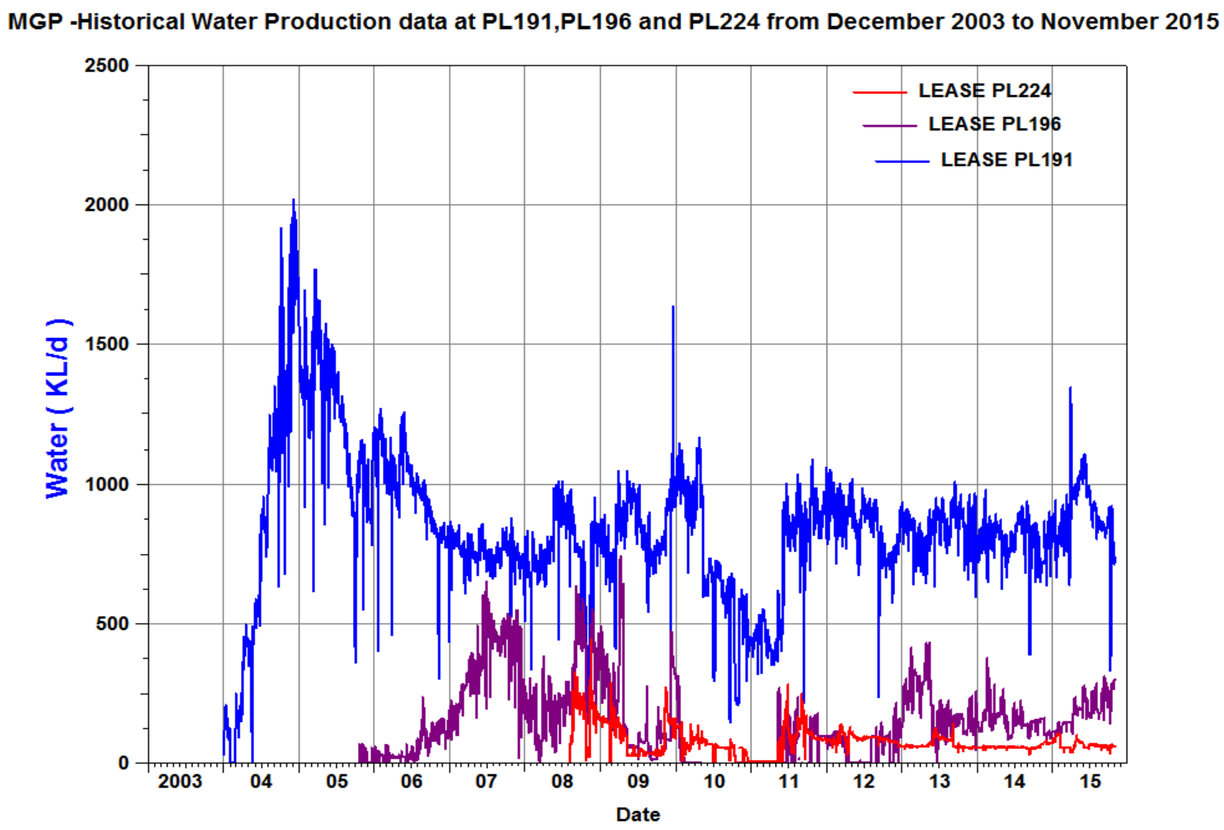

Figure 2: Water produced from production wells on PL191, PL196 and PL224

2.2 Forecast of Production Data – MGP Area

A forecast of the quantity of water to be produced for a 3 year period (commencing 6/1/2016) has been estimated for PL191, PL196 and PL224. In addition to this, a forecast of production has also been provided up until 2025. It should be noted that there is no production forecast for PL223 as plans for the development of PL223 have not been finalised. Field development of PLs 191, 196 and 224 are on-going and any updates to the forecast production will be incorporated into future annual review reporting.

The methodology for developing forecast water production data for the MGP is based on a Decline Curve Analysis (DCA). Historical production of existing wells is matched using DCA. This involves matching the profile of water production with an empirical set of equations. These equations predict the long term behaviour of the well. They are widely used in the industry as wells of all types tend to follow these trends. The parameters in the equations are matched to historical production, and the functions are then used to predict the water (and gas) profiles of the wells. This has proven a reliable method in both gas and water production prediction in the project area given the nature of the production trend. The accuracy of the prediction is subject to uncertainties in the measurement and reporting of the historical water rates.

Forecast production of coal seam gas water for the project is presented in **Table 4.** It should be noted that currently, water production (2018 ML) is from the Moranbah Coal Measures.

Table 4: Forecast water production data for the MGP

Year	Total Forecast Water Production (ML)
2016	279
2017	252
2018	231
2019	213
2020	199
2021	187
2022	177
2023	168
2024	160
2025	152
Total	**2018**

Currently no production testing is forecast in the MGP Area.

2.3 Water Production Summary – ABT Area

Historical water production data for the production testing wells on ATP 742, 831, 1031 and 1103 in the Bowen Basin are summarised in **Table 8**5 to **Table 8**. This indicates a cumulative total of approximately 315 ML of water.

2.3.1 ATP 742

Water production data for the production testing wells in ATP 742 in the project area is summarised in **Table 5**.

Table 5: Summary of Production Testing in ATP 742

Well Name	Date Start	Date End	Total days of water production	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
CE010V	09/04/2015	19/11/2015	186	3.327	0.619	Moranbah Coal Measures
Newlands 10	15/06/2015	19/11/2015	131	1.997	0.262	Moranbah Coal Measures
Byerwen 3	09/02/2015	20/11/2015	235	536.12	0.126	Moranbah Coal Measures
Cumulative Total (ML)					**1**	

2.3.2 ATP 831

Water production data for the production testing wells in ATP 831 in the project area is summarised in **Table 6**.

Table 6: Summary of Production Testing in ATP 831

Well Name	Date Start	Date End	Total days of water production	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
CM005FR	13/12/2012	01/05/2014	295	10.030	2.958	Baralaba Coal Measures
CM004F	14/11/2012	22/05/2014	364	10.972	3.993	Baralaba Coal Measures
BR08F	05/07/2015	15/11/2015	133	8.843	1.176	Baralaba Coal Measures
BR06F	08/07/2015	15/11/2015	131	13.562	1.776	Baralaba Coal Measures
Cumulative Total (ML)					**10**	

2.3.3 ATP 1031

Water production data for the production testing wells in ATP 1031 in the project area is summarised in **Table 7**.

Table 7: Summary of Production Testing in ATP 1031

Well Name	Date Start	Date End	Total days of water production	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
PY031	29/07/2013	25/09/2014	27	3.7	1.390	Rangal Coal Measures

Well Name	Date Start	Date End	Total days of water production	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
VM010V	07/11/2013	02/11/2014	354	30.826	7.829	Rangal Coal Measures
VM011V	07/11/2013	14/11/2014	365	15.480	5.650	Rangal Coal Measures
PY030	20/12/2012	06/12/2014	38	1.03	0.553	Rangal Coal Measures
PY012A	10/06/2015	19/06/2015	7	0.364	0.003	Rangal Coal Measures
PY011A	13/06/2015	19/06/2015	1	0.142	0.000142	Rangal Coal Measures
Cumulative Total (ML)					**15**	

2.3.4 ATP 1103

Water production data for the production testing wells in ATP 1103 in the project area is summarised in **Table 8**.

Table 8: Summary of Production Testing in ATP1103

Bore Name	Date Start	Date End	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
HY001	29-Nov-08	23-Apr-09	1.801	0.243	Rangal Coal Measures
MB05V	12-Nov-08	10-Jul-09	0.438	0.122	Moranbah Coal Measures
MB04V	12-Nov-08	26-Aug-09	0.148	0.0411	Moranbah Coal Measures
MB06	12-Nov-08	26-Aug-09	0.245	0.068	Moranbah Coal Measures
MB07V	12-Nov-08	27-Aug-09	0.118	0.032	Moranbah Coal Measures
MB03V	12-Nov-08	27-Aug-09	0.213	0.059	Moranbah Coal Measures
HY01	23-Apr-09	28-Aug-09	1.906	0.244	Rangal Coal Measures
HY02	18-Nov-08	28-Aug-09	0.498	0.136	Rangal Coal Measures
SRJ001	29-Jun-09	03-Mar-10	23.183	6.653	Moranbah Coal Measures
SRJ002	29-Jun-09	04-Mar-10	20.525	5.911	Moranbah Coal Measures
SRJ003	29-Jun-09	04-Mar-10	45.644	12.186	Moranbah Coal Measures
RHGU020	26-Aug-09	24-Apr-10	3.669	0.880	Moranbah Coal Measures
RHGU019	26-Aug-09	19-Jul-10	2.073	0.665	Moranbah Coal Measures
LW006	03-Aug-09	06-Aug-10	15.837	4.973	Moranbah Coal Measures
LW007	03-Aug-09	14-Aug-10	25.974	8.337	Moranbah Coal Measures
LW005	03-Aug-09	15-Aug-10	105.362	39.826	Moranbah Coal Measures
COX10	04-Nov-09	04-Oct-10	16.223	3.342	Rangal Coal Measures
RHGU001	12-Nov-08	08-Oct-10	7.190	5.529	Moranbah Coal Measures
RHGU002	14-Dec-08	01-Nov-10	20.363	15.008	Moranbah Coal Measures
RH014GL1	29-Dec-08	03-Nov-10	4.297	3.081	Moranbah Coal Measures
COX016	19-May-10	25-Jan-11	7.467	1.067	Rangal Coal Measures
RH013GL1	19-Mar-09	30-Jan-11	0.834	0.566	Moranbah Coal Measures
WW019	22-Dec-09	31-Jan-11	1.790	0.816	Moranbah Coal Measures

Bore Name	Date Start	Date End	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
WW020	19-Dec-09	31-Jan-11	3.522	1.641	Moranbah Coal Measures
WW023	24-Aug-10	31-Jan-11	3.052	0.656	Fort Cooper Coal Measures
SC006LC	28-Sep-09	31-Jan-11	3.034	1.541	Rangal Coal Measures
RHGM008	11-Nov-08	01-Feb-11	4.182	3.358	Moranbah Coal Measures
RHGM009	11-Nov-08	01-Feb-11	2.165	1.791	Moranbah Coal Measures
SC007LC	30-Sep-09	09-Feb-11	1.654	0.889	Rangal Coal Measures
SC008LC	28-Sep-09	24-Mar-11	2.461	1.299	Rangal Coal Measures
RHGU003	11-Nov-08	24-Feb-11	5.248	4.009	Moranbah Coal Measures
RH015GL1	29-Dec-08	24-Mar-11	4.877	3.823	Moranbah Coal Measures
KC008	03-Jul-10	24-Mar-11	4.792	1.509	Rangal Coal Measures
KC009	02-Jul-10	24-Mar-11	0.528	0.134	Rangal Coal Measures
WW018	12-Dec-09	31-Mar-11	16.262	7.659	Moranbah Coal Measures
WW021	28-Aug-10	24-Apr-11	12.875	2.678	Fort Cooper Coal Measures
COX11	04-Nov-09	24-May-11	7.051	3.032	Rangal Coal Measures
SRJ020	10-May-10	24-May-11	1.562	0.834	Moranbah Coal Measures
COX018	21-Apr-10	24-May-11	10.427	3.659	Rangal Coal Measures
RHGM007	11-Nov-08	02-Jun-11	2.987	2.643	Moranbah Coal Measures
SRJ021	25-May-10	12-Jun-11	2.434	1.273	Moranbah Coal Measures
RH023GL	09-Apr-10	04-Aug-11	4.503	2.075	Moranbah Coal Measures
RH027GU	18-Apr-10	11-Aug-11	5.788	3.131	Moranbah Coal Measures
SRJ019	10-May-10	06-Sep-11	1.155	0.630	Moranbah Coal Measures
RH022GL	09-Apr-10	16-Sep-11	5.943	3.411	Moranbah Coal Measures
RH024GL	09-Apr-10	16-Sep-11	1.709	0.977	Moranbah Coal Measures
RH025GU	10-Apr-10	03-Oct-11	4.928	2.651	Moranbah Coal Measures
RHGM35	01-Sep-11	15-Nov-11	4.191	0.318	Moranbah Coal Measures
RHGM035	14-Oct-09	24-Jan-12	6.297	5.219	Moranbah Coal Measures
COX019	10-Jun-10	23-Jun-12	4.922	2.912	Rangal Coal Measures
COX020	09-Jun-10	30-Jun-12	5.209	3.089	Rangal Coal Measures
COX021	10-Jun-10	23-Jun-12	5.364	3.261	Rangal Coal Measures
RH014	27-Apr-12	11-Sep-12	6.378	0.739	Moranbah Coal Measures
RH026GU	18-Apr-10	20-Dec-12	5.422	5.290	Moranbah Coal Measures
WW015F	19-Apr-12	16-Feb-13	4.517	1.151	Fort Cooper Coal Measures
PD141V	16-Feb-13	15-Mar-13	2.928	0.079	Moranbah Coal Measures
WW016F	19-Apr-12	15-Apr-13	2.721	0.821	Fort Cooper Coal Measures
RH031F	29-Oct-11	16-Apr-13	5.693	1.837	Fort Cooper Coal Measures
RH033F	01-Nov-11	16-Apr-13	2.461	0.936	Fort Cooper Coal Measures

Bore Name	Date Start	Date End	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
RH028F	17-Nov-11	21-Apr-13	6.152	1.925	Moranbah Coal Measures
RH030F	16-Nov-11	25-May-13	1.896	0.544	Moranbah Coal Measures
CX014V	24-Jul-13	11-Nov-13	3.934	0.436	Rangal Coal Measures
RH080A	04-Jul-13	08-Jan-14	1.062	0.118	Moranbah Coal Measures
CX013V	24-Jul-13	31-Mar-14	6.426	1.088	Rangal Coal Measures
NP041V	06-Dec-13	29-Jun-14	3.947	0.572	Moranbah Coal Measures
OD011F	05-Aug-13	08-Jul-14	2.896	0.988	Rangal Coal Measures
OD012F	05-Aug-13	08-Jul-14	1.175	0.410	Rangal Coal Measures
PD131V	08-Jul-13	12-Jul-14	5.528	1.631	Moranbah Coal Measures
OD021F	18-Mar-13	11-Aug-14	0.849	0.487	Rangal Coal Measures
OD022F	16-Mar-13	11-Aug-14	0.964	0.570	Rangal Coal Measures
EF032V	17-Aug-13	30-Aug-14	3.161	1.161	Rangal Coal Measures
WB010LCV	31-May-13	25-Sep-14	9.359	4.442	Rangal Coal Measures
EF031V	15-Sep-13	15-Oct-14	16.387	6.536	Rangal Coal Measures
PD091V	01-Jun-13	03-Nov-14	13.852	7.039	Moranbah Coal Measures
WB011LCV	30-May-13	26-Nov-14	1.007	0.543	Rangal Coal Measures
PD100V	10-Jun-14	01-Feb-15	5.012	2.556	Moranbah Coal Measures
PD130V	08-Jul-13	11-Feb-15	13.072	6.575	Moranbah Coal Measures
PD140V	15-Feb-13	19-Feb-15	5.386	3.899	Moranbah Coal Measures
NP040A	06-Dec-13	15-Jun-15	5.506	1.530	Moranbah Coal Measures
PD111V	11-Jun-14	10-Jul-15	9.995	3.948	Moranbah Coal Measures
CX101	07-Nov-13	18-Aug-15	4.944	2.536	Rangal Coal Measures
MD040V	29-Sep-13	23-Aug-15	9.502	5.178	Rangal Coal Measures
MD041V	30-Sep-13	17-Sep-15	11.379	6.463	Rangal Coal Measures
EF061V	15-Apr-14	23-Oct-15	0.561	0.307	Rangal Coal Measures
PD122V	22-Jun-13	30-Oct-15	12.226	9.304	Moranbah Coal Measures
CX100	04-Nov-13	31-Oct-15	6.352	2.648	Rangal Coal Measures
EF060V	04-May-14	31-Oct-15	2.275	1.241	Rangal Coal Measures
PD120V	22-Jun-13	01-Nov-15	11.533	9.203	Moranbah Coal Measures
RH051F	10-Sep-13	01-Nov-15	1.354	0.362	Moranbah Coal Measures
CX090V	21-Jul-14	01-Nov-15	10.654	5.646	Rangal Coal Measures
CX091V	15-May-14	01-Nov-15	3.195	1.722	Rangal Coal Measures
PD101V	22-Jun-14	01-Nov-15	2.964	1.476	Moranbah Coal Measures
PD110V	09-Jun-14	01-Nov-15	8.214	4.189	Moranbah Coal Measures
RH050F	10-Sep-13	02-Nov-15	1.263	0.381	Moranbah Coal Measures
RH052F	10-Sep-13	02-Nov-15	2.466	0.660	Moranbah Coal Measures

Bore Name	Date Start	Date End	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
Cumulative Total (ML)				289	

2.4 Forecast Appraisal Program in ABT Area

At present, there are no new pilot testing programs planned for ATP 1031. Additional production testing is being considered for ATPs 742, 831and 1103, subject to additional geological appraisal and evaluation. However, proposed locations and schedules for production testing, should it proceed, have not yet been determined.

Forecasts for future production testing volumes cannot be provided. Instead, the IAA resulting from production testing has been estimated based on modelled impacts as at November 2015 resulting from all production testing in ABT area undertaken prior to that date. Based on available production testing well data, the impacts predicted for the IAA is the same as the LAA. Future water production as part of on-going production testing will be reviewed as part of the annual review process. The resultant impacts will be assessed based by comparing actual water production volumes with the largest modelled drawdown resulting from an individual production testing well. To date, the maximum amount of water produced from a single well was 39 ML at well LW005 over 2009 and 2010. The 5 m drawdown contour extended up to 1.5 km from production testing well LW005. A comparison of actual water production volumes will be undertaken for future production testing wells against LW005. Where production testing volumes are lower than LW005, it is assumed that the resultant drawdown will also be less.

2.5 Bowen Gas Project

Arrow's proposed BGP involves a phased expansion of Arrow's CSG production in the Bowen Basin to supply the liquefied natural gas (LNG) export market. An environmental impact statement (EIS) for the BGP has been approved by the State and Federal governments. The BGP entered front-end engineering design (FEED) in late 2014.

The project is divided into 3 phases (1, 2 and 3). It is assumed that production from Phase 1 will commence in 2019. However, the exact commencement of the project is subject to completion of FEED and Final Investment Decision (FID). Should any delays to the production schedule occur, this will be identified in the annual review of the UWIR. The annual review will include an evaluation of whether the identified delay represents a material change in information or material change to the predicted Immediately Affected Area or Long Term Affected Area.

Phase 1 of the proposed project runs from north of Moranbah to Glenden and, in the future, south of Moranbah (Phases 2 and 3). This area lies within the ATPs 1103, 742, 1031 assessed in this UWIR (the BGP). As part of the FEED process, a development scenario has been used as the reference case for the UWIR. The field development process will be an iterative process that will be ongoing through the life of the Project as gas reserves mature and actual production is realised. This includes definition of number of wells, well locations, field infrastructure, gas reserves and water production. It is important to note that the reference case presented in the UWIR represents a conservative scenario. In this scenario, water production estimates are "P10" which represents a high case i.e. there is only a 10 % chance that water production at these high rates will be realised and a 90% chance that less water will be produced.

A forecast of the quantity of water produced for a 3 year period (commencing 6/1/2016) has been estimated for the BGP. In addition to this, a forecast of production has also been provided up until 2049. Forecast production of coal seam gas water for the project is presented in **Figure 3** below. Field development of the BGP is on-going and any updates to the forecast production will be incorporated into future annual review reporting.

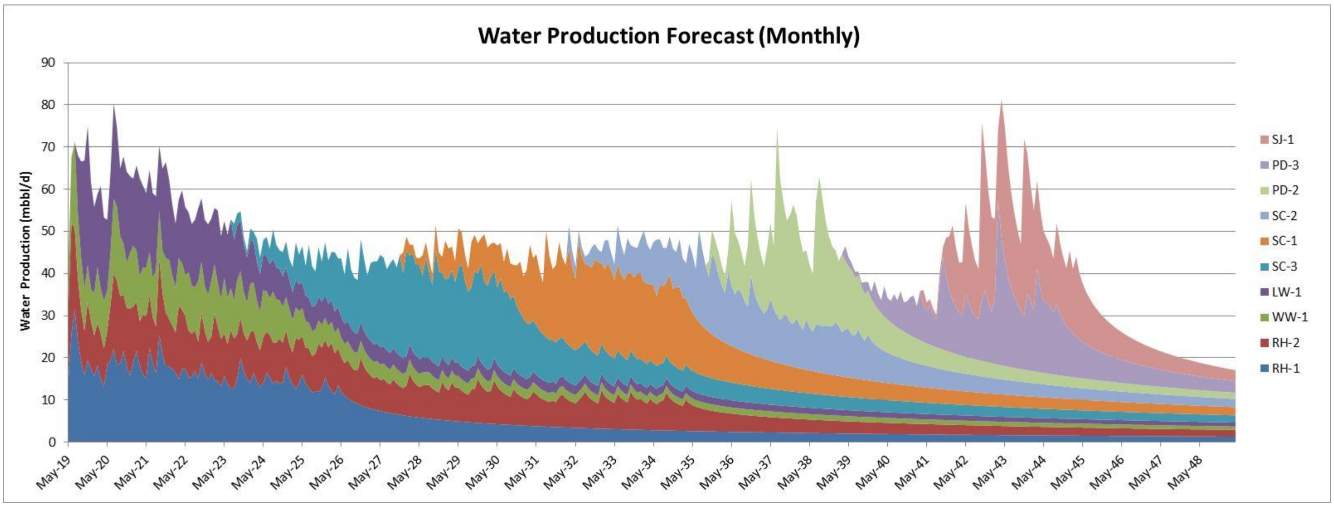

Figure 3: BGP Water Production Profile

3 EXISTING CONCEPTUAL MODEL

The conceptual hydrogeological model was described in the previous UWIRs for PLs 191, 196, 223, 224 (Arrow Energy, 2012a), ATPs 1103 (Arrow Energy, 2012b) and 1031 (Arrow Energy, 2014a). This was based predominantly on a desktop review of available groundwater related data including data from neighbouring coal mines, hydrogeological reports and records obtained from the DEHP and DNRM.

Since then an EIS (Arrow Energy, 2012c) and SREIS (Arrow Energy 2014b) were prepared for the BGP. The geological and hydrogeological setting of the Project Area was described in detail in the Bowen Gas Project EIS and SREIS groundwater chapters which are included in **APPENDIX A** and **B** of this UWIR respectively. A summary of the conceptual hydrogeological model (**Figure 10**), including geology and aquifers is provided in the following sections.

Since the EIS and SREIS, Arrow has undertaken site specific groundwater monitor bore drilling, monitoring, testing and baseline assessments which provided an update to the understanding of the conceptual hydrogeological model. This is discussed in more detail in Section 7 of this report.

3.1 Geological Summary

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 sedimentary sequence of Permo-Triassic clastics, which attain a maximum thickness of 9,000 m in the depocentre of the Taroom Trough.

Deposition in the Bowen Basin commenced during an Early Permian extensional phase, with fluvial and lacustrine sediments and volcanics being deposited in a series of half-grabens in the east while in the west a thick succession of coals and non-marine clastics were deposited. Following rifting there was a thermal subsidence (sag) phase extending from the Early to Late Permian, during which a basin-wide transgression allowed deposition of deltaic and shallow marine, predominantly clastic sediments as well as extensive coal measures. Foreland loading of the basin spread from east to west during the Late Permian, resulting in accelerated subsidence, which allowed the deposition of very thick successions of Late Permian marine and fluvial clastics, again with coal and Early to Middle Triassic fluvial and lacustrine clastics. Sedimentation in the basin was terminated by the Middle to Late Triassic (Geoscience Australia 2008).

The surface geology mapped across the Project Area is diverse (**Figure 4**). Approximately half of the Project area is covered by Late Tertiary and Quaternary unconsolidated sediments. This cover includes the Isaac River alluvial sediments, with thicknesses of 10 to 50 m along the Isaac River. The characteristics of the superficial Quaternary alluvium reflect the nature of the source rocks, weathering, transport, and depositional conditions. Poorly sorted clay, silt, sand and gravel represent floodplain alluvium: locally mottled, poorly consolidated sand, silt, clay and minor gravel, generally dissected by high-level alluvial deposits reflect present stream valleys.

The Tertiary sediment cover includes thick, clay-rich laterite, a result of the laterisation of Permian units during the Tertiary period. In addition, Tertiary aged infill includes palaeochannel deposits and basalt flows provide surficial cover across the Project area. The major Tertiary formations mapped in the Project area 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: the Late Permian Blackwater Group (Fort Cooper Coal Measures, Moranbah Coal Measures and Rangal Coal Measures) in the northernmost and north-eastern portion of the Project area; the mid-Triassic Moolayember Formation and Clematis Sandstone in the north-central portion of the Project area, and the Early Triassic Rewan Group can be found the northern portion of the Project area.

The stratigraphy of the Bowen Basin is summarised in **Table 9**. The Late Permian Blackwater Group comprises (from oldest to youngest) the Moranbah Coal Measures (MCM), the Fort Cooper Coal Measures (FCCM), and the Rangal Coal Measures (RCM).

Table 9: Regional Stratigraphy Bowen Basin

Period		Stratigraphic Unit			Description
Quaternary		Alluvium Alluvium, colluvium and other sediments in floodplains, alluvial fans, and high terraces			Clay, silts, sand, gravel, floodplain alluvium
Tertiary		Suttor Formation			Clay, silt, sand, gravel, colluvium, fluvial and lacustrine deposits including cross-bedded quartz sandstone, conglomerate, claystone
Tertiary		Basalt			Olivine rich weathered basaltic sands, weathered basalt, and fresh basalt flows
Tertiary		Duaringa Formation			Mudstone, sandstone, conglomerate, siltstone, oil shale, lignite and basalt
Triassic		Mimosa Group	Moolayember Formation		Mudstone, lithic sandstone, interbedded siltstone, mudstone, sandstone and thin coal seams.
Triassic		Mimosa Group	Clematis Sandstone		Cross-bedded quartz sandstone, some quartz conglomerate and minor red-brown mudstone.
Triassic		Mimosa Group	Rewan Formation		Green lithic sandstone, pebble conglomerate, red and green mudstone
Permian	Late	Blackwater Group	Rangal Coal Measures		Coal seams, carbonaceous shale and mudstone, tuff, siltstone and mudstone
Permian	Late	Blackwater Group	Fort Cooper Coal Measures	Burngrove Formation	Coal, brown and green sandstone, conglomerate, carbonaceous shale, tuff
Permian	Late	Blackwater Group	Fort Cooper Coal Measures	Fairhill Formation	Labile sandstone, quartzose sublabile sandstone, siltstone, mudstone, calcareous and tuffaceous sandstone, volcanic conglomerate, carbonaceous mudstone, coal
Permian	Late	Blackwater Group	Moranbah Coal Measures	MacMillan Formation	Quartzose to sublabile, locally argillaceous sandstone, siltstone, mudstone, carbonaceous mudstone and coal
Permian	Late	Blackwater Group	Moranbah Coal Measures	German Creek Formation	
Permian	Early to Middle	Back Creek Group			Quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite

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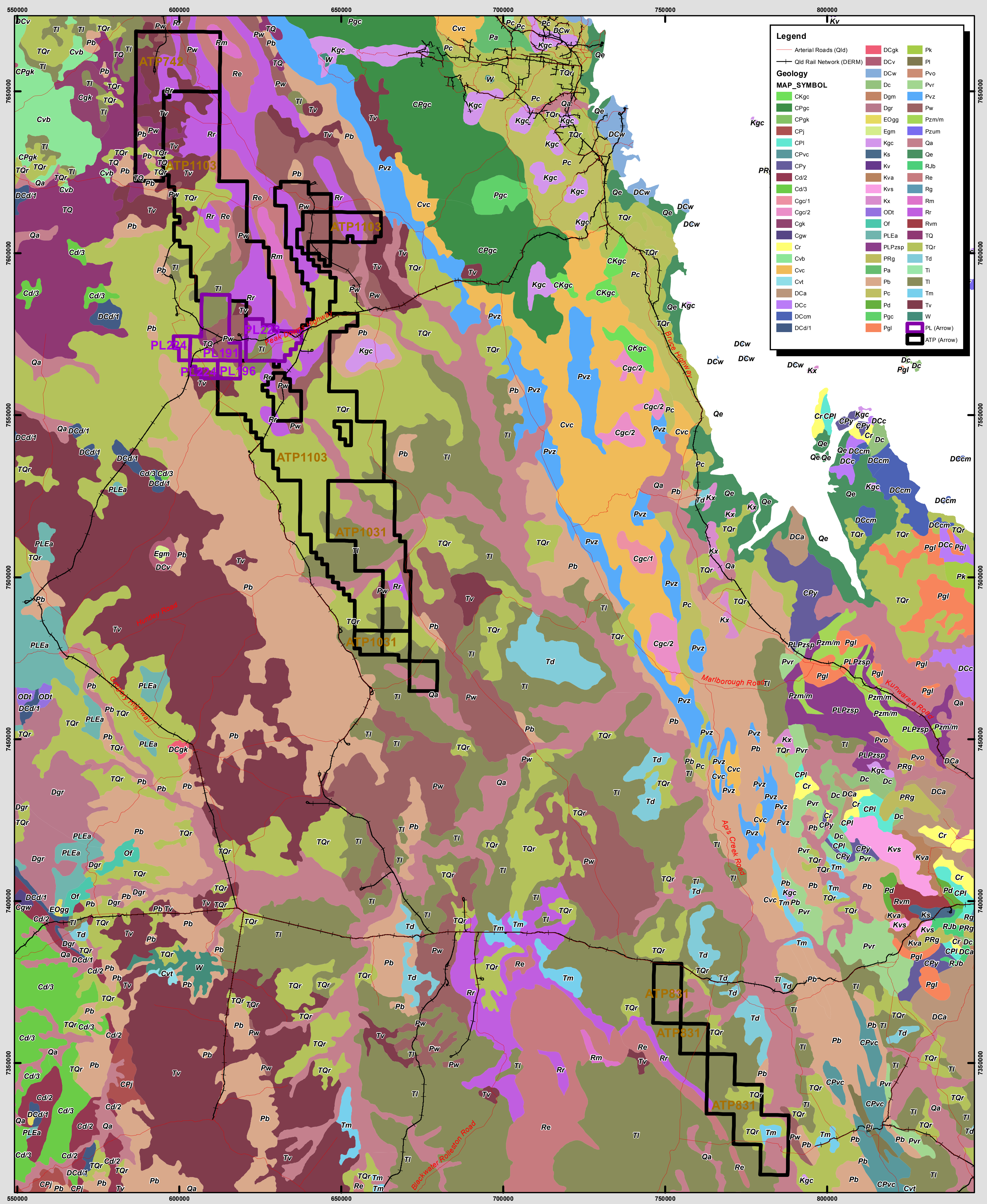

Figure 4. Surface Geology of the Bowen Basin Project area

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 4/01/2016
Issued To: K Singh
Author: tstringer

0 25 50 100
Kilometres
Scale: 1:1,093,000@ A3
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

3.1.1 Target Geological Formations

The principal target within the Project Area has traditionally been the MCM. Production testing has also targeted the RCM. Testing of the FCCM has shown net coal thicknesses of coal of up to 50 metres, some with high methane content.

3.1.1.1 Moranbah Coal Measure Targets

The MCM form part of the Late Permian "Group III" coals deposited in the third and final phase of the formation of the Bowen Basin. The MCM consist of coals, sandstones, siltstones and mudstones and average from 250 m to 300 m in thickness. They are 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:

- The Q seam is split into three main plies, the QA1 (3.5 m thick), QA2 (3 m thick), and QB (1.75 m thick).
- The P seam is the second most targeted source of coal seam methane within the MGP Area. The P seam consists of 3 plies, the GR (3 m thick), PL1 (1.5 m thick), PL2 (0.5 m thick) and averages about 5 m in total thickness.
- The GM seam is the primary target seam within the Project Area. The seam averages 5 m in thickness but thins towards the southeast as a result of seam splitting.
- The Goonyella Middle Lower (GML) seam also forms part of the MCM and in relatively small local pockets, the seam can reach thicknesses of up to 6.5 m.

3.1.1.2 Fort Cooper Coal Measure Targets

The FCCM conformably overlies the MCM and are approximately 400 m thick. Along with the coal seams, sediments of the FCCM include green lithic sandstone, conglomerate, mudstone, carbonaceous, shale, coal, and thin beds of greyish white cherty tuff containing abundant leaf impressions (Jensen, 1968). The FCCM are characterised by up to seven formations (6 – 60 m thick) rich in carbonaceous mud and thin coal seams, and its distinctive tuff beds. These formations are interbedded with 10 m to 30 m thick siltstone and sandstone sequences. The potential target seam of the FCCM is the Girrah Seam. This seam marks the roof of the FCCM (Burngrove Formation) and is one of the few identifiable horizons. The seam is approximately 30 m in thickness with numerous stone bands and a notable radioactive tuff band.

3.1.1.3 Rangal Coal Measure Targets

The final phase of coal deposition in the Bowen Basin in the Late Permian resulted in the formation of Group IV coals. These include, from north to south, the Rangal Coal Measures, Baralaba Coal Measures and the Bandanna Formation. The coals in this group are the most diverse in terms of quality, and also the most widely distributed within the basin. Group IV coals were deposited under fluviatile, lacustrine and paludal conditions (Mutton, A. J. 2003) and comprise sandstones, calcareous sandstone, carbonaceous shale, mudstone, coal, volcano-clastics (tuff), and concretionary limestone.

Figures 5 to 9 provide schematic cross-sections through each of the Arrow tenure (Petroleum Leases 191, 196, 223, 224 and, ATP 742, 831, 1031 And 1103), presented as 5 southwest to northeast orientated sections from the northern-most tenure to the southernmost. Each cross section was generated from the Arrow geological model using Petrel™. The model has been prepared from the latest geological information (incorporating the most recent gas well exploration and testing drilling information, mine drilling and water user data).

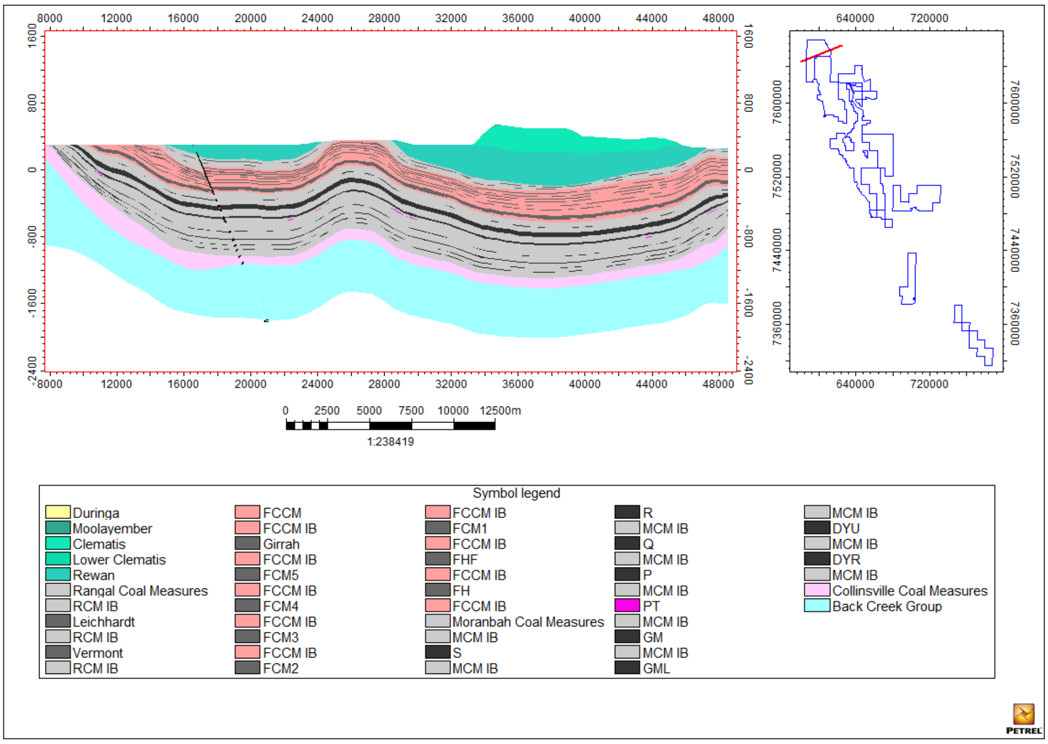

Figure 5 : Stratigraphy underlying ATP 742

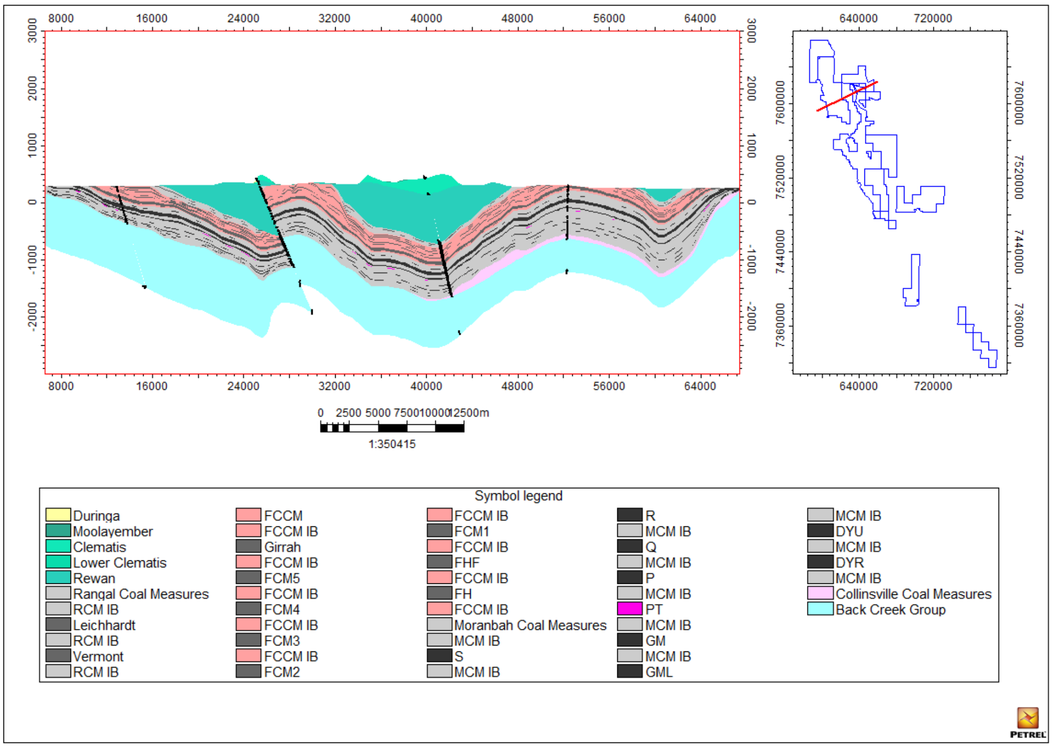

Figure 6 : Stratigraphy underlying northern ATP 1103

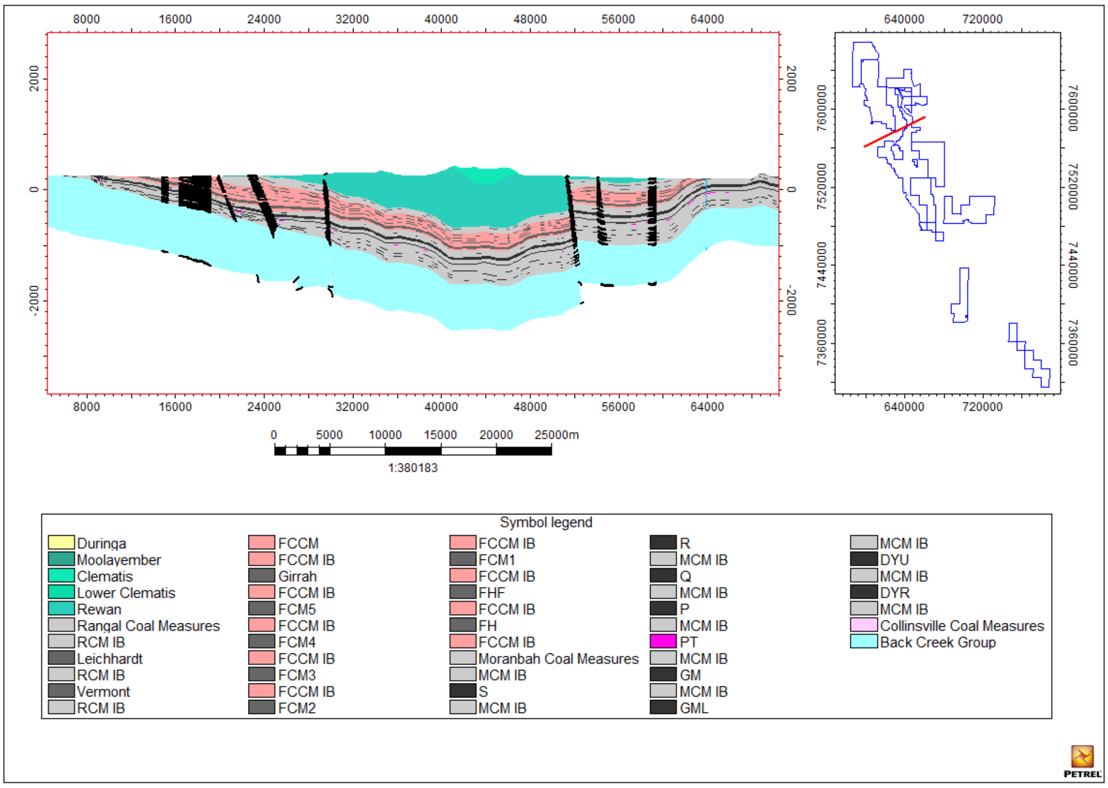

Figure 7 : Stratigraphy underlying MGP Area

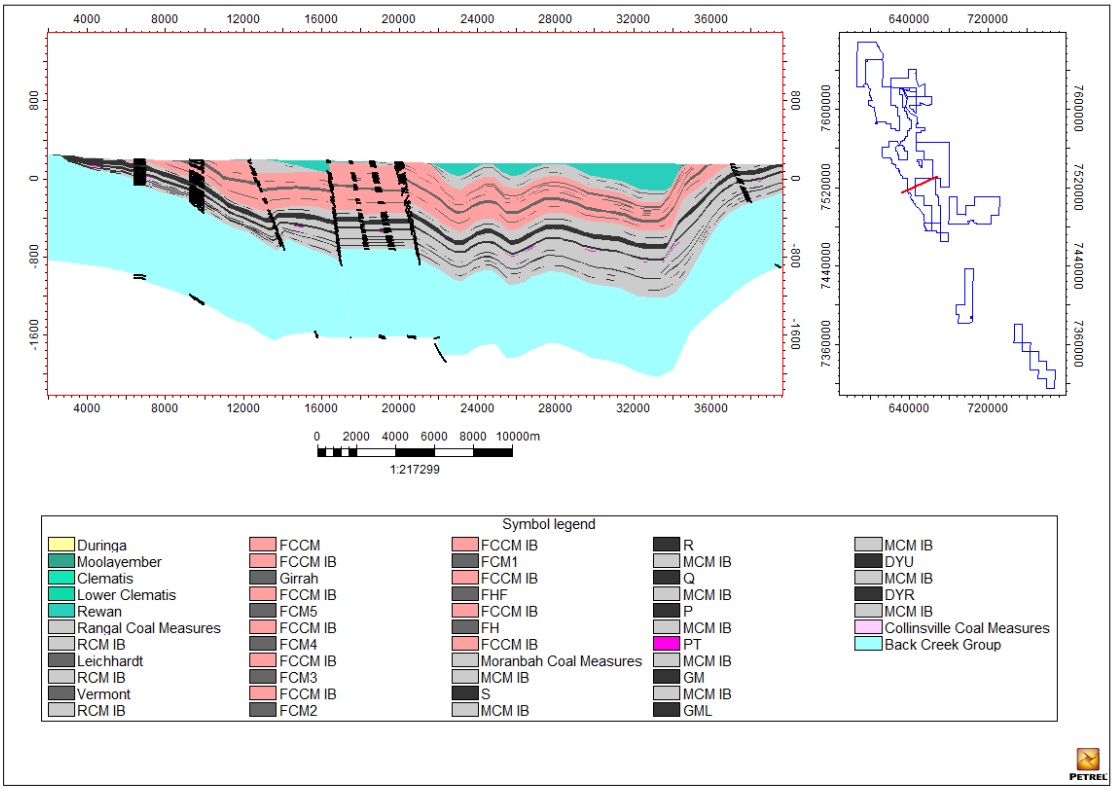

Figure 8 : Stratigraphy underlying ATP 1031

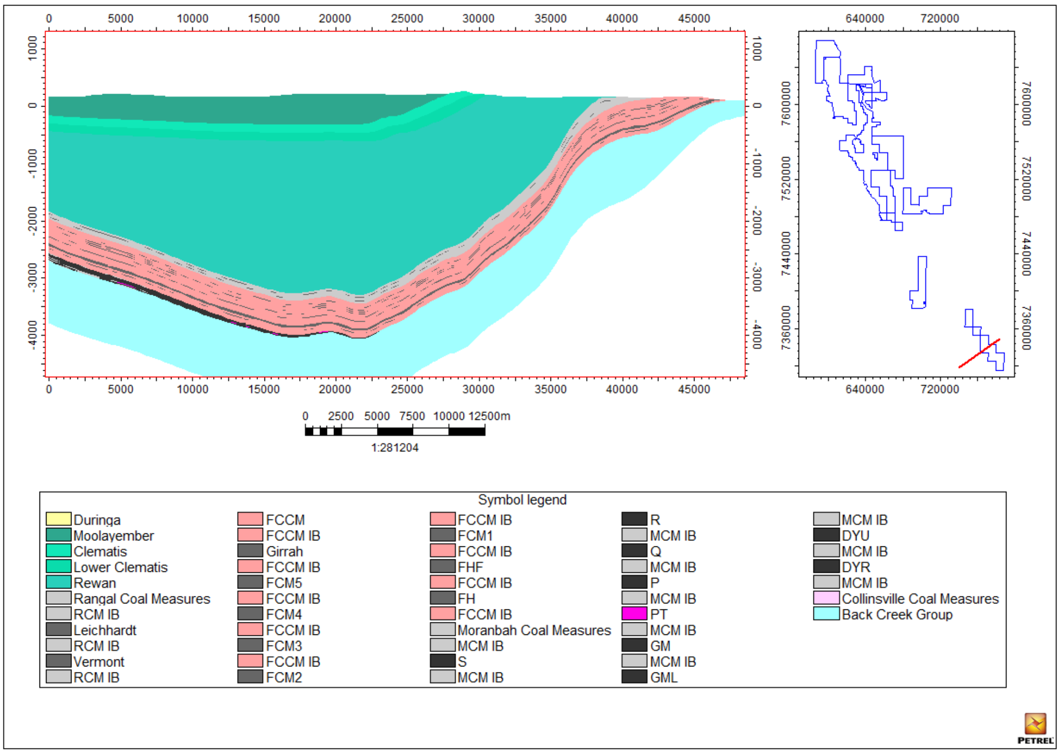

Figure 9 : Stratigraphy underlying ATP 831

3.2 Conceptual Hydrogeological Model

The hydrostratigraphy of the Bowen Basin is summarised in the following table.

Table 10: hydrostratigraphy of the Bowen Basin

Age	Stratigraphic Unit		Lithology	Typical thickness (m)	Aquifer Type
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	Aquitard
	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	Aquitard
Triassic	Moolayember		Mudstone, lithic sandstone, interbedded siltstone, mudstone,	0-200	Confining unit - GAB

	Formation		sandstone and thin coal seams.		
	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
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

These cross sections in **Figures 5 to 9** show the key aquifer layers present at each section location, namely, the coal aquifers. The interburden aquitards and shallower Triassic and Tertiary hydrological units are also presented.

The occurrence and continuity of the above mentioned aquifers is highly dependent on the spatial distribution of the corresponding geological units.

The conceptual representation of the hydrogeology and hydrogeological processes as assessed in the EIS (Arrow Energy, 2012c) is shown in **Figure 10**.

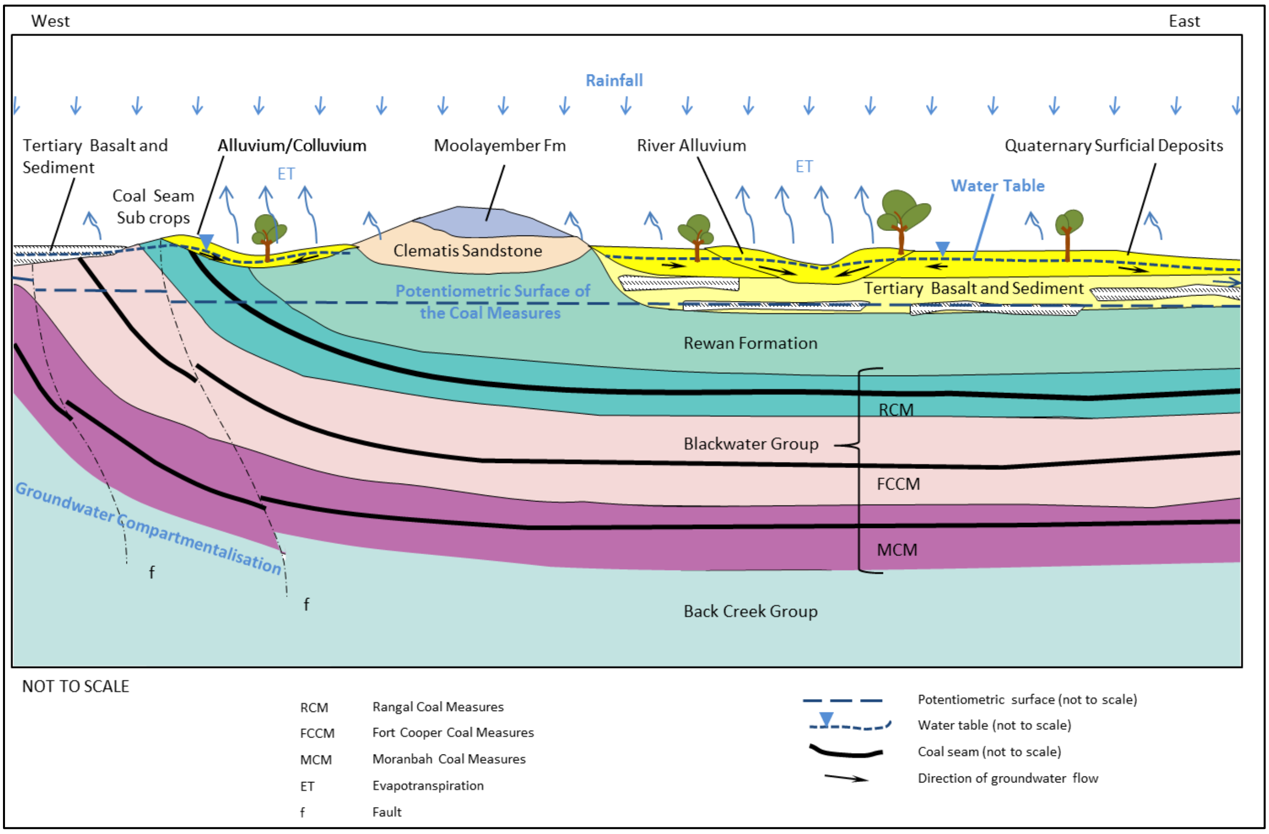

Figure 10: Conceptual Hydrogeological Model (Arrow Energy, 2012c)

A summary of the existing understanding of the hydrogeological setting as conceptualised in **Figure 10**, is provided in the following sections.

3.2.1 Quaternary Alluvium Aquifers

Quaternary alluvium aquifers (alluvium aquifers) form the shallow most aquifers in the Project Area and are generally associated with creek and river systems. The alluvium aquifers typically occupy an area within the river valley which is generally about 500 m wide. Due to the semi-arid climate, the ephemeral nature of the stream flow, and discontinuity of the more permeable gravel and sand layers, the groundwater resources in the Quaternary alluvium in the Project Area are not abundant and groundwater only occurs in isolated areas.

Key aquifer characteristics are:

- May contain groundwater from 5 to 20 meters below ground level (mbgl) and deeper in parts;
- May not be fully saturated all year;
- Are of variable permeability being characterised by relatively high permeability river bed sands and relatively low permeability river bank sediments;
- Hydraulically connected to surface water systems;
- Recharge mainly through direct infiltration of rainfall, overland flow and surface water flow;
- Discharge is generally through evapotranspiration from vegetation, infiltration and recharge to underlying older formations;
- Groundwater quality is highly variable ranging from fresh to very saline;
- Groundwater use is erratic, and no significant extraction areas are recognised from the alluvium aquifers in the Project Area.

3.2.2 Tertiary Sediment Aquifers

The undifferentiated Tertiary sediments and Suttor Formation occurs extensively throughout the northern portion of the Bowen Basin, although outcrops are not continuous, and much of the Tertiary sequence is concealed by younger, overlying Quaternary alluvium and colluvium. The Tertiary sediments generally consist of lenses of palaeochannel gravels and sands separated by sandy silts, sandy clays and clays. Potential for groundwater exists within the more permeable sand and gravel sections of the Tertiary sediments.

Key aquifer characteristics are:

- May contain groundwater from 5 to 30 mbgl;
- Lenses of saturated sand and gravel are limited in extent and separated by sandy silts and clays;
- Highly variable in permeability and porosity and limited in lateral and vertical extent;
- Recharge mainly through direct infiltration of rainfall, overland flow in outcrop areas and vertical seepage from overlying Quaternary alluvium;
- Discharge is generally through evapotranspiration from vegetation, infiltration and recharge to underlying older formations;
- Groundwater quality is typically poor;
- Groundwater use is sparse, and no significant extraction areas are recognised from the Tertiary sediment aquifers in the Project Area.

3.2.3 Tertiary Basalt Aquifers

The spatial distribution of the Tertiary basalt is sporadic within the Bowen Basin. The largest mass occurs to the west of Dysart with several other masses occurring near Moranbah, west of Nebo and northeast of Middlemount (Pearce .B, Hansen .J, 2006a). Groundwater is principally stored and transmitted in the fractures, joints and other discontinuities within the rock mass.

Key aquifer characteristics are:

- May contain groundwater from 23 to 34 mbgl;
- Vesicular basalt acts as localised, discontinuous aquifers;
- Permeability and porosity is highly variable depending on degree of weathering and interconnectedness of jointing and/or fracturing;
- Recharge mainly through direct infiltration of rainfall, overland flow and surface water flow in rock outcrop areas where no substantial clay barriers exist in the shallow subsurface and vertical seepage from overlying aquifers;
- Discharge is generally through flow into adjacent or underlying older formations and evapotranspiration;
- Groundwater quality is variable ranging from fresh to moderately saline;
- Considered unlikely to represent a significant groundwater supply given the isolated and sporadic occurrence of groundwater and highly variable permeability and porosity.

3.2.4 Triassic Aquifers

The Triassic aquifers refers to the Clematis Sandstone. The Moolayember Formation is a recognised aquitard generally overlying and confining parts of the Clematis Sandstone. The distribution of the Clematis Sandstone and Moolayember Formation has mostly eroded but a few remnants occur as outcrops in the north. These two formations form part of the basal section of GAB recharge beds (Pearce .B, Hansen .J, 2006a). The Triassic Rewan Formation is considered to be a regional-scale confining unit (aquitard) along most of the central axis of the Bowen Basin but is absent from the east and west flanks of the basin.

Key aquifer characteristics are:

- Groundwater may be artesian;
- Clematis Sandstone aquifer has a localised presence to only a few small outcrops in the Project Area;
- The Clematis Sandstone aquifer has moderate to good permeability;

- Recharge is localised and mainly through direct infiltration of rainfall, overland flow and surface water flow in outcrop areas;
- Discharge is localised and generally via through flow into adjacent or underlying older formations and evapotranspiration;
- Groundwater use in the Project Area is unknown. Given the limited extent of this aquifer, groundwater supply is likely to be isolated.

3.2.5 Permian Aquifers

The two dominant Permian formations within the Project Area are the Blackwater Group and the Back Creek Group. The coal seams of the Blackwater Group are the more permeable units within the Permian sequences. The coal seams are continuous across the Project Area and constitute the most extensive aquifers. These seams have been extensively mined along the western margin of the Bowen Basin. The Back Creek Group is a confining unit however shallow unconfined groundwater has been known to occur in outcrops/subcrop areas.

Key aquifer characteristics are:

- May contain groundwater from 8 to 55 meters mbgl;
- Confined by low permeability overburden and interburden as well as the overlying Rewan Formation where it exists;
- Low to moderately permeable coal seams;
- Recharge is limited and generally via direct infiltration of rainfall and overland flow as well as downward seepage from overlying aquifers where no clay barriers exist in outcropping/ subcropping areas;
- Discharge is generally through flow into adjacent (outcropping or sub-cropping coal seams) aquifers or seepage into underlying aquifers (via structural discontinuities) and groundwater extraction (CSG, incidental mine gas management, and mine dewatering activities);
- Groundwater quality is generally poor, however varies from being fresh to very saline;
- Groundwater resources associated with the Blackwater Group are typically contained in porous sandstones and fractured shale and siltstones.

4 EIS NUMERICAL GROUNDWATER MODEL

Groundwater modelling has been undertaken previously for the Project Area to predict depressurisation impacts on groundwater resources as a result of CSG production, which include:

- PLs 191, 196, 223, 224 UWIR (2012): Modflow-Surfact numerical groundwater model
- ATP 1103 UWIR (2012): Modflow-Surfact numerical groundwater model
- Bowen Gas Project EIS (2012): Modflow-Surfact numerical groundwater model
- ATP 1031 (2014): MLU Analytical groundwater model

A numerical groundwater model of the Project Area was developed by Arrow (Arrow Energy, 2012a) to predict potential depressurisation impacts on groundwater resources as a result of CSG production (2012 UWIR Model). A new numerical model, the EIS Model, was then developed to support the Environmental Impact Statement (EIS) for Arrow's Bowen Gas Project (Ausenco and Norwest, 2012). The EIS Model is considered to be more robust in comparison to the 2012 UWIR Model. The EIS Model was independently peer reviewed by CDM Smith. The peer review deemed the model fit for the purpose of estimating groundwater impacts created by coal seam gas extraction. The model conforms to best industry practice and fulfils the appropriate criteria of the Australian Groundwater Modelling Guidelines. **Appendix E** provides a detailed report on the numerical model development. Further detail on the EIS Model is provided below.

4.1 Groundwater Model Development

The EIS Model is based on MODFLOW-SURFACT ™ (HGL,inc.) using the Groundwater Vistas (Environmental Solutions, Inc.) graphical-user interface. Model development is summarised below and additional detail is provided in **Appendix E**.

4.1.1 Domain and Grid Design

The numerical model is based on a finite difference grid with 110 columns, 268 rows and 18 layers (**Figure 11**). The model grid is orientated 29 degrees anti-clockwise to align with the Basin's northwest to southeast trend. There are 352,926 active cells in the 18 layers, and cells are uniform with a side length of 1.5 km. The active model domain covers 42,000 km^2 of the northern Bowen Basin, whereas the whole model (active and inactive cells) covers 66,330 km^2. The model grid layers are mostly continuous but are offset in places where major faults have markedly displaced the strata.

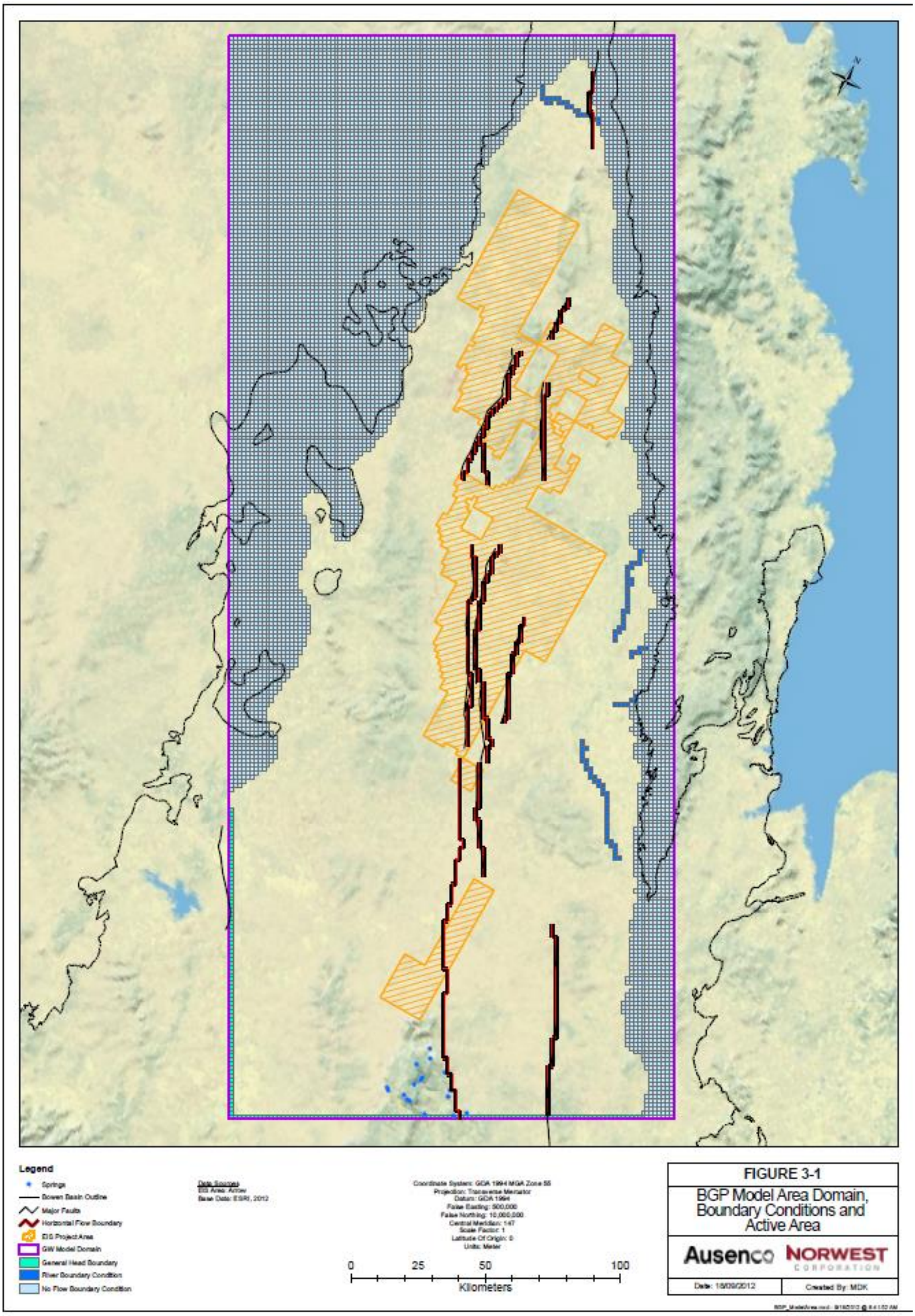

Figure 11: Bowen Model Area Domain

4.1.2 Parameterisation

The key or 'primary' parameters needed to describe the aquifers and aquitards in the model are as follows:

- Geometry (in 3D);
- Hydraulic conductivity (horizontal, vertical and anisotropy);
- Aquifer storativity (specific storage and specific yield);
- Groundwater recharge (average flux rate and zone);
- Evapotranspiration (maximum flux rate, extinction depth and zone); and
- Streams (average stage, river bed conductance and geometry).

The model geometry is based on a 'project geological model', which is a 3D representation of the site stratigraphy and coal seams with the greatest detail available for the target coal seams. Other data used to develop the model include the permeability test data for target coal seams within Arrow's CSG tenements, literature, government databases, and Arrow's other in-house data sets. Relevant field data for estimates of horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), specific storage (Ss), and specific yield (Sy) are relatively sparse for areas away from the Project Area.

Data describing storage properties of the strata are limited. Values were compiled from the literature and also from core compressibility testing obtained in the laboratory. The assumed coal specific storage value (8.5E-5 1/m) was based on the coal compressibility data. Specific storage estimates were validated in transient simulations of water production associated with the MGP Area.

Hydraulic conductivity estimates for the coal seams are based on Arrow reservoir engineering permeability data, and Kh is defined by a set of empirical equations relating permeability to depth for five (5) zones in MCM, and four (4) zones in RCM. Zones were extrapolated to the edge of the Bowen Basin. The Kh:Kv ratio is typically 5:1 for the target coals consistent with that applied in reservoir engineering models within Arrow. Due to anisotropy in Kh the maximum K is typically perpendicular to the strike and it varies spatially. Anisotropy was inferred by matching historic gas and water production rates in specific areas (Ausenco and Norwest, 2012).

4.1.3 Boundary Conditions

The boundary conditions that are applied in the groundwater model to simulate the hydrogeological system are as follows:

- *General Head Boundary* (GHB): The southern boundary of the model increases in depth and dips below the Surat Basin. The regional groundwater flow pattern is mainly towards the Isaac Connors River in the east, and out of the model to the south. A GHB was applied along the southern boundaries in case of a reverse flow. Groundwater head of the GHB range between 60-158 m AHD.
- *River Package*: Rivers, including perennial reaches and gaining reaches, were represented using the standard river package of MODFLOW. These include the Bowen River and the gaining reaches in the Isaac-Connors sub-catchment as interpreted by SKM (2009). Bottom elevation and channel characteristics data are limited and were interpolated from low points of the Shuttle Radar Topography Mission (SRTM). Bottom elevations were assumed to occur in an incision depth of between 14-26 m based on river cross-sections in SKM (2009). A river bed conductance of 0.01 to 1 m/d was assumed. River width was assumed to be 20 m for the Bowen River, and 10 to 20 m for the other streams/rivers based on cross-sections in SKM (2009). River stage heights were added to river bottom elevations based on depths of 1.06 m and 0.13 m as defined by NRM gauging stations. No losing river reaches were identified in the model domain.
- *Evapotranspiration Package*: The potential evapotranspiration rate (PET) and the actual evapotranspiration rate (AET) estimates were obtained from the Bureau of Meteorology (BOM). The difference between PET and AET is the remaining potential demand that is not met by available moisture (on average) and this difference was assumed to be available to remove groundwater that occurs above the rooting depth of vegetation (i.e. the

extinction depth). This PET-AET difference was assigned to the model as a maximum evapotranspiration rate above and extinction depth of 10 m. The extinction depth was calibrated during model development.

- *Groundwater Recharge*: Literature estimates of groundwater recharge were applied in the model in zones defined by the surface geology. A minimum of 1 mm/yr was applied to solid geology outcrops of Triassic and Permian formations, and higher rates of recharge were applied to river alluvium.

4.1.4 Model Calibration

Steady-state calibration was undertaken using a variety of calibration targets to provide a model that is representative of the system pre 1980. In addition to this, transient verification was undertaken which involved matching pressures associated with historical production in the MGP from 2003 to 2012. Steady-state calibration and transient verification are discussed in further detail below.

4.1.4.1 Steady-State Calibration

The primary calibration targets of the model were:

- Bore and well potentiometric levels in appropriately assigned formations;
- Groundwater baseflow to perennial river reaches; and
- Springs (absence of water table above ground surface).

Standing water level data collected post-1980 from bores within 20 km of a known mine site were not used in the calibration. The calibration data set included 27,361 SWL records from 482 bores. These SWL data were averaged and compiled as steady-state targets. No data weighting was adopted. Water levels recorded on the day of drilling were not used. Bore standing water levels (SWL) were converted to AHD using ground elevations collated from Geosciences Australia on an approximately 90 m grid. Temporal trends are evident in bores located in alluvium and Tertiary sediments; however, these are relatively stable with mostly less than 2 m of standard deviation. The majority are for the Quaternary alluvium and Tertiary basalts and sediments, and the bore counts are as follows (details of all model layers are included in **Appendix E**).

- Layer 1 – 269 Alluvium
- Layer 2 – 160 Tertiary
- Layer 4 – 3 Rewan
- Layer 5 - 3 RCM
- Layer 9 – 19 FCCM and MCM
- Layer 18 – 28 Back Creek Group

Springs were only used as a qualitative calibration target by ensuring that water levels (steady-state) were close to the topographic surface but did not rise above the topographic surface (as recognised in the absence of registered springs across the Project Area).

Calibration of the non-time varying parameters (Kh, Kv, Ss, and Sy) was undertaken iteratively in the EIS Model (**Appendix E**) to achieve a match with the calibration targets to an “acceptable level of accuracy”. Calibration results included a root mean square error (RMSE) of 3% for 482 head observations in six (6) separate formations, and a “good” correlation between observed and simulated groundwater heads was reported (R^2=0.9582). The head residuals also appeared “fairly evenly weighted” around zero and only a “slight” under prediction of heads was reported (**Appendix E**). The mean residual was 0.25 m, the head RMS was 11.37 m, and the range of head values was 377.7 m. Most head residuals in layers 1 and 2 were relatively low as they are topographically controlled. The RMSE for Layer 5 was 25.6 % for example.

The groundwater head distribution was similar for all model layers with flows from west and north to the east and south (i.e. towards the drainage lines). Flows within the model river cells indicate gaining reaches with modelled cumulative flows close to the target base flows. The absence of springs was matched qualitatively. The faulting system (HFB) did not have a significant impact on the model calibration or other results.

4.1.4.2 Transient Validation

The EIS Model (refer to **Appendix E**) used transient well test data from 158 CSG production wells of the MGP to validate the model in transient mode. This approach was referred to as a "non-conventional calibration". The field data includes CSG production rates and downhole pressures recorded over eight (8) years from 2003 to mid-2012. Some of the CSG wells intersect and target the P, GM and GML coal seams of the Moranbah Coal Measures (MCM). The other CSG wells intersect the GM and GML coal seams, and the Leichhardt (L5), Vermont (L7) Q (L11), P (L13), GM (L15) and GML (L17) coal seams which extend into the Bowen Gas Project. The data included daily water production data. CSG wells with multi-seam completions were ignored.

Production history in 182 CSG production wells were forced as a boundary condition over 8 years while trying to match the pressure responses at 158 CSG wells. Transient calibration was achieved by adjusting Kh, Kv, Ss, and Sy, especially of the aquitards. The Kv of the interburden layers were reduced compared to initial estimates, whilst keeping the previously estimated values of Kh, Kv, and Ss for the coals. The Kv of interburden was reduced to 1/10,000th of Kh, and Kv of the Rewan Formation was reduced to 1/7,500th of the Kh. The modelled hydrographs for the CSG wells of the MGP showed significantly less drawdown than the actual drawdown, which was expected due to a low relative permeability of the fluid phase for post-production.

4.1.5 Prediction Approach

The EIS Model considers two cases:

1. Base Case: BGP only production
2. Cumulative Case: BGP, MGP and Water Entitlements Registration Database (WERD)

The Base Case predicts only those impacts related to the BGP and assumes no other water production. The model Base Case predictive simulations adopts the pre-1980 steady state model heads as the initial head distribution, then simulates 55 years of production from 2017 to 2072.

The cumulative case is a hypothetical scenario using the Base Case, plus historical and anticipated MGP production and WERD entitlement usage data. The cumulative prediction simulation adopts the pre-1980 steady state model as initial heads, then simulates the historical MGP production and the WERD entitlement production from 2003 to 2011. The resulting depressed heads from the end of the 2011 MGP and WERD production simulation serves as the initial heads in the model simulating future MGP, BGP and WERD production from 2012 to 2122. MGP production is simulated for 38 years from 2012 to 2049. BGP production is simulated for 55 years commencing 2017 to 2072. WERD production is simulated from 2012 to 2122.

4.1.6 Uncertainty Analysis

Following the completion of initial model predictions for the EIS, an assessment of model parameter predictive error/uncertainty, including NSMC and Pareto front analyses, was conducted in order to better understand the model limitations and to identify data gaps (Ausenco and Norwest, 2013). These are modelling methods that utilise statistical methods to generate parameter sets to help calibrate a model. A parameter estimation software package (PEST – Doherty, 2002) was used to undertake the analysis using existing defined parameter zones and reaches in the model. The results classified groups of parameters which could be predicted based on existing observations, and identified areas where future monitoring can better inform ongoing modelling and reduce predictive error.

A report was prepared to present the initial assessment findings and results, and is provided in **Appendix F**. The evaluation indicated that the model parameters associated with alluvium and Tertiary basin infill in the upper two model layers were associated with the least amount of predictive error/uncertainty (Ausenco and Norwest, 2013). The parameters identified as having the greatest predictive error/uncertainty were the majority of the vertical hydraulic conductivities and horizontal hydraulic conductivities in the deeper model layers representing Permian formations. The results of the NSMC and Pareto front uncertainty analysis indicates that the estimates of groundwater drawdown associated with BGP production are conservative. The uncertainty analysis considered other parameter combinations including higher hydraulic conductivity and lower evapotranspiration. The aerial extent of drawdown arising from these simulations was not greater than the Base Case in the majority of cases. The aerial extent of drawdown in the Base Case was at the higher end of predictions compared to the majority of the simulations undertaken in the uncertainty analysis (Ausenco and Norwest, 2013). It is therefore concluded that the simulation used for the impact assessment represents a plausible, conservative assessment of groundwater drawdown arising from BGP production.

This indicates the parameter set used for the modelling process is reasonable. For example, the calibrated conductivity values are considered reasonable when compared to estimates derived from field data and compared to parameters adopted for the OGIA Surat CMA groundwater model, where similar values are seen for comparable lithologies and comparison indicates that the calibrated anisotropy ranges are appropriate.

5 ARROW MONITORING RESULTS

Groundwater monitoring has been undertaken by Arrow based on the UWIR WMS groundwater monitoring network located in the MGP Area. The locations of these bores are shown in **Figure 12**. This site specific data is presented in more detail in the following sections and provide an update to the current understanding of the conceptual hydrogeological model (Section 3.2.1).

5.1 Groundwater Levels

5.1.1 Shallow UWIR Monitoring Data Summary

Groundwater level monitoring has been undertaken since June 2012 in seven shallow groundwater monitoring bores which form part of the UWIR WMS groundwater monitoring network for PLs 191, 196, 223 and 224. **Table 11** provides a summary of these bores.

Table 11: Shallow Groundwater Monitoring Bores

Bore ID	Total Constructed Depth (m)	Screen Interval (mbgl)	Screened Formation
M339W	41.0	35.0 – 41.0	Weathered Tertiary Basalt
M225W	34.0	23.0 – 34.0	Weathered Tertiary Basalt
M340W	27.3	19.3 – 27.3	Weathered Tertiary Basalt
M230W	32.0	29.0 – 32.0	Weathered Tertiary Basalt
M250W	56.5	44.5 – 56.5	Tertiary Sediment
M224W	32.5	26.5 – 32.5	Quaternary Alluvium
M222W	30.2	20.0 – 26.0	Weathered Fort Cooper Coal Measures

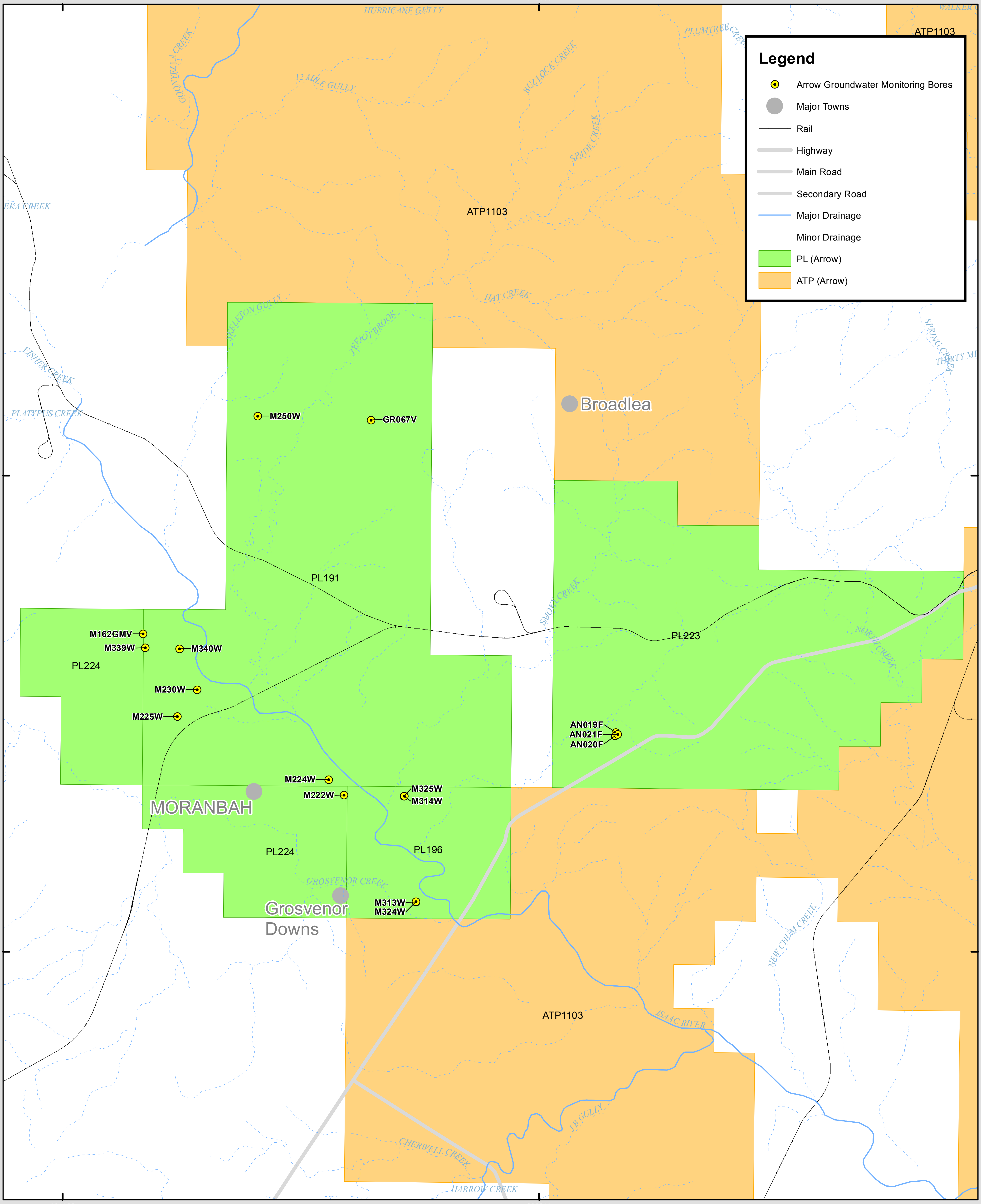

Figure 12. Arrow groundwater monitoring bore network

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Natural Resources and Mines

Date: 20/01/2016
Issued To: Kavita Prasad
Author: tstringer

0 2.5 5 10
Kilometers
Scale: 1:151,000 @ A3
Coordinate System: GDA 1994 MGA Zone 55

N

arrow energy go further

Based on or contains data provided by the State of Queensland (Department of Natural Resources and Mines) [2013]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accept no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws

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

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NOT FOR CONSTRUCTION

The groundwater level monitoring has been undertaken from 2012 to 2015, the results of which are shown in **Appendix C**. Groundwater levels range from 200.4 to 209.2 m Australian Height Datum (AHD) in the weathered Tertiary Basalt aquifer, 233.2 to 233.3 m AHD in the Tertiary Sediment aquifer, 209.9 to 211.7 m AHD in the Quaternary Alluvium aquifer, and 202.4 to 205.9 m AHD in the weathered Fort Cooper Coal Measures aquifer, as is shown in **Figure 13**.

All bores located within close proximity to the Isaac River display similar depths to groundwater levels. **Figure 13** shows that groundwater levels for site M250W is higher, in comparison the other sites given that it is installed in the Tertiary Sediment. M250W is also located more than 10 km north of the other groundwater monitoring sites.

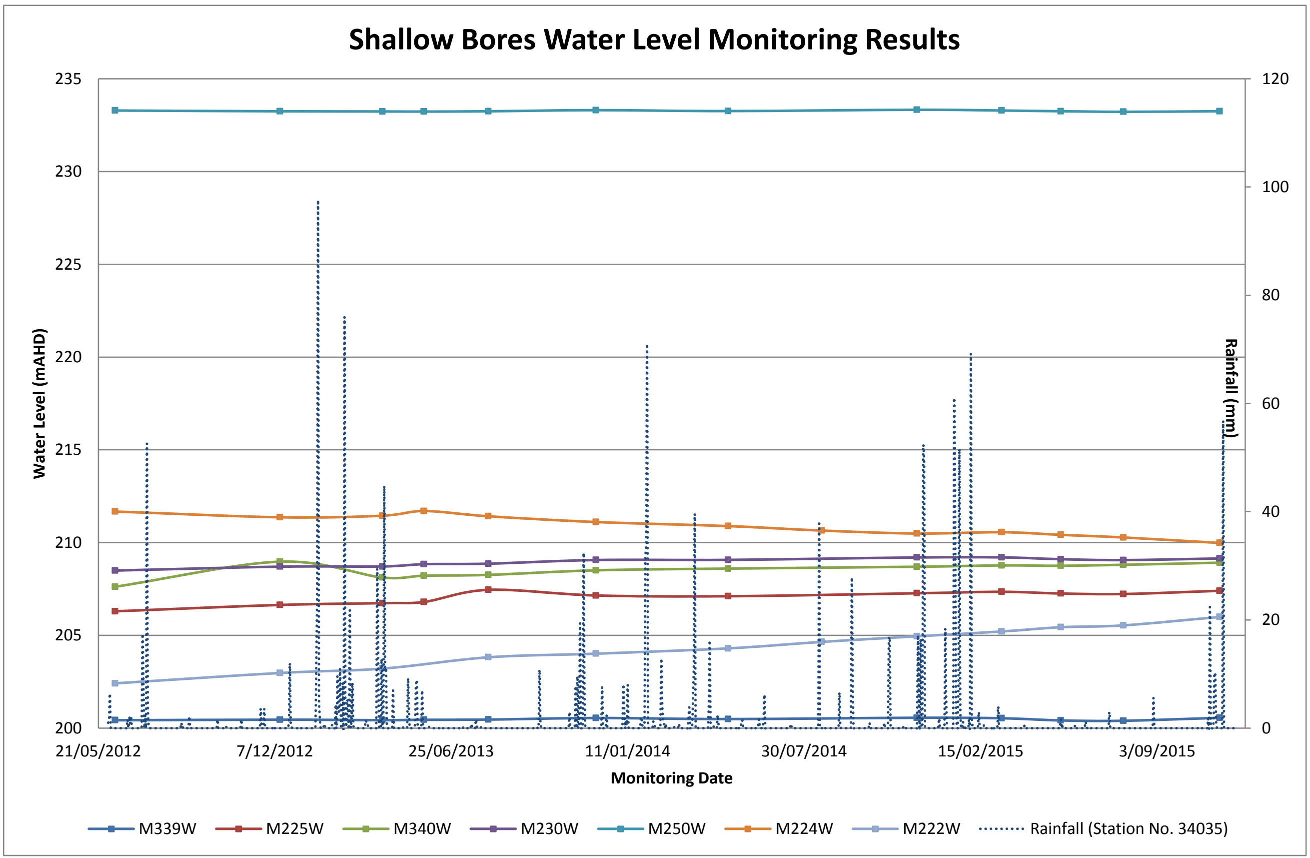

Figure 13: UWIR Shallow Bores Water Level Monitoring Results

A comparison of modelled drawdown predictions made in the previous UWIR with monitoring data to date has been undertaken. This is summarised in the table below.

Table 12: Comparison of modelled vs. actual groundwater level data

Groundwater Monitoring Bore	Modelled Drawdown (end of 2014)	Drawdown in actual groundwater levels	Comments on actual groundwater levels
M339W	No predicted drawdown	No	Groundwater levels have remained steady
M225W	No predicted drawdown	No	Slight rising trend in groundwater levels
M340W	No predicted drawdown	No	Slight rising trend in groundwater levels
M230W	No predicted drawdown	No	Slight rising trend in groundwater levels
M250W	0.05 m	No	Groundwater levels have remained steady
M224W	No predicted drawdown	No	Slight declining trend by 1.6 m in groundwater levels due to natural variation
M222W	0.2 m	No	Rising trend in groundwater levels

Based on this data, drawdown resulting from water production in CSG wells was predicted by the model to occur at sites M250W and M222W, however actual groundwater pressures have not shown any drawdown in these locations. No drawdown resulting from water production in CSG wells was predicted by the model to occur at sites M339W, M225W, M340W, M230W and M224W which is supported by the actual groundwater pressure data.

A slight declining trend is observed in groundwater levels for bore M224W over the monitoring period. This bore is installed in the Quaternary Alluvium within 300 m of the Isaac River. Data from the nearest Isaac River stream gauge (130414A) show a decline in flow from mid-2013 to the end of 2014. There is likelihood that water level decline in bore M224W is in connection to reduced flows in the Isaac River.

No decline in groundwater levels greater than the bore trigger threshold is observed. There is no apparent influence of CSG production to the Quaternary alluvium, weathered Tertiary basalt, Tertiary sediment and weathered Fort Cooper coal measures aquifers where these bores are installed.

5.1.2 Deep UWIR Monitoring Data Summary

Groundwater pressure monitoring has been undertaken in the following deep groundwater monitoring bores which form part of the UWIR groundwater monitoring network for the MGP Area:

- Monitoring since September 2014 for bores M313W, M314W, M324W;
- Monitoring since February 2015 for bore M325W; and
- Monitoring since November 2015 for bores AN019F and M162V.

Table 13 provides details for these bores. Pressure gauge data has been successfully obtained from bores M313W, M314W, M324W, AN019F and M162V. Meaningful pressure gauge data from bore M325W has been difficult to obtain. Available data shows that the permeability of the formation that M325W is installed into is so low that recovery of groundwater pressures take a very long time (in the order of 6 to 12 months).

Table 13: Deep Groundwater Monitoring Bores

Bore ID	Total Constructed Depth (m)	Screen Interval (mbgl)	Screened Formation
M313W	532.4	313.0 – 316.5	Moranbah Coal Measures (QA Seam)
		507.0 – 510.0	Back Creek Group
M314W	560.5	210.5 – 213.5	Moranbah Coal Measures (QA Seam)
		551.5 – 553.5	Back Creek Group
M324W	240.01	163.0 – 166.0	Fort Cooper Coal Measures
		187.0 – 190.0	Moranbah Coal Measures (QA Seam)
M325W	202.25	180.5 – 182.0	Fort Cooper Coal Measures
AN019F	290	269 – 271	Fort Cooper Coal Measures
M162V	276	252 – 256	Moranbah Coal Measures

The groundwater pressure monitoring results are shown in **Figure 14**. Groundwater pressures range from 211.6 to 215.1 m Australian Height Datum (AHD) in the Back Creek Group (BCG), 51.3 to 204.1 m AHD in the Fort Cooper Coal Measures (FCCM), and 86.8 to 203.4 m AHD in the Moranbah Coal Measures (MCM).

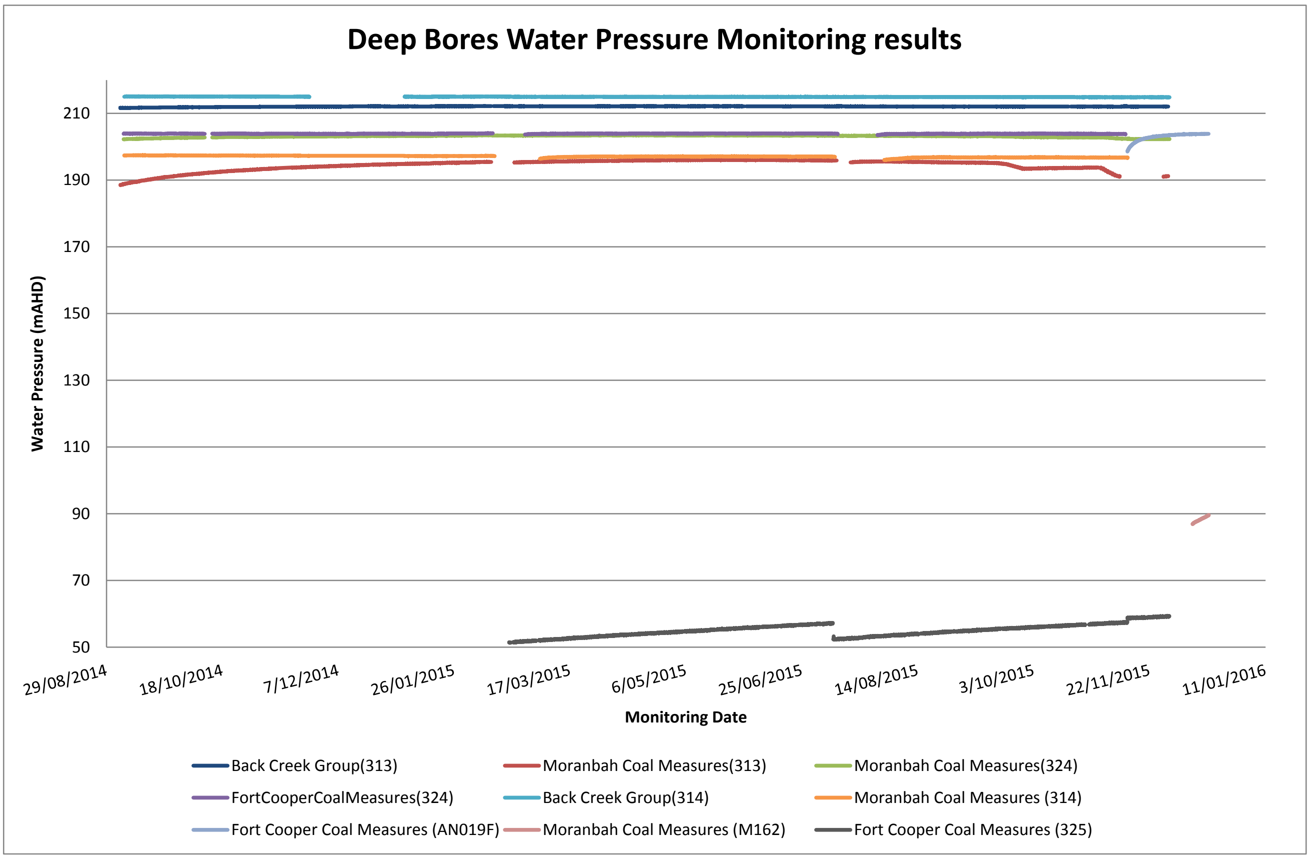

Figure 14: UWIR Deep Bores Water Pressure Monitoring Results

A comparison of modelled drawdown predictions made in the previous UWIR with monitoring data to date has been undertaken. This is summarised in the table below.

Table 14: Comparison of modelled vs. actual groundwater pressure data

Groundwater Monitoring Bore	Modelled Drawdown (end of 2014)	Drawdown in actual groundwater pressures	Comments on actual groundwater pressures
M313W (BCG)	0.1	No	Groundwater pressures have remained steady
M313W (MCM)	1.3	Yes	Groundwater pressure has declined by 4.8 m from September to November 2015
M324W (MCM)	1.3	Yes	Groundwater pressure has declined by 1.1 m from September to November 2015
M324W (FCCM)	No Predicted Drawdown	No	Groundwater pressures have remained steady. Following monitoring events the recovery of

Groundwater Monitoring Bore	Modelled Drawdown (end of 2014)	Drawdown in actual groundwater pressures	Comments on actual groundwater pressures
			pressure can take up to a month.
M314W (BCG)	0.1	No	Groundwater pressures have remained steady. Data shows natural variations in groundwater pressures.
M314W (MCM)	2.8	No	Groundwater pressures have remained steady. Following monitoring events the recovery of pressure can take up to a month. Data shows natural variations in groundwater pressures.
M325W (FCCM)	No Predicted Drawdown	No	Groundwater pressure still recovering since install
AN019F (FCCM)	No Predicted Drawdown	No	Groundwater pressure still recovering since install
M162V (MCM)	0.7	No	Groundwater pressure still recovering since install

Based on this data, drawdown resulting from water produced in CSG wells was predicted by the model to occur at sites M313W (BCG), M314 (BCG), M314 (MCM) and M162V (MCM) however actual groundwater pressures have not shown any drawdown in these locations. No drawdown resulting from water produced in CSG wells was predicted by the model to occur at sites M324W (FCCM), M325W (FCCM), and AN019F (FCCM), which is supported by actual groundwater pressure data.

As shown in the above table, a decline in actual groundwater pressure of 4.8 m and 1.1 m is noted for M313W and M324W respectively in the Moranbah Coal Measures aquifer. Modelled drawdown in the Moranbah Coal Measures aquifer at the end of 2014 at the location of M313W and M324W was predicted to be approximately 1.3 m. These groundwater monitoring bores are located in the southern part of PL 196 and approximately 350 m from existing production well GM052V. Whilst production in GM052V has been intermittently ongoing since 2007, the well did not produce any water between August 2014 and September 2015. It is likely that the decline in actual groundwater pressures in M313W and M324W are in response to the well being turned on in September 2015. Given that M324W is monitoring a shallower interval than M313W, a subdued drawdown response in groundwater pressures is observed in M324W. In addition to this, actual production at GM052V was greater than that previously forecast and modelled for 2014. Hence actual drawdown in M313W is greater than that predicted by the model at the end of 2014.

No decline in groundwater pressures greater than the bore trigger threshold was observed in all groundwater monitoring bores. With the exception of M313W and M324W, there is no apparent influence of CSG production to the BCG, FCCM and MCM aquifers in which these bores are installed.

5.2 Groundwater Flow

A review of vertical gradients was undertaken for two monitoring locations in the MGP Area. Monitoring at each site included:

- Site 1: Back Creek Group (M314W) and Moranbah Coal Measures (M314W) as well as data from monitoring approximately 3 km north west in Fort Cooper Coal Measures (M222W) and Quaternary Alluvium (M224W)
- Site 2: Back Creek Group (M313W), Moranbah Coal Measures (M313W), Moranbah Coal Measures (M324W), Fort Cooper Coal Measures (M324W)

Figure 7 provides a cross section of the aquifers underlying the MGP Area. The Quaternary Alluvium aquifer forms the shallowest aquifer within this area. This is underlain by the weathered FCCM aquifer. Both aquifer systems are considered to be unconfined to semi-confined in nature. The deeper MCM aquifer is a confined, sub-artesian aquifer system. The deepest aquifer system is the confined BCG aquifer.

Figure 15 shows the vertical gradients for site 1. Based on this data, the MCM aquifer has the lowest pressure. There is an apparent gradient toward the MCM i.e. upward from the BCG and downward from the Quaternary Alluvium, to the FCCM and then to the MCM.

There is a slight declining trend in the Quaternary Alluvium which is similar to the declining trend observed in the MCM. However, this is not considered to be as a result of water production in CSG wells to the MCM aquifer at this site. This is likely to be attributable to natural variations in pressures at this site and low recharge rates in this aquifer system. The rising trend in pressure in the FCCM aquifer suggests that these two aquifer systems act in isolation. Hence any potential transmission of impacts from the MCM to the shallow aquifers would be unlikely.

Ongoing monitoring at these sites will provide information on the interconnectivity of aquifers at these sites.

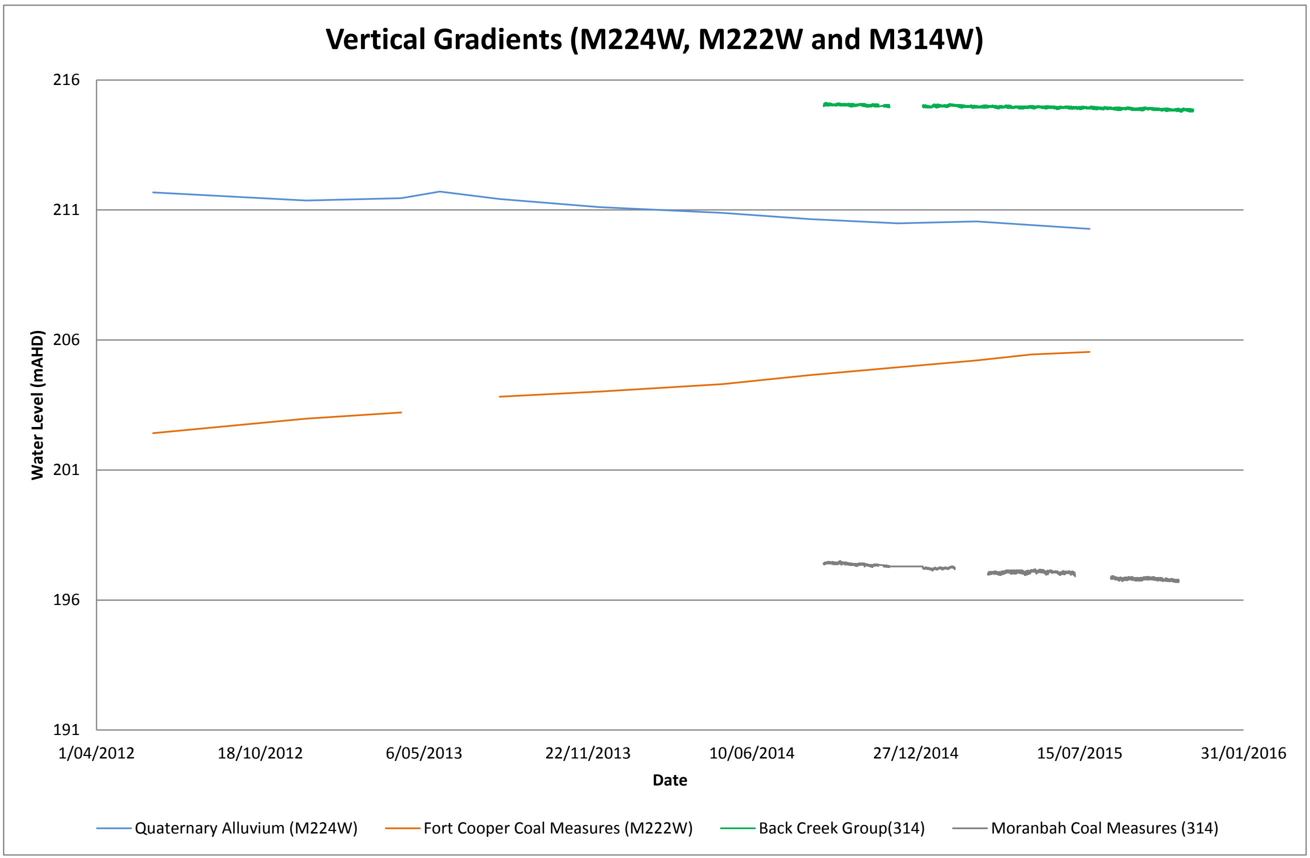

Figure 15: Site 1 - Review of Vertical Gradients for M224W, M222W and M314W

Figure 16 shows the vertical gradients for site 2. Based on this data, the MCM aquifer has the lowest pressure and there is a gradient toward this formation.

As discussed in Section 5.1.2 above, drawdown as a result of water production in CSG wells to the MCM aquifer is evident at site M313W and M324W. Pressure data for the FCCM and BCG at this site indicates that there is no transmission of impacts from the MCM to the shallower FCCM or the deeper Back Creek Group aquifer. This data suggests that impacts are contained within the MCM.

Ongoing monitoring at these sites will provide further information on the interconnectivity of aquifers at these sites.

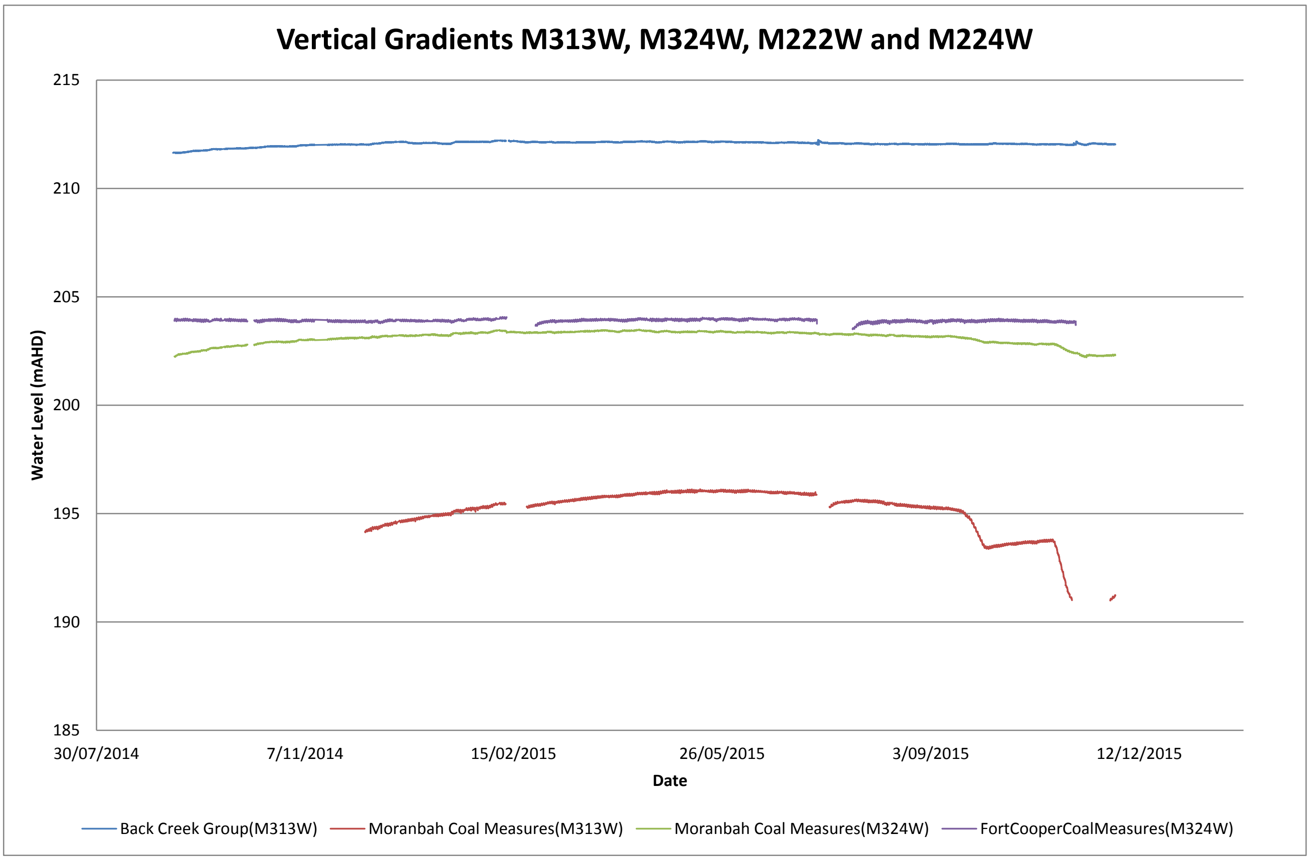

Figure 16: Site 2 - Review of Vertical Gradients for M224W, M222W, M324 and M313W

5.3 Groundwater Quality

Groundwater quality monitoring has been undertaken since June 2012 in seven shallow groundwater monitoring bores which also form part of the UWIR WMS groundwater monitoring network for PL 191, 196, 223 and 224.

Groundwater quality monitoring was also undertaken in four deep groundwater monitoring bores that were completed in July 2014 and two deep groundwater monitoring bores that were completed in November 2015, which also form part of the UWIR WMS groundwater monitoring network.

The groundwater quality monitoring results are shown in **Appendix D**. The primary purpose of groundwater quality monitoring is to identify changes in background water quality. A summary of these results (2012 to 2015) are provided in the following sections.

5.3.1 Shallow aquifer water quality

Table 15 provides a summary of water quality results obtained from bores targeting the shallow aquifers (M339W, M225W, M340W, M230W, M250W, M224W and M222W). This provides an indication of water quality ranges for each parameter analysed based on aquifer type. Results for some parameters between different monitoring locations in the Tertiary Basalt show high degree of variation which is likely to be attributable to the spatial heterogeneity of the hydrogeological system. As displayed by the groundwater level data, recharge by rainfall or streams occurs to shallow aquifers and is likely to result in variations in some parameters at the same monitoring location as shown in the table below. In general, this data shows that:

- Groundwater quality of the quaternary alluvium varies from brackish to saline
- Groundwater quality of the tertiary basalt aquifer varies from brackish to saline
- Groundwater quality of the tertiary sediment aquifer is fresh to brackish
- Groundwater quality of the weathered coal measures is brackish

Table 15: Water Quality – Shallow Monitoring Bores

Parameter	Quaternary Alluvium		Tertiary Basalt		Tertiary Sediment		Weathered Coal Measures	
	Min	Max	Min	Max	Min	Max	Min	Max
pH	5.73	6.46	6.28	8.09	5.42	5.92	6.1	6.81
EC uS/cm (laboratory)	18000	31600	5300	39300	2300	2560	9090	10200
TDS mg/L (laboratory)	14000	27000	3000	29000	1300	1600	6150	9600
Bicarbonate Alkalinity as $CaCO_3$ (mg/L)	174	360	390	810	55	76	275	457
Total Alkalinity as $CaCO_3$ (mg/L)	174	360	390	810	55	76	275	457
Sulphate as SO_4 (mg/L)	710	6200	60	1140	54	92	78	165
Chloride (mg/L)	6200	14000	1490	17000	660	768	3140	4100
Calcium (mg/L)	610	1000	55	190	13	19	290	440
Magnesium (mg/L)	680	1400	85	780	39	46	340	451
Sodium (mg/L)	2600	6200	970	13000	380	510	943	1400
Potassium (mg/L)	8	17	14	150	10	13	9	14
Arsenic mg/L (dissolved)	<0.050	0.008	<0.001	0.002	<0.001	<0.001	<0.001	0.011
Barium mg/L (dissolved)	0.078	0.2	0.048	0.283	0.061	0.11	0.202	3.9
Beryllium mg/L (dissolved)	<0.00001	<0.001	<0.0005	<0.001	<0.0005	<0.001	<0.000001	<0.001
Cadmium mg/L (dissolved)	<0.0001	0.0002	<0.0001	0.0012	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt mg/L (dissolved)	0.007	0.002	<0.001	0.003	<0.0001	0.004	<0.001	0.002
Chromium mg/L (dissolved)	<0.001	<0.01	<0.001	0.007	0.001	0.003	<0.001	0.002
Copper mg/L (dissolved)	<0.00005	0.006	<0.001	0.059	<0.001	0.005	<0.001	0.004
Manganese mg/L (dissolved)	3.78	8.1	<0.005	0.035	0.007	0.076	1.1	1.7

Parameter	Quaternary Alluvium		Tertiary Basalt		Tertiary Sediment		Weathered Coal Measures	
	Min	Max	Min	Max	Min	Max	Min	Max
Nickel mg/L (dissolved)	<0.00005	0.17	0.005	0.131	0.006	0.048	<0.001	0.125
Lead mg/L (dissolved)	<0.0001	<0.01	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001
Vanadium mg/L (dissolved)	<0.001	0.002	<0.001	0.015	<0.001	<0.01	<0.001	<0.01
Zinc mg/L (dissolved)	0.008	0.302	<0.05	0.185	<0.005	0.131	<0.005	0.115
Mercury mg/L (dissolved)	<0.00005	<0.0001	<0.00005	0.001	<0.00005	<0.0001	<0.00005	<0.0001
Fluoride (mg/L)	0.23	0.9	0.29	1.9	0.13	0.6	0.4	1
Phosphate as P (mg/L)	<0.005	0.79	0.026	0.67	<0.005	1.3	<0.005	2.09

5.3.2 Deep aquifer water quality

Table 16 provides a summary of water quality results obtained from bores targeting the deep aquifers (M313W, M314W, M324W, M325W, AN019F and M162V). This provides an indication of water quality ranges for each parameter analysed based on aquifer type. Results for some parameters between different monitoring locations show high degree of variation which is likely to be attributable to the spatial heterogeneity and low permeability of the hydrogeological system. In addition to this, as displayed by the groundwater pressure data, groundwater recovery for some sites is slow and this is likely to result in variations in some parameters at the same monitoring location. In general, this data shows that:

- Groundwater quality of the Fort Cooper Coal Measures aquifer is fresh to brackish
- Groundwater quality of the Moranbah Coal Measures is fresh to brackish

Table 16: Water Quality – Deep Monitoring Bores

Parameter	Fort Cooper Coal Measures		Moranbah Coal Measures	
	Min	Max	Min	Max
pH	8.13	11.8	8.0	9.4
EC uS/cm (laboratory)	1170	10200	1710	11500
TDS mg/L (laboratory)	707	5430	1160	6970
Bicarbonate Alkalinity as $CaCO_3$ (mg/L)	<1	634	283	1210
Total Alkalinity as $CaCO_3$ (mg/L)	225	720	334	1220
Sulphate as SO_4 (mg/L)	<1	68	2	134
Chloride (mg/L)	188	2920	198	3640
Calcium (mg/L)	2	154	7	46
Magnesium (mg/L)	<1	5	<1	6
Sodium (mg/L)	199	1620	212	2370
Potassium (mg/L)	13	73	12	1450
Arsenic mg/L (dissolved)	<0.001	0.005	<0.001	0.013
Barium mg/L (dissolved)	0.005	2.79	0.236	4.88
Beryllium mg/L (dissolved)	<0.001	<0.001	<0.001	<0.001
Cobalt mg/L (dissolved)	<0.001	0.004	<0.001	0.01
Chromium mg/L (dissolved)	<0.001	0.004	<0.001	0.018
Copper mg/L (dissolved)	<0.001	0.582	<0.001	7.08
Manganese mg/L (dissolved)	<0.001	0.304	0.092	0.446
Nickel mg/L (dissolved)	<0.001	0.009	<0.001	0.032
Lead mg/L (dissolved)	<0.001	0.459	<0.001	2.19
Vanadium mg/L (dissolved)	<0.01	<0.01	<0.01	0.02
Zinc mg/L (dissolved)	<0.005	0.427	<0.005	0.568
Fluoride (mg/L)	0.7	4.5	0.4	2.4
Phosphate as P (mg/L)	0.04	2.01	0.87	65.6

5.4 Groundwater Use

The results from baseline assessments completed by Arrow have been considered as they provide information on groundwater bores and use.

Baseline Assessment Plans (BAP) have been prepared for the ABT Area. The results of the assessments undertaken as part of these are presented in the following sections. It should be noted that baseline assessments have not yet been completed for ATP 831, and will be undertaken in accordance with the BAP.

5.4.1 MGP Area

A BAP was submitted for the MGP Area and approved by the DEHP on 3 July 2012. The baseline assessment process included undertaking field assessments, sourcing information from mining companies and undertaking desktop assessments. A total of 44 assessments including registered (41) and unregistered bores (3) have been undertaken which identified:

- 3 bores which could not be found (7 %)
- 23 bores were abandoned and destroyed (52 %)
- 6 bores were abandoned but still useable (14 %)
- 12 bores have been verified to exist (27 %)

All bores in the baseline assessments were classified in accordance with the status as defined in the groundwater database by the Department of Natural Resources and Mines (DNRM). The exception to this, were bores which could not be found during the baseline assessment. The bores classified as 'could not be found' included those where the identified bore owner was not aware of the existence of any bore at that location or where a physical site inspection did not find any evidence of the bore in the specified location.

The locations of these bores are shown on **Figure 17**. Based on this data, the majority of existing bores are located on PL223, which suggests that groundwater use is limited on PL 191, 196 and 224.

5.4.2 ATP 1103

A BAP was submitted for ATP1103 and approved on 12 November 2013. Based on the information presented in the DNRM Groundwater Database, baseline assessments have been completed on all registered bores that exist within 2 km of production testing wells on ATP1103. A total of 101 assessments, including registered (38) and unregistered bores (63), have been undertaken on ATP1103. The results concluded that:

- 25 bores could not be found (25 %)
- 6 bores are abandoned and destroyed (6 %)
- 27 bores are abandoned but still useable (27 %)
- 43 bores have been verified to exist (42 %)

The locations of these bores are shown on **Figure 18**.

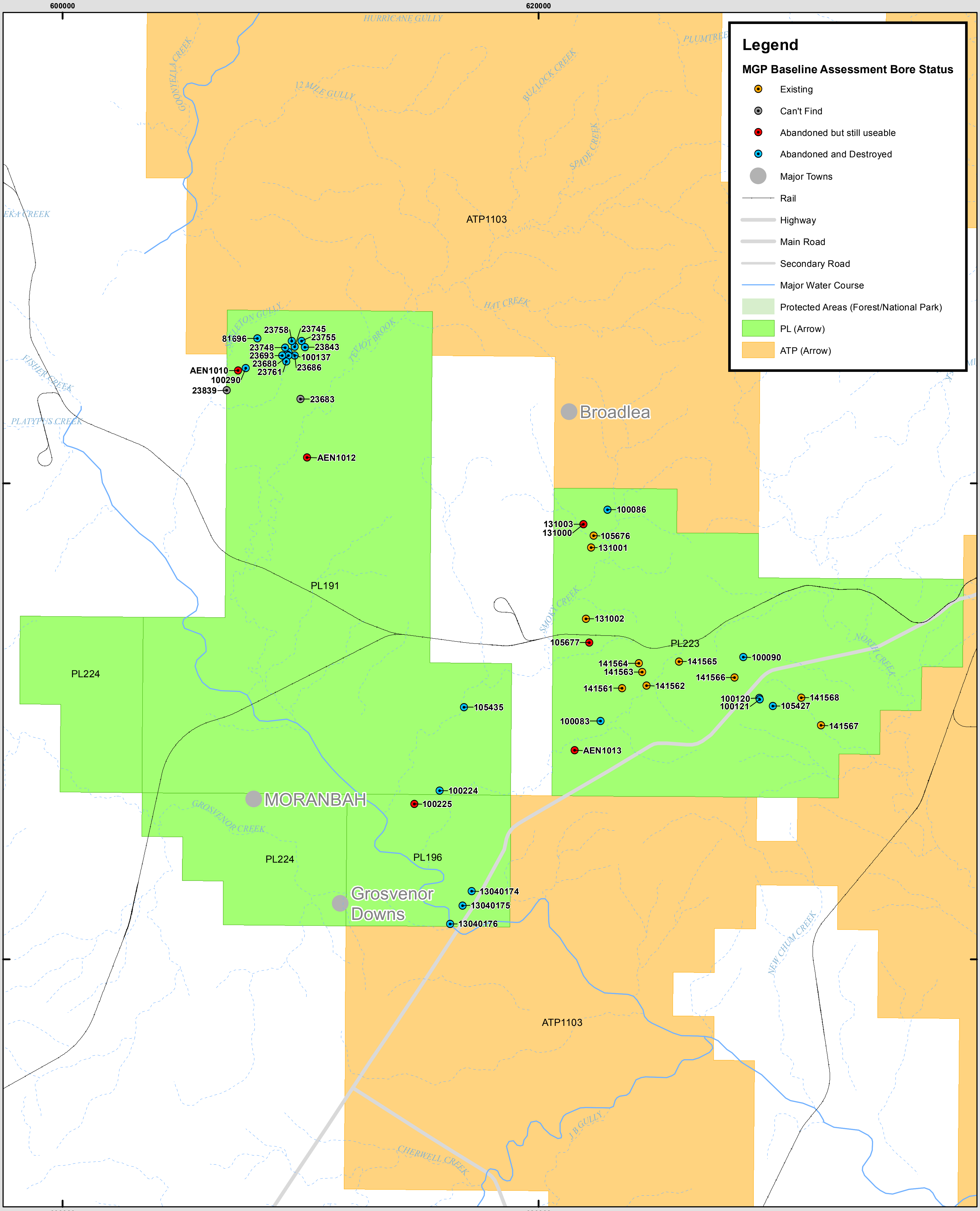

Figure 17. Baseline Assessments for the MGP Area

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Envir. and Resource Mgmt.

Date: 20/01/2016
Issued To: Kavita Singh
Author: tstringer

0 2.5 5 10 Kilometers

Scale: 1:150,900 @ A3
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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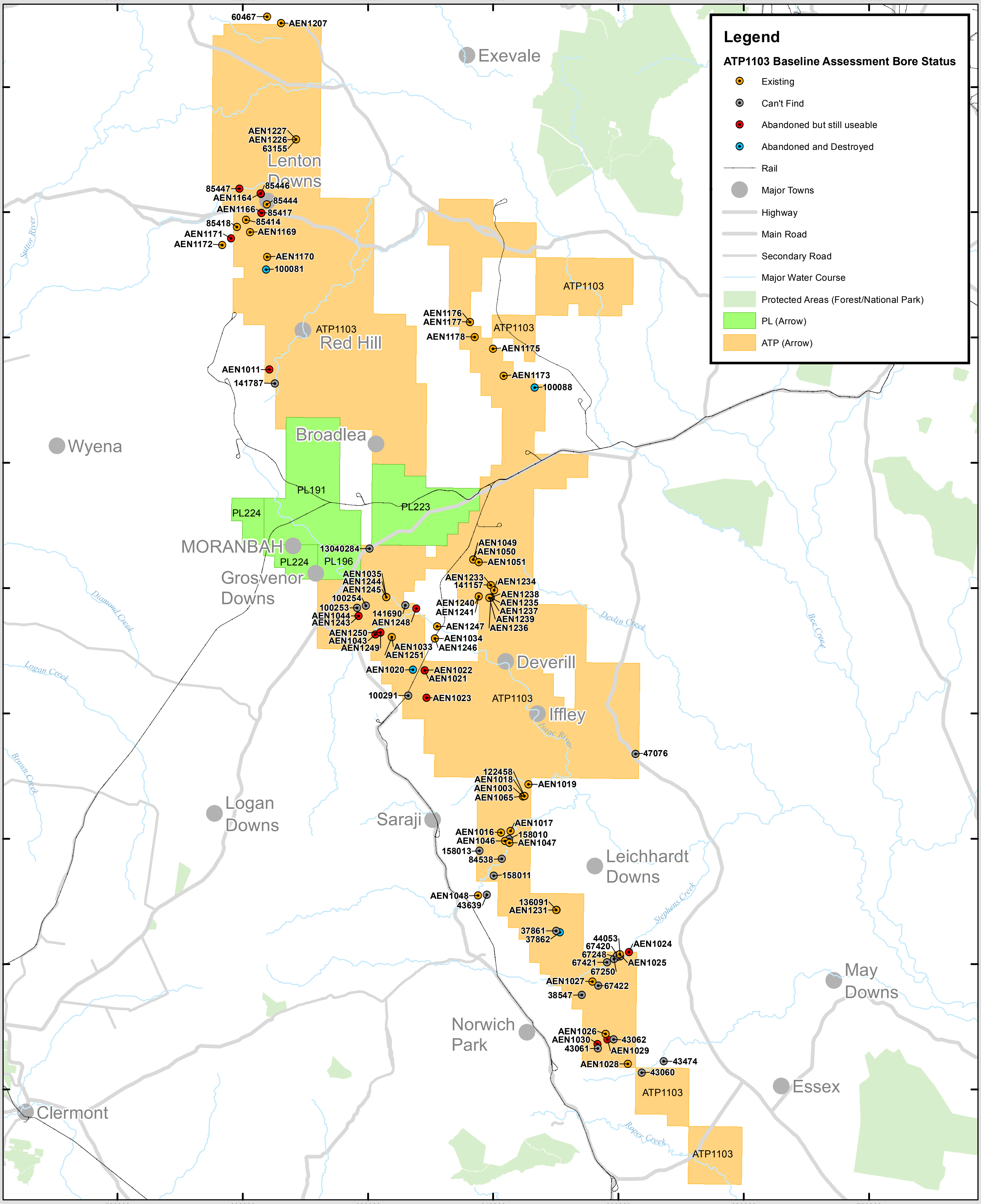

Figure 18. Baseline Assessments for ATP1103

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Envir. and Resource Mgmt.

Date: 20/01/2016
Issued To: Kavita Singh
Author: tstringer

0 5 10 20 30 40 Kilometers

Scale: 1:574,000 @ A3
Coordinate System: GDA 1994 MGA Zone 55

N

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5.4.3 ATP 1031

A BAP was submitted for ATP1031 and approved on 16 April 2013. Based on the information presented in the DNRM Groundwater Database, baseline assessments have been completed on all registered bores that exist within 2 km of production testing wells on ATP 1031. To date, 44 assessments, including registered (29) and unregistered bores (15), have been undertaken on ATP1031. The results concluded that:

- 21 bores could not be found (48 %)
- 2 bores are abandoned and destroyed (4 %)
- 13 bores are abandoned but still useable (30 %)
- 8 bores have been verified to exist (18 %)

The locations of these bores are shown on **Figure 19**.

5.4.4 ATP 742

A BAP was submitted for ATP742 and approved on 22 October 2015. Based on the information presented in the DNRM Groundwater Database, baseline assessments have been completed on all registered bores that exist within 2 km of production testing wells on ATP 742. To date, a total of 13 assessments have been undertaken on ATP742. The results concluded that:

- 3 bores are abandoned but still useable (23%)
- 10 bores have been verified to exist (77%)

The locations of these bores are shown on **Figure 20**.

5.4.5 Future Baseline Assessments

An update of the DNRM Groundwater Database has been undertaken in 2015. Whilst a number of baseline assessments have been completed for Arrow's tenements, in particular the MGP Area, the update to the DNRM Groundwater Database has resulted in a number of additional water bores for assessment. These will be reviewed and BAP's revised accordingly.

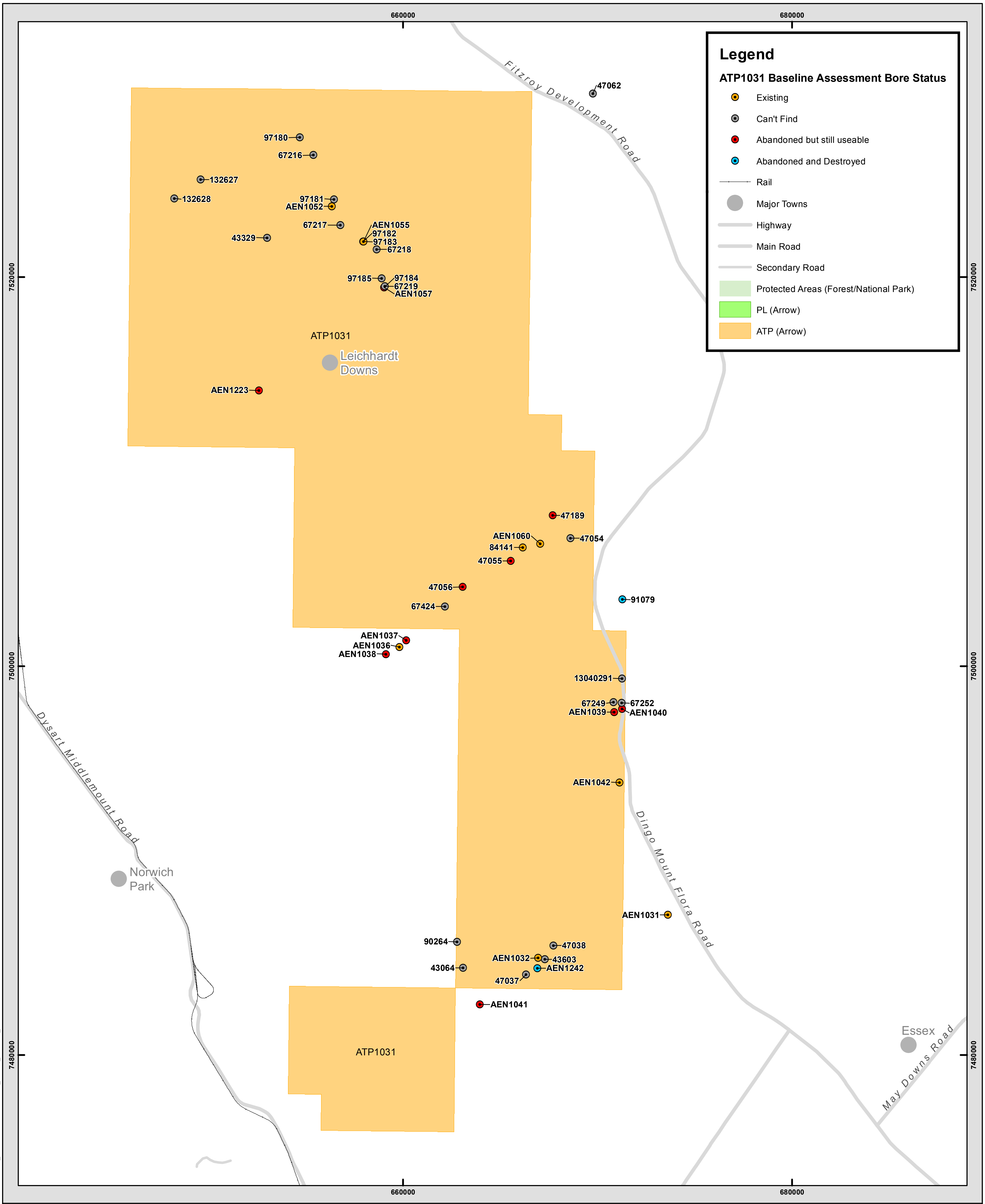

Figure 19.

Baseline Assessments for ATP 1031

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Envir. and Resource Mgmt.

Date: 20/01/2016
Issued To: Kavita Singh
Author: tstringer

0 2.5 5 10 Kilometers

Scale: 1:180,000 @ A3
Coordinate System: GDA 1994 MGA Zone 55

N

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ARROW ENERGY - BOWEN BASIN GAS PROJECT

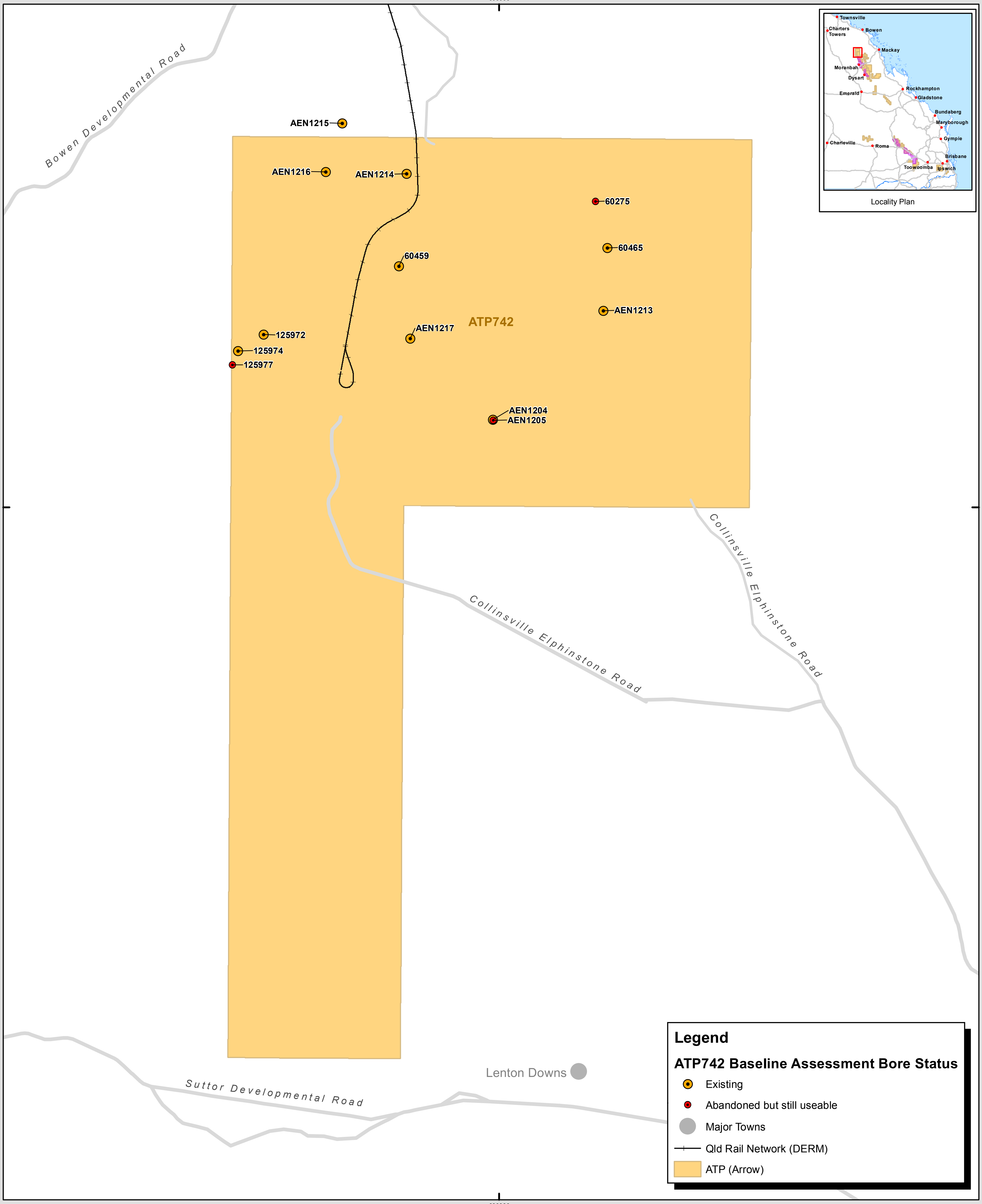

Figure 20. Baseline Assessments for ATP 742

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 20/01/2016
Issued To: K Singh
Author: tstringer

0 5 10
Kilometres
Scale: 1:180,000 @ A3
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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5.5 Aquifer Testing

Hydraulic testing was undertaken during the period 1 July 2013 to 5 July 2013 on groundwater monitoring bores within PLs 191, 196, 223 and 224 as shown in **Figure 21**. Some of these sites form part of the UWIR WMS. The remaining sites that aren't included in the WMS for PLs 191, 196, 223 and 224 are shallow groundwater monitoring bores that have been installed for the purposes of Environmental Authority (EA) compliance and have been included for reference purposes.

The method of testing was by slug testing utilising a PVC slug filled with local washed river sand.

5.5.1 Testing

The general procedure for each slug test was as follows:

1. Depth to groundwater measured in the well,
2. Logging equipment Insitu Level Troll 500 (programmed to record every 15 seconds) installed 0.2 to 0.3 m up from the bottom of the well,
3. Well left for a minimum of one hour to gather baseline groundwater level measurements,
4. Slug inserted to below groundwater level. Depth to groundwater measured in the well,
5. Well left for a minimum of two hours for groundwater level to stabilise,
6. Slug removed from the well. Depth to groundwater measured in the well, and
7. Well left for a minimum of two hours for groundwater level to stabilise. Level Troll 500 removed from well. Depth to groundwater measured in the well.

The dimensions of the PVC slugs are 1.02 m by 0.04 m. Wells with less than one metre of water were not tested as part of the program.

5.5.2 Analysis

The analysis of the slug test data was performed using Aqtesolv software. The analysis method used was the Bouwer-Rice method.

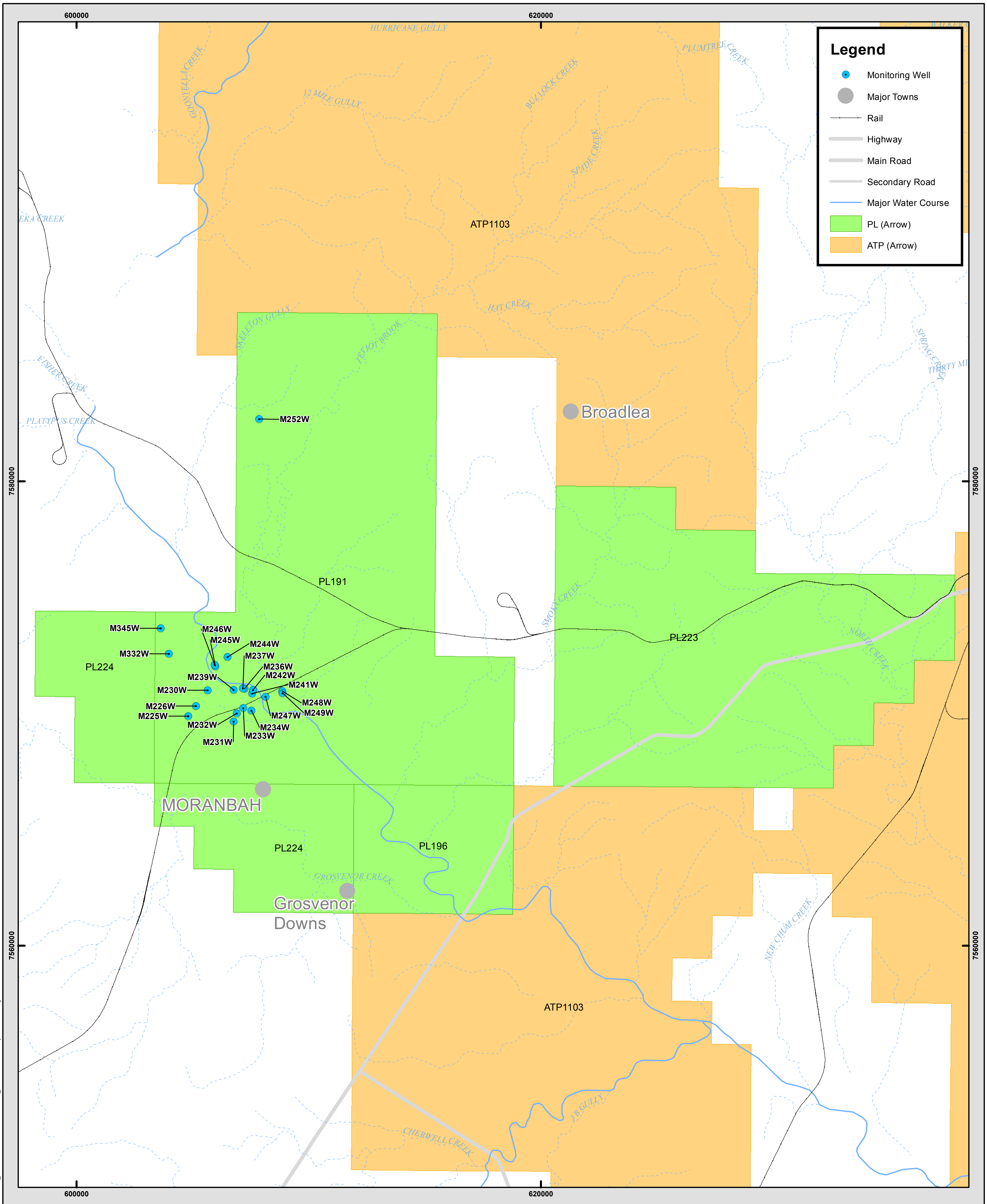

Figure 21.

Hydraulic Testing Sites

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Natural Resources and Mines

Date: 4/01/2016
Issued To: Kavita Prasad
Author: tstringer

0 2.5 5 10
Kilometers
Scale: 1:151,000 @ A3
Coordinate System: GDA 1994 MGA Zone 55

N

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5.5.3 Results

The hydraulic conductivity values determined from the slug tests data are summarised in **Table 17** below. Three of the tests were unable to be analysed due to unsuitable data.

Table 17: Summary of Hydraulic Conductivity Values

Monitoring Well ID	Screened Formation	Test Type	Hydraulic Conductivity (K)(m/d)	Well Average Hydraulic Conductivity (K)(m/d)*
M225W	Weathered Tertiary Basalt	Falling Head Test	unsuitable data to perform analysis	6.21×10^{-1}
		Rising Head Test	6.21×10^{-1}	
M226W	Weathered Tertiary Basalt	Falling Head Test	1.00×10^{-2}	7.94×10^{-3}
		Rising Head Test	5.88×10^{-3}	
M230W	Weathered Tertiary Basalt	Falling Head Test	4.35×10^{-1}	3.49×10^{-1}
		Rising Head Test	2.64×10^{-1}	
M231W	Weathered Tertiary Basalt	Falling Head Test	4.35×10^{-1}	3.5×10^{-1}
		Rising Head Test	2.65×10^{-1}	
M232W	Quaternary Alluvium	Falling Head Test	1.50	1.40
		Rising Head Test	1.30	
M233W	Quaternary Alluvium	Falling Head Test	unsuitable data to perform analysis	2.71×10^{-1}
		Rising Head Test	2.71×10^{-1}	
M234W	Quaternary Alluvium	Falling Head Test	8.51×10^{-2}	1.02×10^{-1}
		Rising Head Test	1.19×10^{-1}	
M236W	Quaternary Alluvium	Falling Head Test	1.39×10^{-2}	1.07×10^{-1}
		Rising Head Test	3.96×10^{-2} to 3.60×10^{-1}	
M237W	Quaternary Alluvium	Falling Head Test	1.65×10^{-2}	1.90×10^{-2}
		Rising Head Test	2.15×10^{-2}	
M239W	Quaternary Alluvium	Falling Head Test	4.27×10^{-2}	5.89×10^{-2}
		Rising Head Test	7.50×10^{-2}	
M241W	Weathered Tertiary Basalt	Falling Head Test	6.03×10^{-2}	5.87×10^{-2}
		Rising Head Test	5.72×10^{-2}	
M242W	Weathered Tertiary Basalt	Falling Head Test	2.31×10^{-2} to 9.08×10^{-2}	6.1×10^{-2}
		Rising Head Test	6.91×10^{-2}	
M244W	Weathered Fort Cooper Coal Measures	Falling Head Test	1.04	1.02
		Rising Head Test	9.96×10^{-1}	
M245W	Quaternary Alluvium	Falling Head Test	8.18×10^{-3}	1.21×10^{-2}
		Rising Head Test	1.61×10^{-2}	
M246W	Quaternary Alluvium	Falling Head Test	5.56×10^{-2} to 3.85×10^{-1}	2.19×10^{-1}
		Rising Head Test	5.26×10^{-2} to 2.89×10^{-1}	
M247W	Weathered Fort Cooper Coal Measures	Falling Head Test	1.95×10^{-1}	2.71×10^{-1}
		Rising Head Test	3.46×10^{-1}	
M248W	Quaternary Alluvium	Falling Head Test	3.68×10^{-1}	4.15×10^{-1}

Monitoring Well ID	Screened Formation	Test Type	Hydraulic Conductivity (K)(m/d)	Well Average Hydraulic Conductivity (K)(m/d)*
		Rising Head Test	4.62×10^{-1}	
M249W	Quaternary Alluvium	Falling Head Test	3.00×10^{-1} to 1.09×10^{-2}	7.87×10^{-1}
		Rising Head Test	1.42	
M252W	Tertiary Sediment	Falling Head Test	2.69×10^{-1} to 1.22	4.25×10^{-1}
		Rising Head Test	1.06×10^{-1}	
M332W	Weathered Tertiary Basalt	Falling Head Test	1.61×10^{-3}	1.61×10^{-3}
		Rising Head Test	Unsuitable data to perform analysis	
M345W	Quaternary Alluvium	Falling Head Test	1.59×10^{-2} to 5.77×10^{-2}	3.28×10^{-2}
		Rising Head Test	7.60×10^{-3} to 5.02×10^{-2}	

*This is an average of the hydraulic conductivity based on the tests undertaken for each site

5.5.4 Discussion

The hydraulic conductivity values derived from the slug test analyses fit within the average values for the different lithologies observed from the well borelogs. Average hydraulic conductivity values are provided in **Table 18**.

Table 18: Average Hydraulic Conductivity Values

Geological Material	Average Hydraulic Conductivity Values[1]
Clay	10^{-8} to 10^{-2}
Fine sand	1 to 5
Sand and gravel mixes	5 to 100
Clay, sand and gravel mixes	10^{-3} to 10^{-1}

Notes:

1. Kruseman and de Ridder, 2000. *Analysis and Evaluation of Pumping Test Data*. Second Edition.

6 SPRINGS

Section 379 of the Water Act 2000 defines a potentially affected spring as a spring overlying an aquifer affected by underground water rights if –

(a) The water level in the aquifer is predicted, in an underground water impact report or final report, to decline by more than the spring trigger threshold at the location of the spring at any time; and
(b) The cause of the predicted decline is, or is likely to be, the exercise of the underground water rights.

The spring trigger threshold for an aquifer is a decline in the water level of the aquifer that is 0.2 m. Hence, an assessment of potentially affected springs is based on where the long term predicted impact on water pressures at the location of the springs resulting from the extraction of water exceeds 0.2 m.

Springs in the project area refer to spring vent, spring complex or watercourse springs. Spring vents are a single point in the landscape where groundwater is discharged at the surface. A spring complex is a group of spring vents located in close proximity to each other. A watercourse spring is a section of a watercourse where groundwater enters the stream from an aquifer through the stream bed. DEHP maintains an inventory of identified springs in the Queensland Springs Dataset. Many of these sites have been studied in detail through the completion of field surveys including those completed in 2011 by KCB and the Queensland Herbarium (KCB, 2012 and Queensland Herbarium, 2012). An assessment of spring vents and water course springs has been undertaken as part of the BGP SREIS. Reference should be made to **Appendix B** for a detailed assessment of springs within the Project Area.

Based on this data, the only springs identified proximal to Arrow project tenure are found in a cluster of springs present to the west and south-west of ATP831 (illustrated in **Figure 22**), lying in the Mimosa and Planet Creek sub-catchments of the Dawson/Mackenzie River catchments. These springs are located:

- Greater than 100 km south of ATP 1103 which forms part of the future BGP
- Greater than 50 km west of current production testing wells in ATP 831

Arrow has undertaken limited production testing at four locations within their ATP 831 tenure (at the Baralaba and Coomooboolaroo sites). Appraisal for the tenement is still ongoing; however currently there is no forecast for future production on ATP 831. The BGP, for which future production is forecast, does not incorporate ATP 831 and is situated greater than 100 km north of the identified springs. Predicted impacts to the identified springs, as a result of production and production testing within the Project Area do not exceed the spring trigger threshold. As such, impacts to these springs as a result of the project will not be considered further in this UWIR.

The following watercourse springs were identified in the BGP SREIS:

- Site W114: Mimosa Creek Tributary;
- Site W113: Mimosa Creek;
- Upper reaches of the Connors River, Funnel Creek, Denison Creek and Lotus Creek;
- Mid reaches of the Connors River and Funnel Creek; and
- Lower reaches of the Isaac River

The locations of these watercourse springs are shown in **Figure 22**.

Figure 22 also shows the areas where the water level is predicted to decline by greater than 0.2 m in both the shallow and deep aquifers. This is based on the 2016 Bowen UWIR Model which is discussed in more detail in Section 8. The 2016 Bowen UWIR Model predicts changes to groundwater level due to the extraction of groundwater for CSG production and production testing in the MGP Area, BGP and simulates no other groundwater extraction (base case).

As shown in the map, the 0.2 m drawdown areas for the shallow aquifers are isolated occurrences with limited spatial extent. In addition to this, a number of the 0.2 m drawdown areas overly existing open cut mines and therefore these areas are not considered relevant as they have been mined out and will not contain any previously unidentified springs.

No spring vents, spring complexes or watercourse springs have been identified to exist within the 0.2 m drawdown area. The known springs are located greater than 50 km away from the predicted 0.2 m drawdown area. Therefore, based on available data, impacts to springs as a result of the Project Area activities will be negligible. A Spring Impact Management Strategy will not be prepared as part of this UWIR.

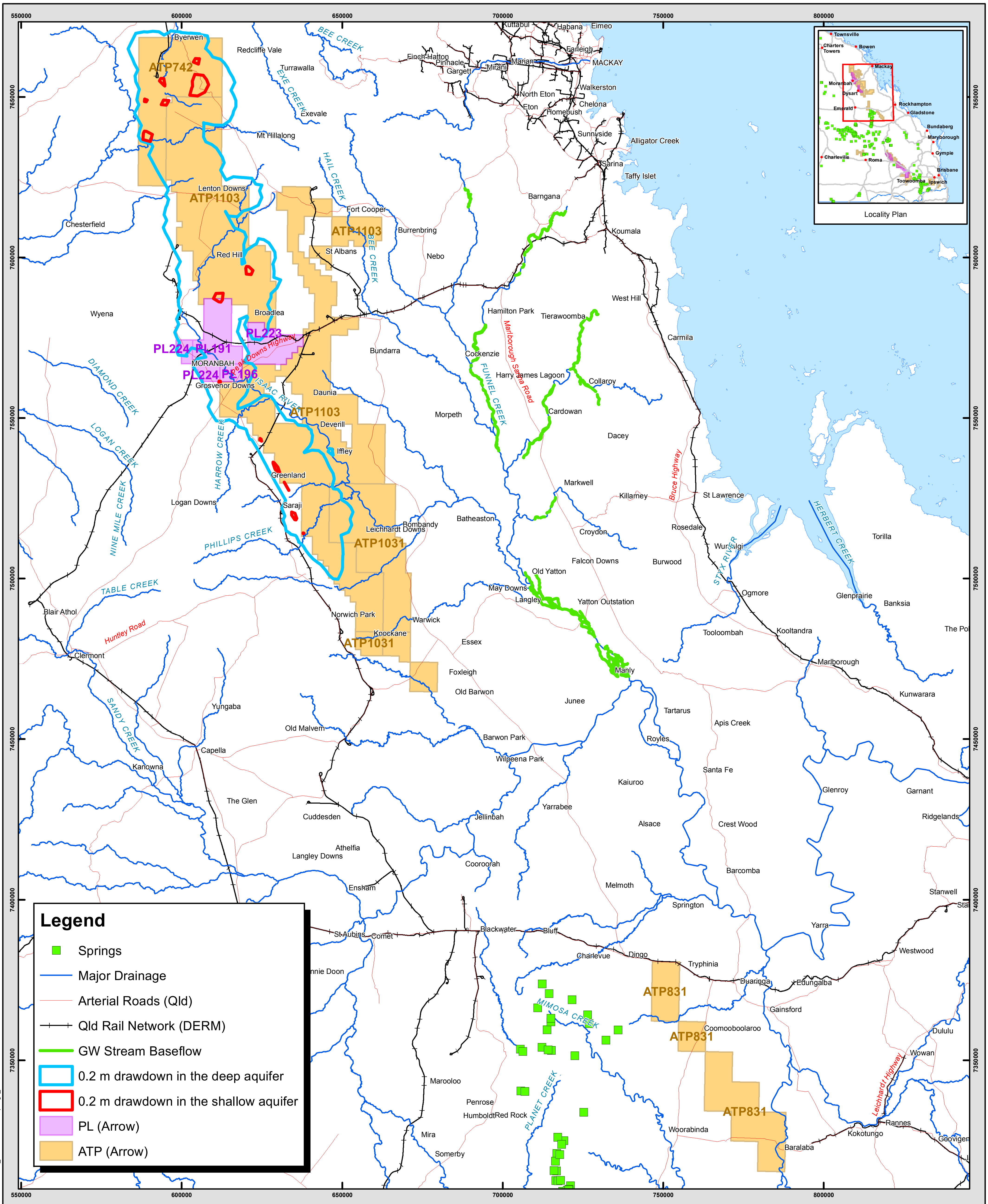

Figure 22. **Location of Springs**

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 9/08/2016
Issued To: K Singh
Author: tstringer

0 25 50 100
Kilometres
Scale: 1:1,093,000 @ A3
Coordinate System: GDA 1994 MGA Zone 55

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Document: V:\Products\Australia\Queensland_CommonEnvironment\151118_UWIR2015\mxd\Springs_B.mxd

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7 UPDATED CONCEPTUAL HYDROGEOLOGICAL MODEL

A conceptual hydrogeological model was developed as part of the MGP UWIR, ATP 1103 UWIR and ATP 1031 UWIR. This was updated as part of the EIS and SREIS for the Project Area as has been depicted in Section 3 of this report. The validity of the existing conceptual hydrogeological model was reviewed in light of the new data presented in Section 5 of this UWIR. This review is presented below.

7.1 Water Levels and Flow

The groundwater monitoring network detailed in the WMS for the MGP Area has been implemented. Data obtained from groundwater monitoring bores making up the WMS provide site specific observations on groundwater levels/pressures and interconnectivity. The table below provides a comparison of this data. Overall, the existing conceptual model as presented in Section 3 remains valid. Whilst site specific data is provided in the table below, on a regional scale groundwater levels, flow and quality will vary.

Table 19: Data comparison

Existing Conceptual Model	Supporting data collected since previous UWIR
Shallow aquifers are recharged mainly through direct infiltration of rainfall, overland flow and surface water flow;	Water table aquifers are recharged by rainfall as depicted in bore M222W
Shallow aquifers are hydraulically connected to surface water systems	Water table aquifers in some locations are in connection with rivers/streams (generally losing stream) as depicted in bore M224W
Rewan Formation is considered to be a regional-scale confining unit (aquitard). The coal seams are further confined by low permeability overburden and interburden.	No evidence of interconnectivity between shallow and deep aquifers Depressurisation impacts notable within the coal measures in monitoring bores located within 350 m of existing production wells. Propagation of impacts within the coal measures not readily identifiable in monitoring bores located 4.5 km from existing production wells, thus suggesting low permeability target formations
Coal seams are low to moderately permeable	Water pressure recovery data suggests that the permeability of the coal seams is considered to be low to very low. Water quality of the coal seam aquifers is highly variable indicating spatial heterogeneity of the hydrogeological system.
Groundwater quality of the Quaternary Alluvium aquifer is highly variable ranging from fresh to very saline	Groundwater quality of the Quaternary Alluvium aquifer is considered to be brackish to saline.
Groundwater quality of the Tertiary Basalt aquifer is variable ranging from fresh to moderately saline	Groundwater quality of the Tertiary Basalt aquifer is considered to be brackish to saline.
Groundwater quality of the Tertiary sediment aquifer is	Groundwater quality of the Tertiary sediment aquifer is

Existing Conceptual Model	Supporting data collected since previous UWIR
typically poor	considered to be fresh to brackish
Groundwater quality of the Permian aquifers is generally poor, however varies from being fresh to very saline	Groundwater quality of the Permian aquifers is considered to range from fresh to brackish

7.2 Aquifer Parameters

A comparison of aquifer parameters from the slug test results as presented in section 5.5 and the calibrated EIS Model value range is presented in the table below.

Table 20: Hydraulic Conductivity results comparison

Formation	Slug test range (m/day)	Calibrated model range (m/day)	Comparison
Basalt (weathered)	0.0061 to 0.62	0.05	Calibrated model range falls within the slug test range
Alluvium (Quaternary)	0.010 to 1.4	1 to 40	Calibrated model range is higher than the slug test range, but there is some overlap
FCCM (weathered)	0.027 to 1.02	0.0001 to 0.0044	Calibrated model range is lower than the slug test range
Tertiary Sediments	0.43	1 to 40	Calibrated model range is higher than the slug test range

Overall the results provide a satisfactory level of consistency with the modelled values. The slug test data is representative of the conditions at the specific bore locations which fall in the MGP Area. The groundwater model encompasses the Project Area and on a regional scale, the hydraulic conductivity values will vary.

7.3 Groundwater Users

Baseline assessments have been undertaken by Arrow. This data provides information on groundwater users within the Project Area and suggests that groundwater use is limited on PLs 191, 196 and 224.

7.4 Conclusion

Groundwater monitoring data obtained to date is focussed around the MGP Area as this is Arrow's only production field in the Project Area. The existing conceptual hydrogeological model aims to represent the system over the Project Area. Whilst the above data provides some updates, it is concluded that the groundwater monitoring data obtained to date is in support of the conceptual hydrogeological model as presented in Section 3 of this report. The EIS Model has been developed based on the existing conceptual hydrogeological model. Therefore, no update is required to the set up and calibration of the EIS Model. The EIS Model is considered to be suitable for predicting depressurisations impacts as a result of CSG operations for the Project Area as part of this UWIR.

8 UPDATED MODELLING

The EIS Model has been updated as part of the development of the UWIR, hereafter referred to as the 2016 Bowen UWIR Model. The set up and calibration of the 2016 Bowen UWIR Model remains unchanged from the EIS Model, however updates have been made to the wells simulated in the model to reflect historical and forecast production and historical production testing as detailed in Section 2. A summary of the model development and updates are described below.

In addition to the numerical model, an analytical technique has been used to assess impacts associated with production testing from two wells located on ATP 831. As per Section 1, these wells fall within the Surat cumulative management area but have been assessed as part of this UWIR.

Groundwater modelling has been undertaken to make predictions about the groundwater impacts.

8.1.1 UWIR numerical groundwater model update

The 2016 Bowen UWIR Model predicts changes to ground water level due to the extraction of groundwater for CSG production and production testing in the MGP Area and BGP and simulates no other ground water extraction. This includes:

- Historical production and production testing wells in PLs 191, 196, 223, 224
- Historical production testing wells in ATP 1103
- Historical production testing wells in ATP 1031
- Historical production testing wells in ATP 742
- Forecast production wells in PLs 191, 196, 223, 224
- Forecast production wells in the Bowen Gas Project

Details of historical water production associated with the above mentioned wells are provided in Sections 2 of the UWIR and have been modelled accordingly.

The 2016 Bowen UWIR Model adopts the pre-1980 steady state model as initial heads, then simulates the historical production and production testing in the MGP Area and production testing in the BGP from 2003 to 2015. The resulting groundwater levels were then used as the initial heads in the model to simulate forecast production within the MGP Area and BGP from 2016 to 2049. MGP production is simulated for 9 years from 2016 to 2025. BGP production is simulated for 30 years commencing 2019 to 2049.

8.1.2 Analytical Groundwater Model

Production testing occurs over a limited time for each bore and abstracts a finite amount of water. Section 2 provides details of water production associated with production testing on PLs 191, 196, 223, 224 and ATPs 1103, 1031, 742 and 831.

All production testing wells have been modelled in the numerical groundwater model excepting wells Baralaba 6 (BR006F) and Baralaba 8 (BR008F) within ATP831. These two wells fall within the Surat Cumulative Management Area but fall outside of the 2016 Bowen UWIR Model domain. Analytical modelling has been used to provide estimates of decline in water level in response to the abstraction of groundwater associated with production testing in these two wells. This is described in more detail in the following sections.

8.1.2.1 Analytical Model Set Up

A two dimensional analytical solution has been used to assess the potential impacts of groundwater extraction as a result of production testing undertaken in two wells at ATP831. Multi-Layer Unsteady state (MLU) for Windows has been used to compute drawdown associated with this production testing. MLU for Windows combines:

- An analytical solution technique for well flow in layered aquifer systems;
- The superposition principle, both in space (multiple wells) and time (variable discharges);
- The Lavenberg-Marquardt algorithm for parameter optimisation (automated curve fitting).

This combination of techniques allows all tests to be analysed in a consistent way with a single user interface. The key assumptions/limitations of MLU include:

- All layers are assumed homogeneous, isotropic and of infinite extent
- Only groundwater flow resulting from pumping and injection wells can be modelled.

These assumptions are reasonable given the small scale of abstraction and extensive nature of the unit.

The model has been set up into 3 layers to represent the target coal seam Baralaba Coal Measures aquifer, the Rewan Formation aquitard and the shallow Quaternary alluvium aquifer. Based on the groundwater assessment undertaken for the Bowen Gas Project EIS, the hydraulic properties of each of the major hydrostratigraphic units were estimated as low, base case, and high values. It should be noted that the production testing wells have been installed in the Baralaba Coal Measures which are equivalent to the Rangal Coal Measures in the north of the basin. The vertical hydraulic conductivity (Kv) ranges from 0.00001 – 0.001 m/day for the Rewan Formation, 0.00001 – 0.005 m/day for the Rangal Coal Measures, and 0.02 – 2 m/day for the Quaternary Alluvium. The storage values range from 0.000005 - 0.0005 for the Rewan Formation and the Rangal Coal Measures, and 0.00005 – 0.005 for the Quaternary Alluvium. The values used for the analytical model are shown in the below table and represent the "base case" in line with the numerical groundwater model.

Table 21: Layers and parameters used for the analytical model set up

Model Layer	Aquifer/Aquitard	Thickness (m)	Kh (m/day)	Kv (m/day)	Storage
Layer 1	Quaternary Alluvium	50	2	0.2	0.0005
Layer 2	Rewan Formation	399	0.005	0.0001	0.00005
Layer 3	Rangal Coal Measures	167	0.005	0.0005	0.00005

The pumping regime was entered into the model and calculations made for drawdown over time. The production testing schedule is presented in Section 2.3.

9 PREDICTION OF IMPACTS

Predictions have been made of decline in water level induced by Arrow's CSG operations. Potential impacts as a result of production associated with the MGP Area, ABT Area and BGP are described in the following sections.

It should be noted that the predictions made in the groundwater model will be validated with the monitoring data as part of the annual review process. This will provide confirmation of predicted impacts against actual impacts occurring if any.

9.1 Immediately Affected Area (IAA)

The IAA of an aquifer is the area within which water levels are predicted to decline as a result of CSG water extraction by more than the trigger threshold within three years of the consultation day for the report (6 January 2016). The trigger thresholds are specified in the *Water Act 2000*. They are 5 m for consolidated aquifers (such as sandstone) and 2 m for unconsolidated aquifers (such as sands).

Impacts associated with forecasts of the quantity of water produced for a 3 year period (commencing 6/1/2016) has been predicted for the MGP Area and the BGP. **Figure 23** shows the extent of the IAA in the MCM.

The IAA resulting from production testing has been estimated based on model predictions for impacts as at November 2015 for all production testing undertaken in ATPs 1103, 1031, 831 and 742. **Figure 23** shows the extent of the IAA at the end of 2015.

Key observations about the IAA are as follows:

- There is no IAA (predicted drawdown greater than 2 m trigger threshold) for unconsolidated aquifers in the Project Area;
- There are larger areas of IAA (predicted drawdown greater than 5 m trigger threshold) for the Moranbah Coal Measures. This is associated with proposed production in PLs 191, 196, and 224;
- The IAA (predicted drawdown greater than 5 m trigger threshold) for consolidated aquifers (Moranbah, Rangal and Baralaba Coal Measures) for production testing wells are localised within the immediate vicinity of each production testing well.
- There are no other areas of IAA (predicted drawdown greater than 5 m trigger threshold) for consolidated aquifers in the Project Area;

Information on groundwater bores has been compiled from the DNRM Groundwater Data Base and Water Management System. In addition to this, the groundwater bores has been verified by Baseline Assessments undertaken by Arrow (refer Section 5.4). Whilst bore 162068 is shown to be existing on PL191, this bore is a mine water supply bore targeting the shallow Basalt aquifer and does not exist within the IAA (which is limited to the MCM in this area). Bore 85444 is located near pilot testing wells LW005, LW006V and LW007V. This bore a landholder bore targeting the shallow Basalt/Tertiary Sediment aquifer and does not exist within the IAA (which is limited to the MCM in this area).

A review of the Baseline Assessment data against the IAA concludes that there are no existing or useable bores in the IAA.

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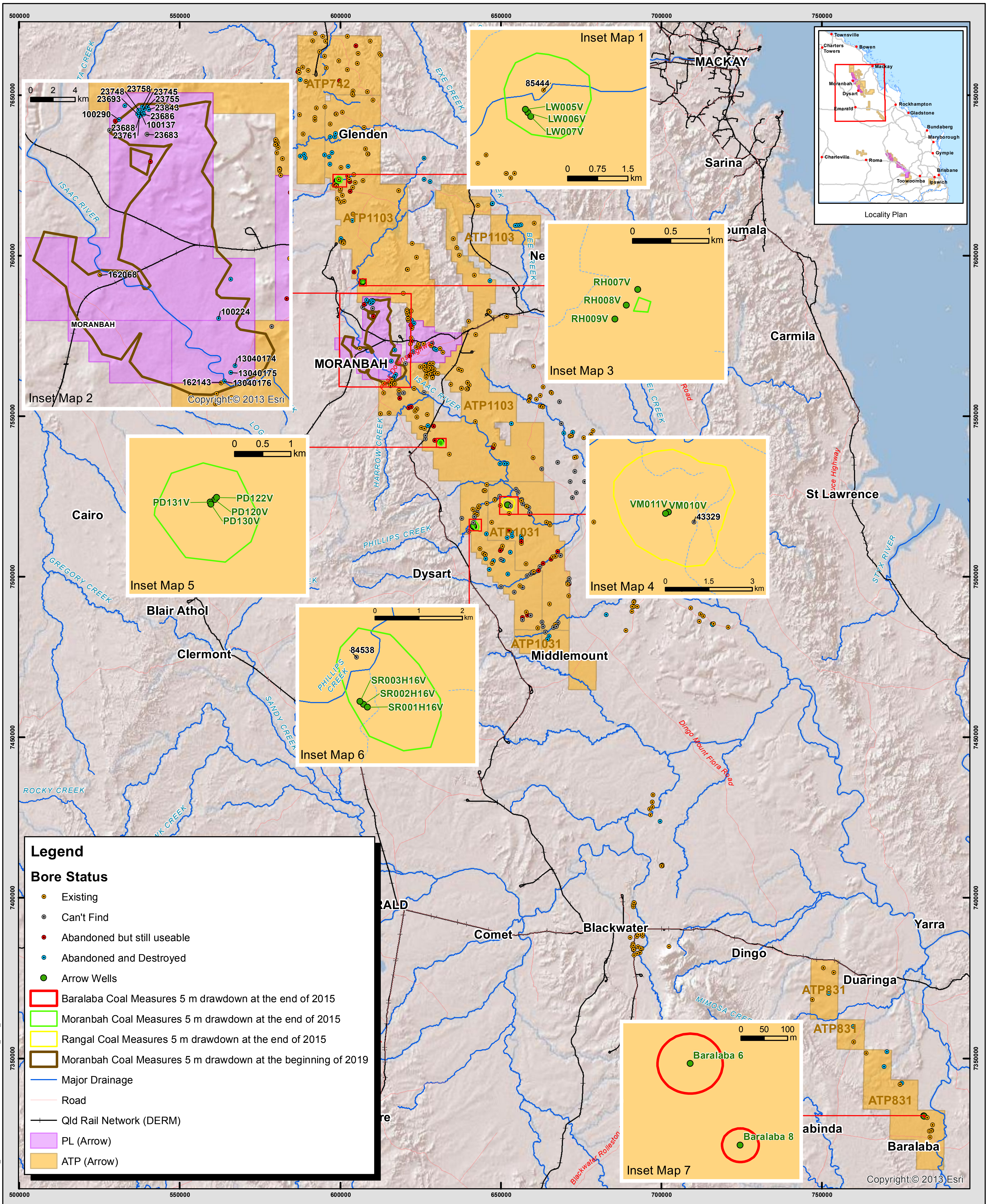

Figure 23. **Extent of the Immediately Affected Areas**

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 20/01/2016
Issued To: K Singh
Author: tstringer

0 25 50 100
Kilometres
Scale: 1:1,093,000@ A3
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.

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no warranty is given that the information contained on this map is free from error or omission. Any reliance placed on such information shall be at the sole risk of the user. Please verify the accuracy of all information prior to using it.

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9.2 Long-term Affected Area (LAA)

The LAA of an aquifer is the area within which water levels are predicted to decline by more than the trigger thresholds at any time in the future. The trigger thresholds are specified in the *Water Act 2000*. They are 5 m for consolidated aquifers (such as sandstone) and 2 m for unconsolidated aquifers (such as sands). The quantity of water produced has been forecast until 2025 for the MGP. The quantity of water produced has been forecast until 2049 for the BGP. The timeframe within which the LAA has been determined is up until 2169 (i.e. 120 years post the cessation of the BGP). **Figure 24** shows the extent of the LAA in the RCM and MCM associated with the MGP and the BGP. Maximum impacts in the RCM and MCM will occur at different times at different geographic locations based on the phased field development of the MGP and BGP. However, maximum impacts occur towards the end of project life which is from approximately 2025 to 2035 for the MGP and from approximately 2049 to 2059 for the BGP.

Future production testing volumes cannot be provided given that they are undertaken for exploration and appraisal purposes. Modelled predictions of impacts are based on historical production testing volumes as at November 2015 in the ABT area. Based on available data, the impacts predicted for the IAA is the same as the LAA for production testing wells as depicted in Figure 23 above.

Key observations about the LAA are as follows:

- There is no LAA (predicted drawdown greater than 2 m trigger threshold) for unconsolidated aquifers in the Project Area;
- There are larger areas of LAA (predicted drawdown greater than 5 m trigger threshold) for the Rangal Coal Measures. This is associated with proposed production in the BGP.
- There are larger areas of LAA (predicted drawdown greater than 5 m trigger threshold) for the Moranbah Coal Measures. This is associated with proposed production in the BGP as well as PLs 191, 196, 224.
- There are localised areas of LAA's (predicted drawdown greater than 5 m trigger threshold) within the immediate vicinity of some production testing wells for the Moranbah, Rangal and Baralaba Coal Measures.
- There is no predicted LAA in any other consolidated aquifers.

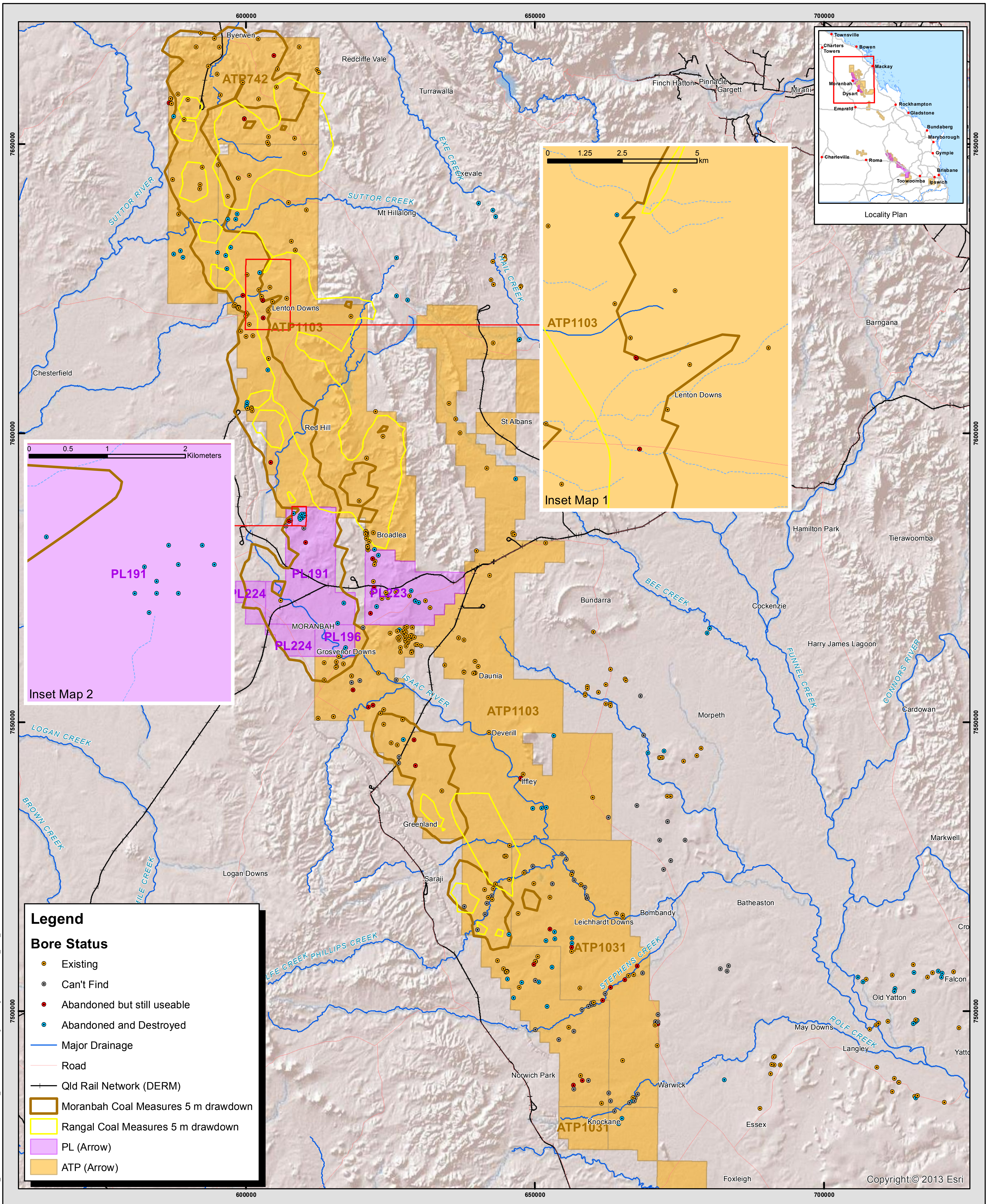

Figure 24. Extent of the Long-term Affected Areas

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 20/01/2016
Issued To: K Singh
Author: tstringer

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Kilometres

Scale: 1:607,150 @ A3
Coordinate System: GDA 1994 MGA Zone 55

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10 WATER MONITORING STRATEGY

10.1 Groundwater Monitoring Program

A water monitoring strategy is required for the Project Area shown in **Figure 23** and **24.** This incorporates the development of a groundwater monitoring program.

The groundwater monitoring program has been developed to undertake:

- Site and regional groundwater level monitoring data in the deeper aquifers;
- Site and regional groundwater level and quality monitoring data in the shallow aquifers;
- Assessment of site aquifer parameters for shallow and deep aquifers through model calibration;
- Characterisation of interconnectivity of aquifers underlying the site; and
- Characterisation of surface water – groundwater interaction (particularly with Isaac River on-site).

In order to meet the aforementioned objectives, a groundwater monitoring program that includes a representative suite of bores in the shallow, intermediate and deep groundwater systems is proposed. The major groundwater systems to be monitored include:

- Shallow groundwater systems (water-table) comprised of:
  - Quaternary alluvium, and
  - Tertiary basalt and sediments.
- Intermediate groundwater systems (confined / unconfined) of Triassic outcrop formations including the Clematis Sandstone; and
- Deep groundwater systems (confined aquifers) of:
  - Blackwater Group at the CSG target depths, and
  - Blackwater Group sub-crops including the Rangal Coal Measures, Fort Cooper Coal Measures and Moranbah Coal Measures.

Given that CSG operations in the Project Area have been on-going for a number of years and the extent and potential for impacts greater than the bore trigger threshold appears limited, data reflecting background conditions exists beyond the local area of the Project Area. Therefore, the proposed groundwater monitoring program comprises two phases, being proximal and distal monitoring during and post CSG extraction.

Site specific geological and hydrogeological data collected during drilling will be used to update the conceptual model. This will provide further data to monitor for predicted future impacts to groundwater levels and quality.

The scope for establishing an appropriate groundwater monitoring program for the Project Area includes:

- Identifying existing bores (such as groundwater monitoring bores installed to satisfy conditions of the relevant Environmental Authorities or landholder bores) which may provide data suitable for inclusion to the monitoring program;
- Identifying where additional dedicated groundwater monitoring bores are required. Target aquifers and locations are influenced by the areas of water level decline in excess of the bore trigger threshold and monitoring of aquifers unaffected by taking of water, i.e. background sites;
- Identifying existing Arrow well sites that are located within the vicinity of target monitoring locations for conversion to future groundwater monitoring bores; and
- Review and report results of monitoring annually.

A desktop bore inventory will be undertaken to identify other existing bores in the region. It is likely that data for some of the bores identified in the inventory will be appropriate for inclusion in the monitoring program. Data will be considered suitable if bores are:

- Screened in aquifers where impacts have been predicted;
- Compliant with the Minimum Construction Requirements for Water Bores in Australia (National Minimum Bore Specifications Committee, 2003) or the Code of Practice for constructing and abandoning coal seam gas wells and associated bores in Queensland (DNRM, 2013)
- In good condition;
- Suitable for conversion to a groundwater monitoring bore; and
- The owners grant access to their bore for monitoring.

Depending on the level of detail of the bore inventory, additional work (such as bore condition assessments) may have to be undertaken before an existing bore can be considered to be suitable.

The proposed groundwater monitoring network is discussed in more detail in the following sections of this report.

10.1.1 Groundwater Monitoring Network

A regional aquifer groundwater monitoring network has been developed. The purpose of this monitoring network is to monitor the future effects of decline in water level and establish baseline groundwater level and quality data.

10.1.1.1 MGP Area

A total of 16 groundwater monitoring bores form the groundwater monitoring network for the MGP Area. The details for the groundwater monitoring network are included in **Appendix G. Figure 25** provides an overview of the spatial distribution of the groundwater monitoring network.

Possible sensitive ecosystems exist in association with the Isaac River which runs through the predicted peak decline area for the MCM. Shallow formations (alluvium and basalt) in this area have a higher environmental value and are more likely to be used as a groundwater source. Whilst impacts greater than the bore trigger threshold are not predicted to occur in the shallow formations, seven groundwater bores monitoring shallow aquifers (Quaternary alluvium, Tertiary basalt) have been installed as at June 2012. Groundwater monitoring has been undertaken in these bores for over 3 years and an adequate baseline dataset has been established. It should be noted that some of these bores have been installed to provide information on vertical movement and transmission of impacts to shallow aquifers.

Within the Project Area, drawdown that is predicted to be greater than the bore trigger threshold is centred around PLs 191, 196 and 224. Based on this, the groundwater monitoring network includes four deep groundwater bores within the predicted maximum impact area (greater than 5 m drawdown) for the IAA. They monitor the deep CSG target (Moranbah Coal Measures), Fort Cooper Coal Measures and the underlying Back Creek Group. These four bores have been installed as at July 2014. Monitoring of these bores has been undertaken for over 1 year. A review of this data shows that meaningful pressure gauge data from bore M325W has been difficult to obtain. Available data indicates that the permeability of the formation that M325W is installed in is so low that recovery of groundwater pressures take a very long time (in the order of 6 to 12 months). This causes difficulties associated with monitoring of this bore. It is proposed that water quality sampling of M325W be removed from the UWIR WMS. Groundwater pressures will continue to be logged at M325W. The remaining sites that undertake water quality sampling in the WMS prove sufficient in meeting the monitoring objectives as defined above.

Following the completion of the Baseline Assessment, it was concluded that there are no existing landholder bores on PLs 224, 191, and 196. Existing landholder bores however, are located on PL 223. Consequently, five monitoring bores were proposed to monitor impacts between the IAA and the existing landholder bores on PL 223, as well as locations distal to the IAA for background monitoring. These bores have been installed as at November 2015. **Appendix G** provides the status of these bores.

10.1.1.2 BGP

A water monitoring strategy incorporating a groundwater monitoring program has also been developed for the BGP. The development scenario for the BGP is yet to be finalised, and resultantly forecasted impacts to groundwater may change in the future. The proposed groundwater monitoring program is indicative only at this stage and may change in the future to be more reflective and relevant to the finalised BGP development scenario and groundwater impacts.

It is proposed that up to 29 groundwater monitoring bores will be installed in the BGP area which will comprise both Arrow and landholder bores. The details for the proposed groundwater monitoring network are included in **Appendix G**. It should be noted that monitoring bore names are indicative and will change. The primary reasoning behind the location and number of groundwater monitoring bores that make up the groundwater monitoring network will be to provide good spatial coverage of groundwater monitoring points consistent with the hydrogeological significance of the unit and the likelihood for the unit to be impacted by the BGP. The purpose of this monitoring network is to monitor the future effects of decline in water level and establish baseline groundwater level and quality data. It is envisaged that this data will provide input into future refinement of the groundwater model.

These bores have been proposed to be installed conditional on conversion to a PL. The applicability of the proposed monitoring network will be reviewed and further refinement of the groundwater monitoring strategy will be conducted as part of the annual review. The groundwater monitoring strategy will also be reviewed and amended for the revised UWIR due in three years from the date of the approved UWIR.

10.1.1.3 ABT Area

Production testing has been undertaken in the ABT Area resulting in localised IAAs around some of the production testing wells on ATP 1103, 1031 and 831. Production testing is undertaken for exploration and appraisal purposes, is short term in nature and yields limited volumes of water. Groundwater modelling indicates extremely limited extent (in the immediate vicinity of production testing wells) and duration of water level decline by more than the bore trigger threshold for the Rangal, Moranbah and Baralaba Coal Measures.

A field development plan has not been prepared for ATP 831 and only production testing has been undertaken on this tenement as part of the exploration and appraisal process. The proposed BGP does not include ATP 831.

Based on this, for the duration of each production testing well, the WMS for the ABT area includes:

- The quantity of water produced from the production testing wells will be monitored and assessed as part of the annual review.
- The production testing wells will be monitored to assess the change in water level in the formation into which the production testing wells are installed.
- The underground water impact report will be updated at the review date to include the impacts of new production testing on the predictions presented in the UWIR.
- A Bore assessment will be undertaken on any landholder bore within the IAA.

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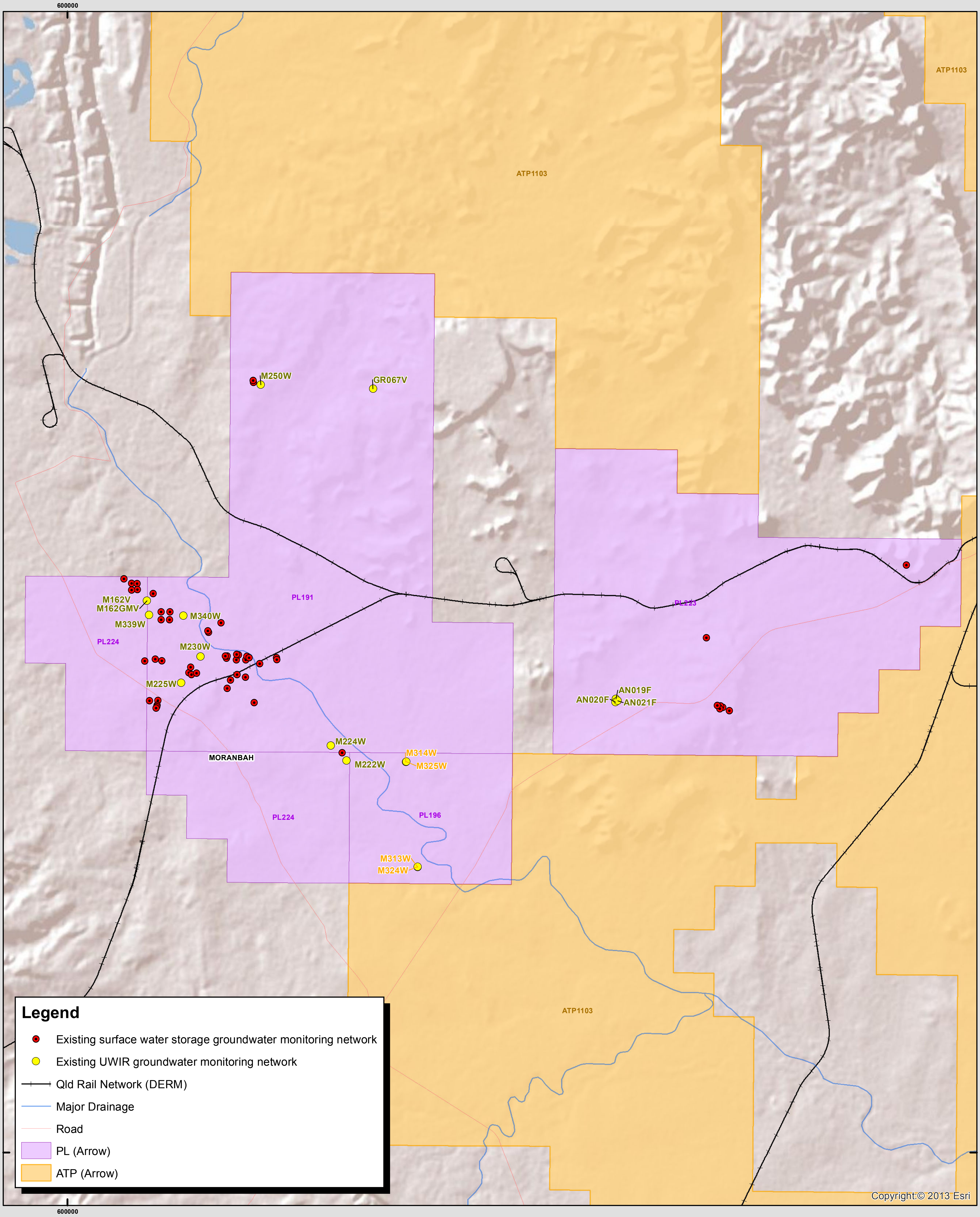

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Figure 25. **Groundwater Monitoring Network**

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 20/01/2016
Issued To: K Singh
Author: tstringer

0 5 10
Kilometres
Scale: 1:152,000 @ A3
Coordinate System: GDA 1994 MGA Zone 55

N

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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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10.1.2 Groundwater Monitoring Frequency

The groundwater monitoring frequency for the exiting WMS bores are shown in the table below. **Appendix G** provides a summary of monitoring status and duration for MGP Area groundwater monitoring network.

Table 22: Existing WMS groundwater monitoring frequency

Bore	Shallow/Deep Bore	Monthly Water Level	Quarterly (shallow) or 6 Monthly (deep) Water Quality	Six Monthly Water Level	Annual Water Quality
M339W	Shallow	June 2012 to January 2016		January 2016 Onwards	
M225W	Shallow	June 2012 to January 2016		January 2016 Onwards	
M340W	Shallow	June 2012 to January 2016		January 2016 Onwards	
M230W	Shallow	June 2012 to January 2016		January 2016 Onwards	
M250W	Shallow	June 2012 to January 2016		January 2016 Onwards	
M224W	Shallow	June 2012 to January 2016		January 2016 Onwards	
M222W	Shallow	June 2012 to January 2016		January 2016 Onwards	
M313W	Deep	July 2014 to January 2016		January 2016 Onwards	
M314W	Deep	July 2014 to January 2016		January 2016 Onwards	
M324W	Deep	July 2014 to January 2016		January 2016 Onwards	
M325W	Deep	July 2014 to January 2016		January 2016 Onwards	No Water Quality Monitoring
GR067V	Deep	November 2015 to November 2016		December 2016 Onwards	
M162V	Deep	November 2015 to November 2016		December 2016 Onwards	
AN019F	Deep	November 2015 to November 2016		December 2016 Onwards	
AN020F	Shallow	November 2015 to November 2016		December 2016 Onwards	
AN021F	Shallow	November 2015 to November 2016		December 2016 Onwards	

Water quality parameters listed in Table 23 and Table 24 will be tested for all bores listed in Table 22 except M325W.

For any future WMS bores, groundwater level/pressure monitoring is proposed to be undertaken on a monthly basis for a period of 12 months. Following this, groundwater level monitoring is proposed to be undertaken on a six-monthly basis for the remainder of the CSG production operations.

For any future WMS bores, groundwater quality monitoring is proposed to be undertaken on a six-monthly basis for a period of 12 months. Following this, groundwater quality monitoring is proposed to be undertaken annually for the remainder of the CSG operations.

The groundwater monitoring frequency is based on:

- Limited groundwater level variation from climatic or seasonal fluctuations due to the depth of these confined formations (low recharge) and low permeability – for determining baseline levels

- Length of time over which groundwater level impacts develop as a result of the CSG development
- 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)

Data will be reviewed on an annual basis and presented in the annual review report to DEHP as prescribed in Section 11. This review will include a comparison of groundwater data to model predictions.
Following the establishment of baseline groundwater quality, the frequency of sampling and analyses may be modified for some or all of the chemical parameters.

10.1.3 Groundwater Monitoring Procedure

Groundwater monitoring will be conducted in accordance with Arrow Energy's (Arrow's) Water Quality Sampling Manual (**Appendix H**). This procedure has been prepared with reference to; the DEHP's (2009) Monitoring and Sampling Manual 2009, Version 2, AS/NZS 5667.1:1998 Water quality - Sampling - Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples, and AS/NZS 5667.11:1998 Water quality - Sampling - Guidance on sampling of groundwaters.

During monitoring events, visual inspections will be undertaken by field staff to provide an assessment on bore integrity. Any observed bore defects will be noted and reported with follow up maintenance actions proposed. This aims to ensure that the bore is maintained and in a secured and operating condition.

10.1.4 Groundwater Monitoring Parameters

It is proposed that an initial comprehensive laboratory analysis should be carried out for the first four groundwater monitoring events. Following this, an assessment should be undertaken by a suitably qualified hydrogeologist to assess the suitability of the groundwater quality parameters monitored. If considered appropriate, a reduced suite of chemical parameters and sample frequencies may be proposed.

The proposed field parameters and the laboratory analytical schedule for groundwater samples are listed in **Table 23** and **Table 24** below respectively. Water quality parameters listed in Table 23 and Table 24 will be tested for all bores listed in Table 22 except M325W.

Table 23: Field parameters monitoring suite

Parameter	
Temperature (^oC)	Redox Potential (Eh)
Electrical Conductivity (EC)	Dissolved Oxygen (DO)
pH	

Table 24: Chemical parameters monitoring suite

Parameter	
Lab pH, EC and Total Dissolved Solids (TDS)	Calcium (Ca^{2+})
Total Alkalinity	Sodium (Na^+)
Bicarbonate/Carbonate HCO_3^-/CO_3^{2-}	Potassium (K^+)
Fluoride (F^-)	Magnesium (Mg^{2+})
Strontium (Sr)	Nitrite (NO^{2-}), Nitrate (NO^{3-}), Ammonia (NH^{4+})
Chloride (Cl^-)	Total Phosphorous (PO_4^{3-})
Sulphate (SO_4^{2-})	Total and Dissolved organic carbon (TOC/DOC)
Methane (CH_2)	Metals (dissolved): arsenic (As), barium (Ba), beryllium (Be), boron (B), chromium (Cr), cobolt (Co), Copper (Cu), Iron (Fe), Lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), vanadium (V), zinc (Zn)

10.1.5 Assessment of Aquifer Parameters

Groundwater pressure data collected as part of the WMS will provide the basis for future groundwater numerical model updates. As part of this, re-calibration of the numerical groundwater model using transient groundwater level data will enable the refinement of parameterisation of hydraulic conductivity values.

10.1.6 Baseline Assessment Program

The Water Act requires petroleum tenure holders to carry out baseline assessments of water bores located on a tenure prior to production commencing on that tenure. These baseline assessments are carried out in accordance with a baseline assessment plan approved to EHP and in accordance with guidelines issued by EHP.

A program for baseline assessment for the LAAs is also required as part of the WMS. This program incorporates water bores predicted to be impacted on land outside the tenures. Since water level or water pressure impacts in many parts of the LAAs will not occur for a very long time, it is not proposed to undertake the baseline assessments for bores in the entire LAA. Baseline assessments are best carried out just before the impacts are expected to occur. If they are carried out too early the information collected will be out of date and be of degraded use for assessing changes.

Based on this, the program for carrying out baseline assessments for the LAAs is to progressively expand the area assessed so that assessments are completed soon before impact is predicted to occur. A predicted impact of 1 m within three years has been adopted as the trigger for carrying out a baseline assessment. When a new UWIR is prepared in three years' time, a new 1 m impact area will be established. This is consistent with the approach adopted for the Surat Cumulative Management Area UWIR.

Figure 26 shows the area within which water pressure decline of more than 1 m is expected within three years. The baseline assessment program will include all water bores located in the IAA aquifer the area of an aquifer where at least 1 m of drawdown is predicted within the next three years. **Figure 26** identifies two potential bores (RN 162379 and RN 81447) located off tenure but within the 1 m drawdown area. However, further investigation of these two bores found that they are either not a water bore or not installed into the area of an aquifer where at least 1 m of drawdown is predicted within the next three years. Bore 162379 is a coal seam monitoring bore and is not a water bore. Bore 81447 is located within the Basalt aquifer. Less than 1 m of drawdown is predicted in this aquifer within the next three years at the location of this bore.

Based on this, there are no water bores located off tenure but within the 1 m drawdown area that are in the IAA aquifer within the area of an aquifer where at least 1 m of drawdown is predicted within the next three years. Therefore no additional baseline assessments are required off tenure for the 1 m drawdown area.

ARROW ENERGY - BOWEN BASIN GAS PROJECT

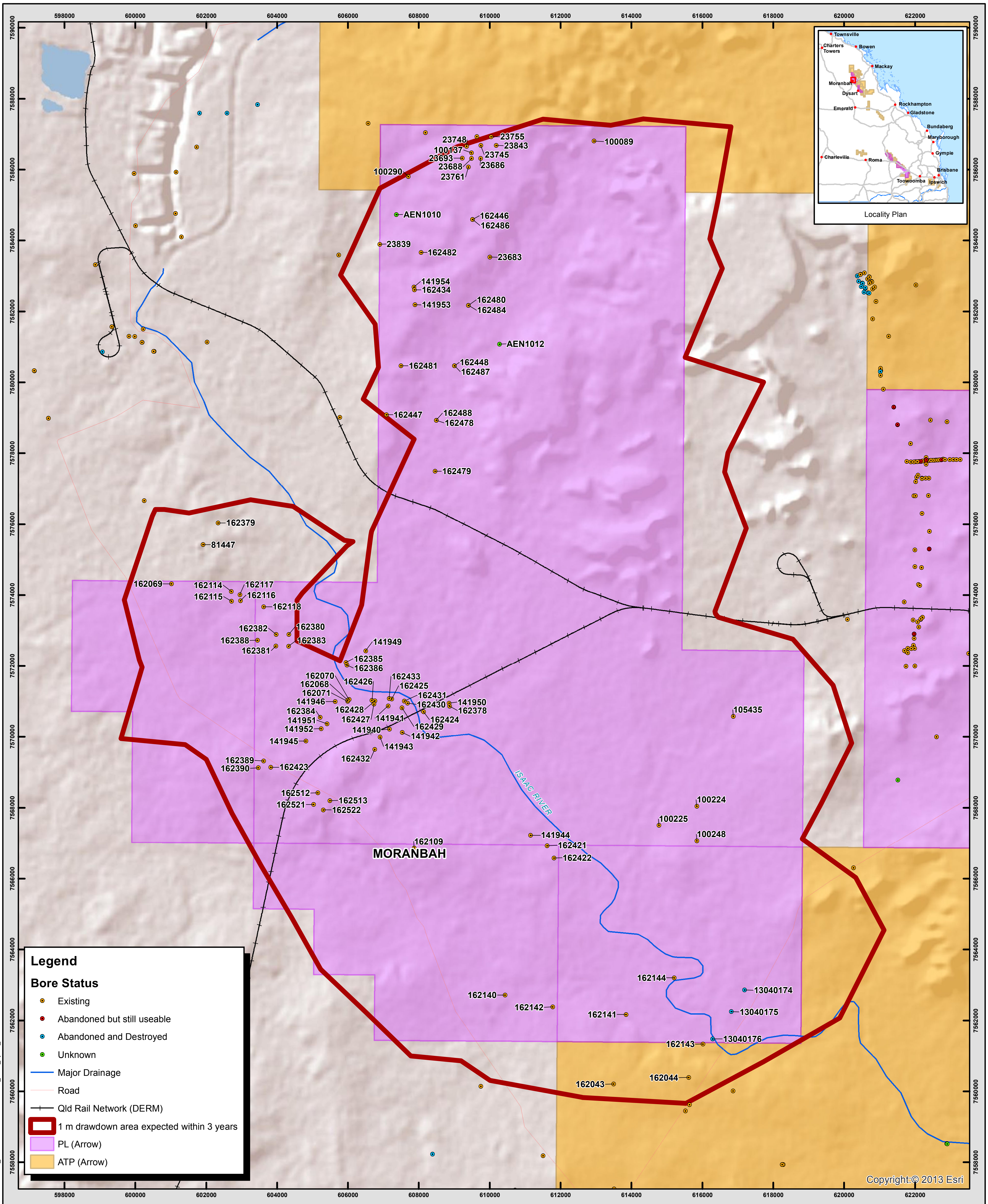

Figure 26.

1 m drawdown area expected within 3 years

Source: Arrow Energy Pty Ltd
Geosciences Australia
Dept. Envir. and Resource Mgmt.

Date: 8/08/2016
Issued To: K Singh
Author: tstringer

0 5 10
Kilometres

Scale: 1:99,000 @ A3
Coordinate System: GDA 1994 MGA Zone 55

N

arrow energy
go further

Based on or contains data provided by the State of Queensland (Department of Environment and Resource Management) [2011]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accept no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws

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

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, no warranty is given that the information contained on this map is free from error or omission. Any reliance placed on such information shall be at the sole risk of the user. Please verify the accuracy of all information prior to using it.

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Document: V:\Products\Australia\Queensland_CommonEnvironment\151118_UWIR2015\mxd2\Drawdown_MGP_3year_.mxd

NOT FOR CONSTRUCTION

10.2 Water Production Monitoring

The quantity of water taken during production of CSG will be monitored according to the process described in Section 2.

11 ANNUAL DATA REVIEW

This report will be reviewed annually. The review will consider:

- new hydrogeological data that significantly alters the conceptual model;
- whether new production testing or production has been undertaken or is planned; and
- whether the predictions made in Section 9 have materially changed.

The program for the implementation of the strategy will be reported to DEHP on an annual basis as part of the annual review. The annual review will provide progress on the implementation of the WMS. In addition to the annual review, the UWIR will be updated every three years. In addition to this, as required under section 378(1) (d) of the Water Act 2000, an annual update will also be provided to the OGIA about the implementation of the WMS.

Glossary

Term	Meaning
Abstraction	The removal of water from a resource e.g. the pumping of groundwater from an aquifer.
Adsorption	The adhesion of molecules of gas, liquid, or dissolved constituents to a surface (compare Desorption)
Aeolian	Sedimentary deposits formed by wind.
Alluvium	Unconsolidated deposits such as sands, gravels and clays deposited by flowing water such as rivers and streams.
Anistropy	Anisotropy is the property of being directionally dependent, as opposed to isotropy, which implies homogeneity in all directions.
Anthropogenic	Caused by human activity.
Aquatic Ecosystems	The abiotic and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and their fringing vegetation.
Aquifer	A saturated geological layer or formation that is permeable enough to yield economic quantities of water.
Aquiclude	A geological formation having zero permeability to water, such as un-fractured crystalline rock.
Aquitard	A geological formation having low (but not zero) permeability to water, such as a silty or clayey layer.
Argillaceous	A geological formation containing significant proportions of clay minerals.
Artesian Aquifer	A confined aquifer with the potentiometric level above ground level.
Artesian Bore	A borehole where the potentiometric level is above ground level.
Attenuation	The reduction in concentration of a contaminant. This may be due to degradation, dispersion or dilution.
Avulsion	Abandonment of an old river channel and the creation of a new one.
Baseflow	Sustained flow of a stream in the absence of direct run-off, due to groundwater discharge.
Bore	A hole drilled in the ground to obtain samples of soil or rock, intersect groundwater for extractive use, monitoring or investigation, or for a range of other purposes. In Australia is also a commonly used term for a constructed groundwater well.
Brackish	Water containing moderate salt concentrations significantly less than sea water, with Total Dissolved Solids typically between 1,000 and 10,000 mg/L. (Compare Fresh, Saline and Brine).
Brine	Saline water with a total dissolved solids concentration greater than 40,000 mg/L or coal seam gas water after it has been concentrated through water treatment processes and/or evaporation.
Calcareous	Containing significant proportions of calcium carbonate.
Catchment	An area which discharges to a common point.

Term	Meaning
Coal Seam Gas Water	Groundwater that is necessarily or unavoidably brought to the surface in the process of coal seam gas exploration or production. Coal seam gas water typically contains significant dissolved salts, has a high sodium adsorption ratio (SAR) and may contain other components that have the potential to cause environmental harm if released to land or waters through inappropriate management. Coal seam gas water is a waste, as defined under the section 13 of the Environment Protection Act. (DEHP, 2011).
Colluvium	Sedimentary deposit formed primarily by gravity forces, typically at the base of a slope or a cliff.
Cone of Depression	The area of drawdown produced in the watertable or groundwater potentiometric surface due to pumping.
Confined Aquifer	An aquifer in which groundwater is confined under pressure.
Confining Layer	Geological material through which significant quantities of water cannot move, located below unconfined aquifers, above and below confined aquifers.
Contaminant	A contaminant can be a gas, liquid or solid, an odour, an organism (whether alive or dead), including a virus, energy (including noise, heat, radioactivity and electromagnetic radiation), or a combination of contaminants.
Contamination	The release (whether by act or omission) of a contaminant into the environment.
Cuesta	A ridge formed by gently tilted sedimentary rock strata.
Desorption	The processes releasing molecules of gas, liquid, or dissolved constituents from a surface (compare Adsorption).
Discharge	Removal of water from or flow out of an aquifer, including flow to surface water, another aquifer, or artificial means such as pumping. See also ‘abstraction’.
Discharge Area	An area where groundwater flows out of an aquifer.
Disconformity	A break in the sequence of sedimentary deposition followed by resumed sedimentation, where the buried non-depositional surface lies between parallel strata on a regional scale.
Dissolved Solids	Soluble compounds such as salts which are in solution.
Down Warp	A downward bend in sedimentary layering caused by tectonic movement.
Drawdown	The drop in the watertable or potentiometric level when water is being pumped from a well.
Ecosystem	A system made up of the community of living things (animals, plants, and microorganisms) which are interrelated to each other and the physical and chemical environment in which they live.
Facies	A horizon of sedimentary rock formed under a particular set of environmental conditions, resulting in a distinct assemblage of sedimentary structures, mineralogy, grainsize, fossils and other features.
Fault	A structural discontinuity in a rock mass or geological formation.
Fluvial	Pertaining to a river or stream.
Fluvio-Lacustrine	Pertaining to a combined environment involving a river or stream and lake conditions.
Flux	The rate of flow (mass transport) of a fluid or other material or compound transported by that fluid.

Term	Meaning
Formation	A geological structure such as a rock mass or layer.
Fresh Water	Water containing low salt concentrations, typically less than 1,000 mg/L. (Compare Brackish, Saline and Brine).
Gilgai	A group of undulations and closed depressions at the soil surface, caused by the presence of swelling clays and seasonal movement due to changes in moisture content. Gilgai may range in size from a few meters up to 100 m across, and have a typical vertical amplitude of 30-50 cm.
Groundwater	Any sub-surface water, generally present in an aquifer or aquitard.
Groundwater Flow	The movement of water in an aquifer.
Heavy Metals	Metallic elements of atomic weight greater than that of Iron (e.g. Copper Arsenic, Mercury, Chromium, Cadmium, Lead, Nickel and Zinc).
Heterogeneous	Having different properties or composition at different locations.
Hydraulic Conductivity	A standard measure of the permeability of a geological formation or its ability to transmit groundwater flow.
Hydraulic Gradient	The slope of the watertable in an unconfined aquifer, or the potentiometric surface in a confined aquifer.
Hydraulic Head	A measure of the pressure head of water in aquifer, commonly measured as the elevation to which water will rise in a constructed well.
Hydrogeology	The study of the inter-relationships of geologic materials and processes with water, especially groundwater.
Hydrostatic Pressure	The pressure exerted by a fluid at equilibrium due to the force of gravity.
Indurated	Pertaining to a rock or soil hardened by mineral re-crystallisation due to heat, pressure or chemical precipitation.
Infiltration	Rainfall penetration into the soil profile or sub-surface. Infiltrated water that accesses the water table is one component of groundwater recharge.
Jam-ups	The flat tops of mesas formed by erosional processes.
Labile	Unstable, likely to change or decompose.
Lateritisation	A process of weathering, dissolution and leaching resulting in a hard crust dominated by iron and aluminium oxides.
Lithology	The physical composition of a rock.
Marine Regression	A period of sea level fall over geological time.
Marine Transgression	A period of sea level rise over geological time.
Meander Scar	A remnant landform caused by the abandonment of a stream bend which has first produced a cutoff-meander, oxbow lake or billabong, and been gradually infilled by sediment such that it no longer contains open water.
Mesa	An elevated area of land with a flat top and sides that are usually steep cliffs.
Montmorillonite	A clay mineral with swelling properties.
Mound spring	A naturally occurring outlet of upwelling groundwater, with a characteristic mound or crater shape formed by deposition of minerals.
Nutrients	A chemical that an organism needs to live and grow, or a substance used in an organism's metabolism obtained from its environment.
Onlap	A sedimentation regime occurring during a marine transgression.

Term	Meaning
Offlap	A sedimentation regime occurring during a marine regression.
Palaeochannel	Unconsolidated sediments or semi-consolidated sedimentary rocks deposited in ancient, currently inactive river and stream channel systems.
Peat	A sedimentary deposit dominated by partially-decomposed plant material, and considered to be an early stage in the formation of coal.
Perched Aquifer	An unconfined aquifer of limited extent located above the true watertable.
Perennial	A stream or river (channel) that has continuous flow in parts of its bed all year round during years of normal rainfall.
Permeability	The ability to transmit fluids through a porous medium.
Piezometer	A type of well specifically constructed in an aquifer for monitoring purposes, and screened at a specific depth to provide measurements of pressure head at that point.
Piezometric Level	The pressure head of water measured in a piezometer, from a specific depth or point in an aquifer.
Porosity	The ratio of void spaces in a geological formation compared to the bulk formation volume.
Potable Water	Water of suitable quality for human consumption.
Potentiometric Level	A measure of the pressure head of water in an aquifer at a given location, usually used in reference to a confined aquifer.
Potentiometric Surface	An imaginary layer which defines the potentiometric levels for a confined aquifer. In an unconfined aquifer it is more commonly termed as the watertable.
Pyroclastic	Material which is deposited from air-borne particles ejected by a volcanic eruption.
Recharge	Addition of water to or flow into an aquifer (generally) from rain. Also used to describe water entering an aquifer from surface water, groundwater, or artificial means.
Recharge Area	An area in which water enters an aquifer.
Reactivated Fault	A pre-existing fault in a geological setting which becomes the preferred surface to accommodate movement during a new period of tectonic activity.
Regolith	The unconsolidated or weathered geological material at the Earth's surface.
Runoff	Rain water that flows across the land surface without entering the sub-surface.
Saline Water	Water containing high levels of dissolved salts, typically between 10,000 and 40,000 mg/L. (Compare Fresh, Brackish and Brine).
Saturated Zone	The zone in which the voids in the rock are completely filled with water. The water table represents the top of the saturated zone in an unconfined aquifer.
Sediment	Unconsolidated geological material which has been formed by a process of deposition as discrete particles.
Sedimentary Sequence	A succession of layers of sedimentary rock caused by sequential deposition.
Semi-Confined Aquifer	A confined aquifer having a leaky confining layer.
Specific Yield	The ratio of the volume of water a rock will release by gravity drainage to the bulk volume of the rock.

Term	Meaning
Spring	The land to which water rises naturally from below the ground and the land over which the water then flows.
Standing Water Level	The depth below natural ground surface to the water level in a well or bore when it is at equilibrium with the surrounding formation (i.e. 'at rest' or 'fully recovered' from pumping). Also referred to as Static Water Level.
Storage Coefficient	A measure of the ability of aquifer material to store water, due to volumetric storage (Specific Yield) plus elastic storage.
Storativity	A measure of the ability of an aquifer to store water. Storativity is a function of storage coefficient and aquifer thickness.
Stratigraphy	The sequential classification of geological materials based on their age of formation.
Sustainable Yield	Amount of water that can be abstracted from an aquifer over a long period of time without dewatering the aquifer or impacting the resource.
Total Dissolved Solids	Concentration of dissolved salts (TDS).
Through Flow	The horizontal movement of water beneath the ground surface, including flow in the unsaturated zone (eg. soil) or saturated zone (eg. aquifer).
Transmissivity	The rate at which an aquifer can transmit water. It is a function of properties of the aquifer material and the thickness of the porous media.
Travertine	A mineral commonly found in caves, composed of finely crystalline calcium carbonate which has been precipitated from solution in groundwater.
Unconfined Aquifer	An aquifer with no confining layer between the water table and the ground surface where the water table is free to rise and fall.
Unsaturated Zone	The part of the geological stratum above the saturated zone, also called the vadose zone. The unsaturated zone may be dry, or may contain water under partially saturated conditions.
Uplift	The relative upward movement of rocks due to tectonic forces.
Vertical Anisotropy	Differing properties of a geological material in the vertical direction compared to horizontal direction.
Water table	The top of the saturated zone in an unconfined aquifer.
Well	A hole drilled into a groundwater resource (aquifer), oil or gas resource reservoir) and constructed with a casing and screen or similar. In Australia also commonly referred to as a 'bore'.
Well Field	A group of boreholes in a particular area having a common use, such as for groundwater, oil or gas extraction.
Well Yield	The flow rate obtainable from an extraction well or bore.

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