Underground Water Impact Report

For Petroleum Leases 191, 196, 223, 224, 486 and Authority to Prospect 1103, 742 and 1031

arrow energy
go further

August 2022

REVISION HISTORY

Revision	Revision Date	Revision Summary
0	February 2022	Initial release for consultation
1	April 2022	Released for review
2	August 2022	Final

TABLE OF CONTENTS

FIGURES

TABLES

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 486 and Authorities to Prospect (ATPs) 1103, 1031, and 742.

A conceptual hydrogeological model was developed as part of the UWIR and includes model predictions of potential depressurisation impacts on groundwater resources as a result of CSG production. The predictions for the UWIR were made using the latest 2021 groundwater model.

This 2022 Bowen 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;
- a program for conducting an annual review of the predictions; and
- the outcome of the update to the groundwater model developed to determine impacts from the proposed development scenarios.

Historical water production from the MGP was 6201.1 ML up to the end of October 2021. In the next 3 years an additional 521.9 ML is forecast to be produced from the MGP (PLs 191, 196, 223 and 224) and 81.6ML from Red Hill Central (PL 486).

The validity of the existing conceptual hydrogeological model was reviewed, and it was concluded that:

- data obtained to date is in support of the existing conceptual hydrogeological model, and
- the 2021 groundwater model is considered to be suitable for predicting depressurisation impacts as a result of CSG operations for the Project Areas as part of this UWIR.

The 2021 groundwater model developed as part of this UWIR simulates historical and forecast production as well as historical production testing. The 2021 groundwater model has been utilised to predict water level decline in aquifers as a result of the taking of water during production of 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) and the Long-term Affected Areas (LAAs; where the predicted drawdown exceeds the bore trigger threshold at any time).

Key findings are:

- within PLs 191, 196, 223, 224 and 486 an IAA exists for the Moranbah Coal Measures associated with production of CSG. There are no useable landholder bores in this IAA.
- within ATPs 742, 1103 and 1031 there are small areas of IAA for the Moranbah Coal Measures and Rangal Coal Measures 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 43 groundwater monitoring bores. The installation of 16 of these groundwater monitoring bores, located on PLs 191, 196, 223 and 224 has been completed and groundwater monitoring has been ongoing within the bores. Monitoring bores as a part of the larger Bowen Gas Project have been installed and additional bores a part of the project will be added as the project increases in area.

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

This report forms the 2022 Bowen UWIR and provides information on the potential decline in water levels in aquifers due to the taking of water during CSG production and CSG production testing activities in Arrow's Bowen Basin tenure (detailed above), as required by the *Water Act (Qld) 2000*.

The Registered Holders of the tenures covered in this report are presented in the table below.

Table 1: Arrow's Tenements, Registered Holder details

Tenure	Registered Holder
PL191, PL196, PL223 and PL224	AGL Energy Limited ACN 115 061 375 CH4 Pty Ltd ACN 092 501 016 Arrow CSG (ATP 364) Pty Ltd ACN 092 970 557
PL486	CH4 Pty Ltd Arrow CSG (ATP364) Pty Ltd
ATP 742	CH4 Pty Ltd ACN 092 501 016
ATP 1031	Bow CSG Pty Ltd ACN 117156742
ATP 1103	AGL Energy Limited ACN 115 061 375 CH4 Pty Ltd ACN 092 501 016 Arrow CSG (ATP 364) Pty Ltd ACN 092 970 557

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 and Dingo. 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 2021:
  - approximately 673 production testing and production wells distributed over 49,225 hectares,
  - an existing gathering system consisting of approximately 267 kilometres of pipeline 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 Bowen Gas Project (BGP) within which exploration and production testing has been undertaken comprise of PL 486 ATPs 1103, 1031, and 742 and including:
  - exploration and Testing within:
    - ATP1103 - including 98 wells used for production testing between 2008 and 2021.
    - ATP 742 - including 3 wells used for production testing between 2015 and 2018;
    - ATP 1031 - including 6 wells used for production testing between 2012 and 2015;
  - future proposed development including:

- Red Hill Central (PL486) - including 31 wells to be used for production between 2022 and 2026. In the area of PL486, production testing commenced in ATP 1103 prior to PL 486 being granted.
- The remainder of the field development plan (FDP) presented in the 2019 Bowen UWIR (within ATP 1103, ATP 742 and ATP 1031) to include 1408 production wells between 2030 and 2060

The MGP and the BGP Areas are collectively referred to as the Project Area and are shown in Figure 1.

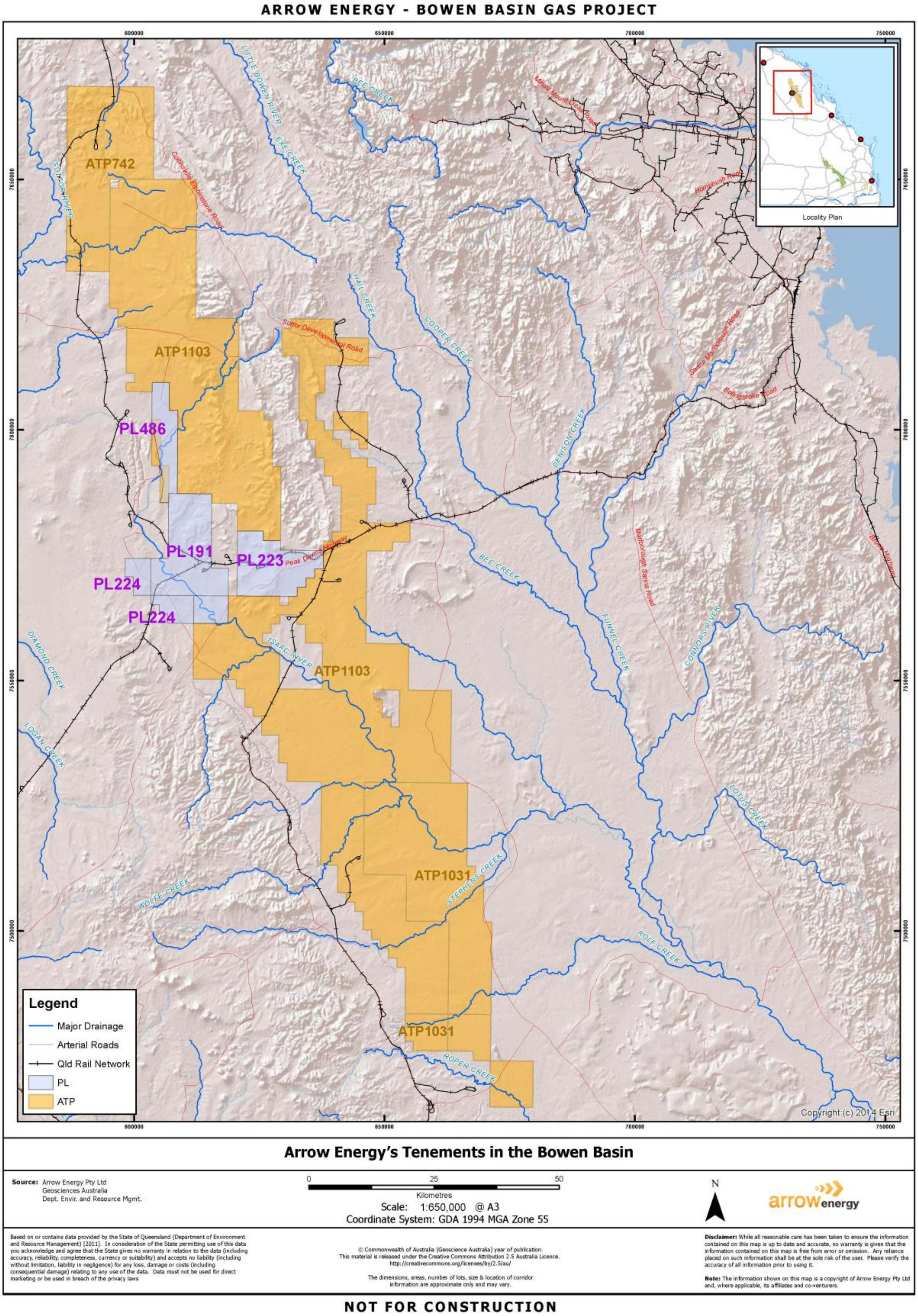


Figure 1: Arrow Energy's Tenements in the Bowen Basin

1.3 Requirement for a UWIR

1.3.1 *Cumulative Management Areas*

The chief executive of DES may declare a cumulative management area (CMA) in areas of concentrated CSG development where the impacts on water levels caused by individual petroleum and gas projects can overlap. In Queensland, the Surat CMA has been declared in the area of planned concentrated CSG development within the Surat Basin.

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. 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;

da) a description of the impacts on environmental values that have occurred, or are likely to occur, because of any previous exercise of underground water rights;

db) an assessment of the likely impacts on environmental values that will occur, or are likely to occur, because of the exercise of underground water rights

   i. during the period mentioned in paragraph (a)(ii); and
   ii. over the projected life of the resource tenure;

e) a program for –

   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;

f) a water monitoring strategy;

g) a spring impact management strategy;

h) if the responsible entity is the office—

  i. a proposed responsible tenure holder for each report obligation mentioned in the report; and

  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;

i) 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 (Qld) 2000*).

1.4.2 *Water Act (Qld) 2000*

Chapter 3 of the *Water Act (Qld) 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 resource 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;
  - require the preparation of UWIRs that establish underground water obligations, including obligations to monitor and manage impacts on aquifers and springs;
  - manage the cumulative impacts of the exercise of 2 or more resource 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 reasons 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 DES. UWIRs are submitted for approval by DES. The OGIA may also advise DES about the adequacy of these reports.

The DES 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);
- Bowen Gas Project Supplementary Report to the EIS (Arrow Energy, 2014b); and
- UWIR for PL 191, 196, 223, 224 and ATP 644, 831, 742, 1031 and 1103 (Arrow Energy 2016)
- UWIR for PL 191, 196, 223, 224 and ATP 644, 831, 742, 1031 and 1103 (Arrow Energy 2019)
- 2017, 2018, 2020 and 2021 Annual Reviews of the UWIR's for PL 191, 196, 223, 224 and ATP 644, 831, 742, 1031 and 1103

Since the development of the previous UWIRs for PLs 191, 196, 223, 224 and ATPs, 831, 742, 1103 and 1031, the conceptual understanding of groundwater occurrence and processes in the Project Area has been updated based on the collection and interpretation of the new data from site.

An assessment of impacts to groundwater from the aforementioned FDP was then 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: Review of the Water Monitoring Strategy (WMS) and Spring Impact Management Strategy (SIMP)

A summary of the reporting requirements as stipulated in the *Water Act (Qld) 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 (Qld) 2000* Reporting Requirements for this UWIR

UWIR reporting requirement	Report Section
s376 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. 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
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	Section 7
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;	Section 7
c) A description of the methods and techniques used to obtain the information and predictions under paragraph (b);	Section 1, Section 3, Section 7
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 7
da) a description of the impacts on environmental values that have occurred, or are likely to occur, because of any previous exercise of underground water rights; db) an assessment of the likely impacts on environmental values that will occur, or are likely to occur, because of the exercise of underground water rights	Section 8
e) A program for – i. Conducting an annual review of the accuracy of each map prepared under paragraph (b)(iv) and (v); and	Section 9

UWIR reporting requirement	Report Section
ii. Giving the chief executive a summary of the outcome of each review, including a statement of whether there has been a material change in the information or predictions used to prepare the maps;	Section 6, Section 7
f) A water monitoring strategy;	Section 4
g) A spring impact management strategy;	Not applicable to the Project Area. Refer to Section 8
h) If the responsible entity is the office – 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 (IAA) – the proposed responsible tenure holder or holders who must comply with any make good obligations for water bores within the IAA;	Not applicable to the Project Area
i) Other information or matters prescribed under a regulation.	No matters identified
<u>**s378**</u> 1(a) Water Monitoring Strategy i. Strategy for monitoring the quantity of water produced the quantity of water produced or taken from the area because of the exercise of relevant underground water rights; and	Section 4
i. changes in the water level of, and the quality of water in, aquifers in the area because of the exercise of the rights;	
b) The rationale for the strategy;	
c) A timetable for implementing the strategy;	
d) A program for reporting to the office about the implementation of the strategy	
2 Strategy must include:	
a) The parameters to be measured; and	
b) The locations for taking the measurements; and	
c) The frequency of the measurements.	
3 A program for a baseline assessment for each bore that is:	
a) Outside the area of a resource tenure; but b) within the area shown on the map prepared under section 376(b)(v)	

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 and allow for comparison against the modelled historical and forecast volumes for the Project Area.

The volumes of water produced from the wells were measured using progressive cavity pumps (PCPs) in the gas production and production testing (appraisal) wells. These pumps work by rotating an eccentric screw which pushes the inflowing water in the well upwards. Consequently, the pumping rate (expressed as a volume/time) is proportional (based on an 'efficiency factor') to the rate of rotation of the pump i.e. there is a direct correlation between a given number of revolutions per minute (rpm) and a corresponding pumping rate. A flow test is undertaken to calculate the volume of water produced from the PCPs i.e. the pump rate and time for a known volume of water to be pumped is used to calculate the 'efficiency factor'. This is applied to a record of the pumps operating rpm to calculate the volume of water pumped. Flow tests are 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.

Forecasts of water production were collated for the Project Area. Production data are provided for each tenure in the following sections.

2.1 Existing Water Production Summary – MGP Area

The total volume of water taken from each PL for the period of 1 January 2019 to 31st October 2021 (hereafter referred to as the 'UWIR reporting period) in the MGP Area during production and production testing is presented in Table 3 along with historical water production rates. 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 (not including production testing).

Table 3: Historical Water Production and Production Testing Data

Tenure	Formation	Production 2003 - 2018	Production 2019 - 2021	Production Testing 2003 - 2018	Production Testing 2019 - 2021
		Volume (ML)	Volume (ML)	Volume (ML)	Volume (ML)
PL191	GM Seam	2367.5	213.0	0	0
	P Seam	1577.1	76.2	0	0
	Q Seam	28.5	57.5	2.7	0
	Moranbah Coal Measures (GM, P, GML, Q Seams)	234.5	15.9	34.7	0
	Fort Cooper Coal Measures and Moranbah Coal Measures	0.0	0	29	0
PL196	GM Seam	190.2	56.2	0	0
	P Seam	141.4	39.9	0	0
	Moranbah Coal Measures (GM, P, GML, Q Seams)	480.9	65.6	0	0
PL223	FG1 Seam	0.0	0	2.8	0
	Rangal Coal Measures	0.0	0	0.4	0
PL224	GM Seam	112.3	16.8	0	0
	P Seam	21.9	2.9	0	0
	Moranbah Coal Measures (GM, P, GML, Q Seams)	110.8	19.9	0	0
TOTAL		**5265.1**	**563.9**	**69.6**	**0.0**

As indicated in Table 3, the water production in the UWIR reporting period totalled 563.9 ML from production and 0 ML from production testing. This is less than the previously (in the 2019 UWIR) forecast production for the period 2016 to 2018 of 634 ML.

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. As shown in Figure 2, the water production volumes in the PL's have steadily decreased over the reporting period.

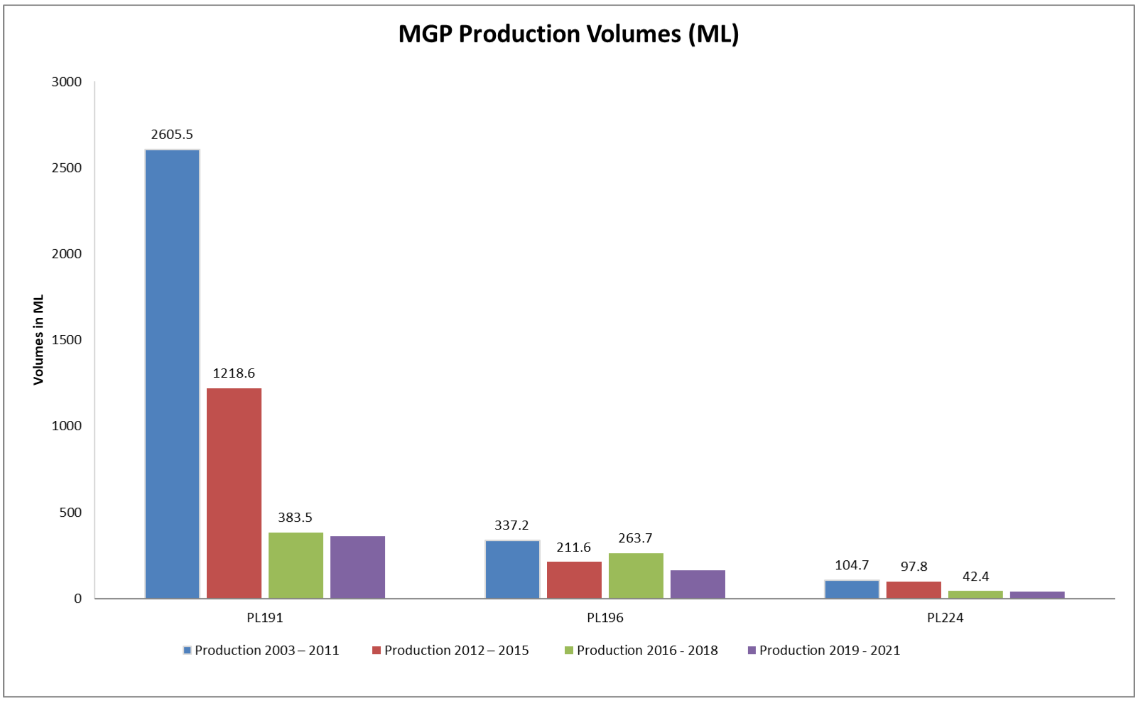


Figure 2: Water produced from production wells on PL191, PL196 and PL224

2.2 Forecast Water Production – MGP Area

The methodology for forecasting water production for the MGP is based on a Decline Curve Analysis (DCA). DCA uses historical production from existing wells to produce a type curve used to forecast water production in proposed wells. DCA 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 coal seam gas industry as wells of all types tend to follow these trends. 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.

A forecast of the quantity of water to be produced for the next 5 years up to 2026 has been prepared for the MGP (PL191, PL196 and PL224. 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 MGP water production forecast for the next 3 years (UWIR reporting interval) commencing 01/01/2022 totals 521.9 ML and the water production forecast from 2022 to 2026 totals 824.5 ML. The MGP is forecast to remain operational until end 2030. No future production testing has been earmarked for the MGP.

Table 4: Forecast water production data for the MGP

Year	Total Forecast Water production (ML)
2022	181.1
2023	179.3
2024	161.5

Year	Total Forecast Water production (ML)
2025	154.0
2026	148.6
Total	**824.5**

2.3 Existing Water Production Summary – BGP Area

Historical water production data for the production testing wells on ATP 742, 1031 and 1103 is summarised in Table 5 to Table 7. The production testing cumulative volume of water over the period totals approximately 305.523 ML of water.

2.3.1 *PL486*

No water production was recorded in PL486. Production testing commenced in ATP 1103 prior to PL 486 being granted. from wells RH098A, RH099A and RH100A. That production testing does not form part of the RHC development. Therefore, production from the RHC development has not commenced.

2.3.2 *ATP 742*

Water production testing data is presented in Table 5. No production testing has been carried out since 31 Dec 2017.

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-Apr-15	31-Dec-17	457	7.428	1.103	Moranbah Coal Measures
Newlands 10	15-Jun-15	31-Dec-17	599	8.318	1.583	Moranbah Coal Measures
Byerwen 3	09-Feb-15	21-Dec-16	616	0.766	0.206	Moranbah Coal Measures
Total (ML)					**2.892**	

2.3.3 *ATP 1031*

Water production testing data is presented in Table 6. Production testing was carried out in the current UWIR reporting period at PY011A and PY012A, with a volume of 0.47 ML.

Table 6: 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-Jul-13	25-Sep-14	27	3.700	1.390	Rangal Coal Measures
VM010V	07-Nov-13	02-Nov-14	354	30.830	7.830	Rangal Coal Measures
VM011V	07-Nov-13	14-Nov-14	365	15.480	5.650	Rangal Coal Measures
PY030	20-Dec-12	06-Dec-14	38	1.030	0.550	Rangal Coal Measures
PY012A	11-Sept-20	16-Feb-21	42	.0067	0.279	Rangal Coal Measures
PY011A	10-Sept-20	16-Feb-21	32	.0061	0.195	Rangal Coal Measures
Cumulative Total (ML)					**15.894**	

2.3.4 *ATP 1103*

The review of production testing undertaken on ATP 1103 is summarised below in Table 7 and includes actual production testing volumes up to 31st December 2021.

Table 7: Summary of Production Testing in ATP 1103

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	3-Mar-10	23.183	6.653	Moranbah Coal Measures
SRJ002	29-Jun-09	4-Mar-10	20.525	5.911	Moranbah Coal Measures
SRJ003	29-Jun-09	4-Mar-10	45.644	12.186	Moranbah Coal Measures
RHGU020	26-Aug-09	24-Apr-10	3.669	0.88	Moranbah Coal Measures
RHGU019	26-Aug-09	19-Jul-10	2.073	0.665	Moranbah Coal Measures
LW006	3-Aug-09	6-Aug-10	23.68	4.973	Moranbah Coal Measures
LW007	3-Aug-09	14-Aug-10	32.96	8.337	Moranbah Coal Measures
LW005	3-Aug-09	15-Aug-10	24.65	6.77	Moranbah Coal Measures
COX10	4-Nov-09	4-Oct-10	16.223	3.342	Rangal Coal Measures
RHGU001	12-Nov-08	8-Oct-10	7.19	5.529	Moranbah Coal Measures
RHGU002	14-Dec-08	1-Nov-10	20.363	15.008	Moranbah Coal Measures
RH014GL1	29-Dec-08	3-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	1.79	0.816	Moranbah Coal Measures
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	1-Feb-11	4.182	3.358	Moranbah Coal Measures
RHGM009	11-Nov-08	1-Feb-11	2.165	1.791	Moranbah Coal Measures
SC007LC	30-Sep-09	9-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	3-Jul-10	24-Mar-11	4.792	1.509	Rangal Coal Measures
KC009	2-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	4-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	2-Jun-11	2.987	2.643	Moranbah Coal Measures
SRJ021	25-May-10	12-Jun-11	2.434	1.273	Moranbah Coal Measures
RH023GL	9-Apr-10	4-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	6-Sep-11	1.155	0.63	Moranbah Coal Measures
RH022GL	9-Apr-10	16-Sep-11	5.943	3.411	Moranbah Coal Measures
RH024GL	9-Apr-10	16-Sep-11	1.709	0.977	Moranbah Coal Measures
RH025GU	10-Apr-10	3-Oct-11	4.928	2.651	Moranbah Coal Measures
RHGM35	1-Sep-11	15-Nov-11	4.191	0.318	Moranbah Coal Measures

Bore Name	Date Start	Date End	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
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	9-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	5.29	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	1-Nov-11	16-Apr-13	2.461	0.936	Fort Cooper Coal Measures
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	4-Jul-13	8-Jan-14	1.062	0.118	Moranbah Coal Measures
CX013V	24-Jul-13	31-Mar-14	6.426	1.088	Rangal Coal Measures
NP041V	6-Dec-13	29-Jun-14	3.947	0.572	Moranbah Coal Measures
OD011F	5-Aug-13	8-Jul-14	2.896	0.988	Rangal Coal Measures
OD012F	5-Aug-13	8-Jul-14	1.175	0.41	Rangal Coal Measures
PD131V	8-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	0.57	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	1-Jun-13	3-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	31-Dec-16	10.812	3.836	Moranbah Coal Measures
PD130V	8-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	6-Dec-13	15-Jun-15	5.506	1.53	Moranbah Coal Measures
PD111V	11-Jun-14	31-Dec-17	17.246	5.201	Moranbah Coal Measures
CX101	7-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	31-Dec-16	0.941	0.377	Rangal Coal Measures
PD122V	22-Jun-13	31-Dec-16	36.426	11.124	Moranbah Coal Measures
CX100	4-Nov-13	31-Oct-15	6.352	2.648	Rangal Coal Measures
EF060V	4-May-14	31-Dec-16	3.575	1.501	Rangal Coal Measures
PD120V	22-Jun-13	31-Dec-16	22.853	10.173	Moranbah Coal Measures
RH051F	10-Sep-13	12-Sep-18	12.922	2.293	Moranbah Coal Measures
CX090V	21-Jul-14	31-Dec-16	16.084	6.046	Rangal Coal Measures
CX091V	15-May-14	31-Dec-16	11.005	2.232	Rangal Coal Measures
PD101V	22-Jun-14	31-Dec-16	4.374	1.786	Moranbah Coal Measures
PD110V	9-Jun-14	31-Dec-17	17.947	6.119	Moranbah Coal Measures
RH050F	10-Sep-13	31-Dec-17	15.777	1.980	Moranbah Coal Measures
RH052F	10-Sep-13	31-Dec-17	12.253	2.134	Moranbah Coal Measures
RH100A	28-May-18	Ongoing	2.90	3.78	Moranbah Coal Measures
RH098A	28-May-18	Ongoing	6.18	8.034	Moranbah Coal Measures
RH099A	28-May-18	Ongoing	0.887	1.154	Moranbah Coal Measures

Bore Name	Date Start	Date End	Average Flow kL/day	Cumulative Flow (ML)	Target Formation
RH060F	01-Jan-18	27-May-18	0.190	0.019	Moranbah Coal Measures
RH061F	20-Nov-15	31-Dec-17	6.640	0.939	Moranbah Coal Measures
RH062F	20-Nov-15	27-May-18	5.291	0.601	Moranbah Coal Measures
PD032F	01-Apr-15	31-Dec-17	5.040	0.974	Moranbah Coal Measures
PD033F	01-Apr-15	31-Dec-17	11.030	1.540	Moranbah Coal Measures
PD034F	01-Apr-15	31-Dec-17	7.286	0.362	Moranbah Coal Measures
Cumulative Total (ML)				**287.208**	

* Numbers have been updated to reflect the latest data

2.4 Forecast Appraisal Program in BGP Area

No new production testing has been planned.

The extent of impact for production testing has been assessed based on both the performance of historical production tests and simulation of historical production testing.

The production test with the greatest water production recorded was from the production testing wells in the Peak Downs area (reported as the Peak Downs IAA area in the 2018 Annual Review) which reported a total of 26.7ML water production between 2013 and 2015. The simulation (2016 UWIR) indicated the 5 m drawdown contour extended up to 1 km from this production test. Actual water production from each production testing well in the annual review data capture period will be compared to the Peak Downs IAA site. If actual water production in the production testing well in the annual review data capture period is equal to or less than the Peak Downs IAA site, then it will be assumed that any resultant IAA would be equal to or less than the Peak Downs IAA site. If water production in the production testing well in the annual review data capture period is greater than the Peak Downs IAA site, then a review of the 1 m drawdown contour will be undertaken to identify any existing or abandoned but useable landholder water supply bores that may be at risk of impact.

The impact of any future water production as part of production testing will be reviewed as part of the annual review in accordance with this methodology.

2.5 Forecast Water Production - BGP

Arrow's proposed BGP involves a phased expansion of Arrow's CSG production in the Bowen Basin. It comprises an update of development plans in the same general areas (i.e. within tenements ATP742, ATP1103, and ATP1031) from those presented in the Supplementary Report to the Environmental Impact Statement (SREIS). The project, as described in the 2016 Bowen UWIR, included development in 3 phases (1, 2 and 3). The groundwater modelling undertaken for the 2016 Bowen UWIR simulated phase 1, 2 and 3 of the BGP (with associated water production of 116 GL) occurring over 30 years commencing 2019 (and continuing to 2049). This production has been revised and the 2022 Bowen UWIR is based on an updated FDP as follows:

- Red Hill Central (PL486) commencing 2022.
- the remainder of the field development plan (FDP) area presented in the 2016 Bowen UWIR (ATP1103, ATP742 and ATP1031) commencing 2030.

A forecast of the quantity of water to be produced against respective project timelines for the BGP FDP has been prepared and discussed below:

- Red Hill Central lies within the footprint of BGP development case and is located approximately 30 km north of the township of Moranbah, and borders the MGP area to the south. Water production from Red Hill Central is currently forecast to occur from 2022 to 2026, with a total of 88.7 ML of water to be produced.

- production from the remainder of the FDP area, tentatively planned from 2030 to 2060, will comprise 1,377 wells and total water production of 81.37 GL.

Table 8: FDP Comparison

FDP		Number of wells	Water production		Timing	
			Total (GL)	Peak (GL)	Start	End
SREIS BGP FDP		4000	153	10.4	2019	2049
BGP FDP	Red Hill Central	31	0.89	0.16	2022	2026
	Remainder of the FDP	1377	81.37	3.80	2030	2060
	Total	**1408**	**82.26**	**3.96**	**2022**	**2060**

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), 1031 (Arrow Energy, 2014a) and the 2016 and 2019 Bowen UWIR. 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 DES and DNRME.

Additionally, an EIS (Arrow Energy, 2012c), SREIS (Arrow Energy 2014b) and GMMP (Arrow Energy 2019) 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 and in the Environmental Setting in the GMMP. A summary of the conceptual hydrogeological model (Figure 8), including geology and aquifers is provided in the following sections.

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 3). 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 in 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
			Basalt		Olivine rich weathered basaltic sands, weathered basalt, and fresh basalt flows
			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.
			Clematis Sandstone		Cross-bedded quartz sandstone, some quartz conglomerate and minor red-brown mudstone.
			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
			Fort Cooper Coal Measures	Burngrove Formation	Coal, brown and green sandstone, conglomerate, carbonaceous shale, tuff
				Fairhill Formation	Labile sandstone, quartzose sublabile sandstone, siltstone, mudstone, calcareous and tuffaceous sandstone, volcanic conglomerate, carbonaceous mudstone, coal
			Moranbah Coal Measures	MacMillan Formation	Quartzose to sublabile, locally argillaceous sandstone, siltstone, mudstone, carbonaceous mudstone and coal
				German Creek Formation	
	Early to Middle		Back Creek Group		Quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite

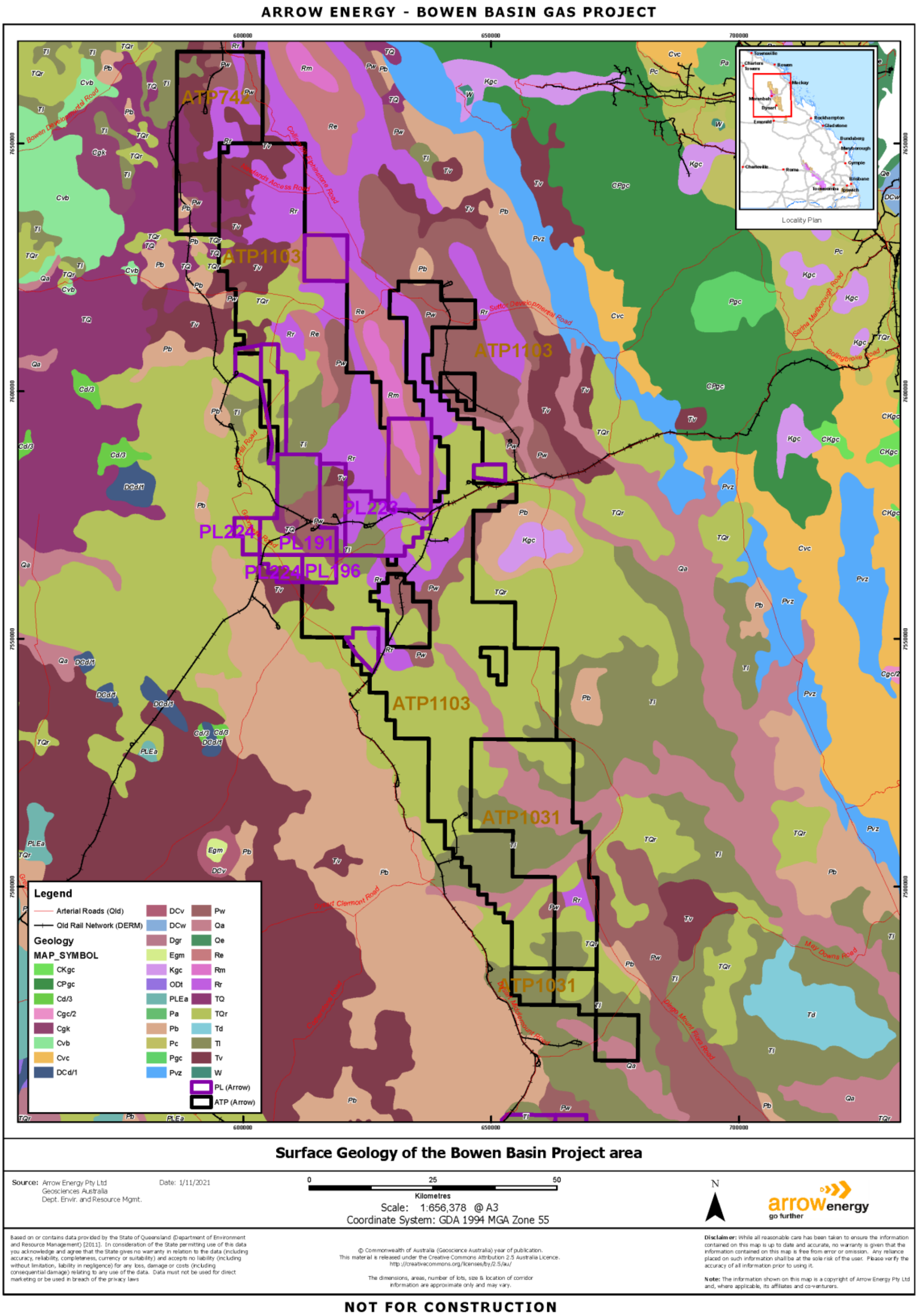


Figure 3: Surface Geology of the Bowen Basin

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.

Figure 4 to Figure 7 provide schematic cross-sections through each of the Arrow tenure (Petroleum Leases 191, 196, 223, 224 and, ATP 742, 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).

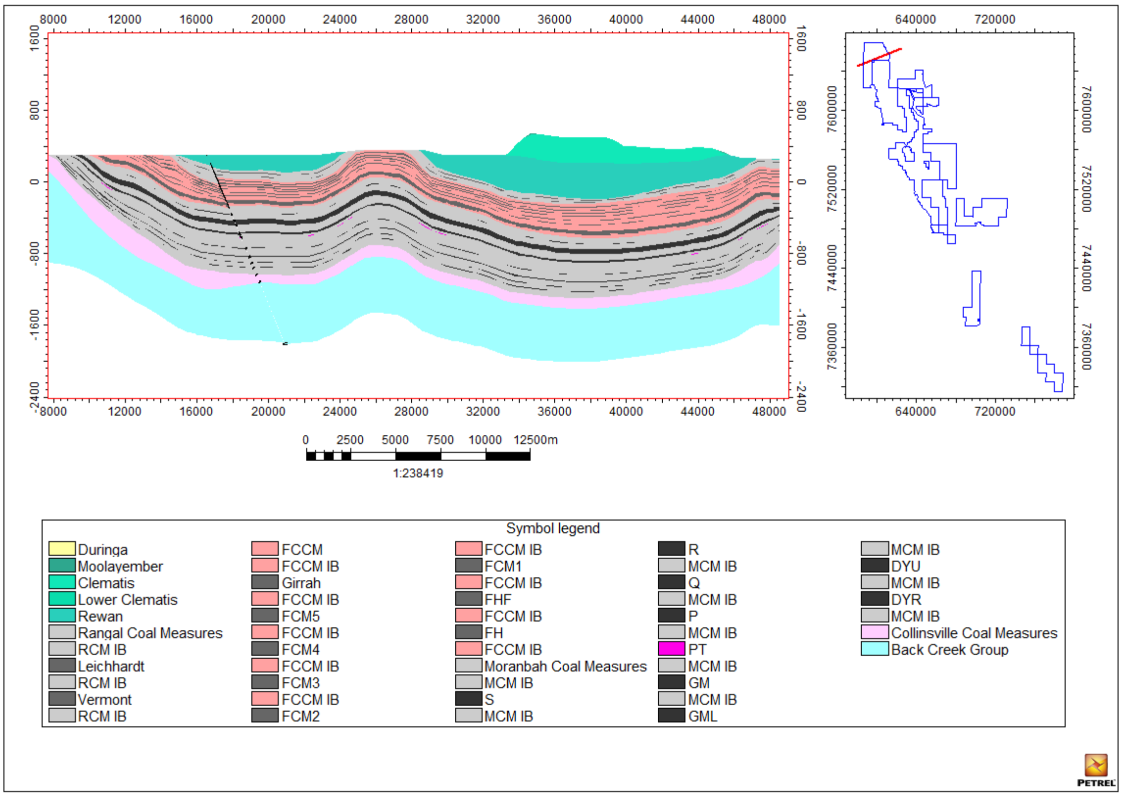


Figure 4 : Stratigraphy underlying ATP 742

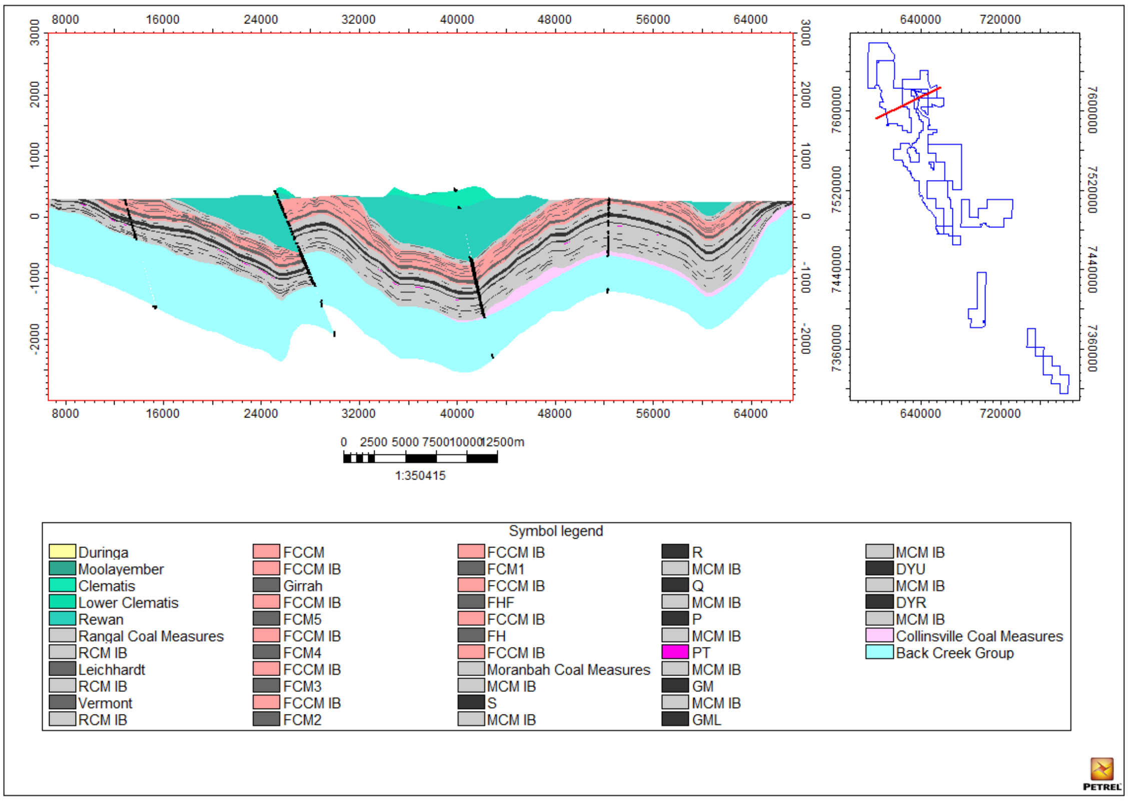


Figure 5 : Stratigraphy underlying northern ATP 1103

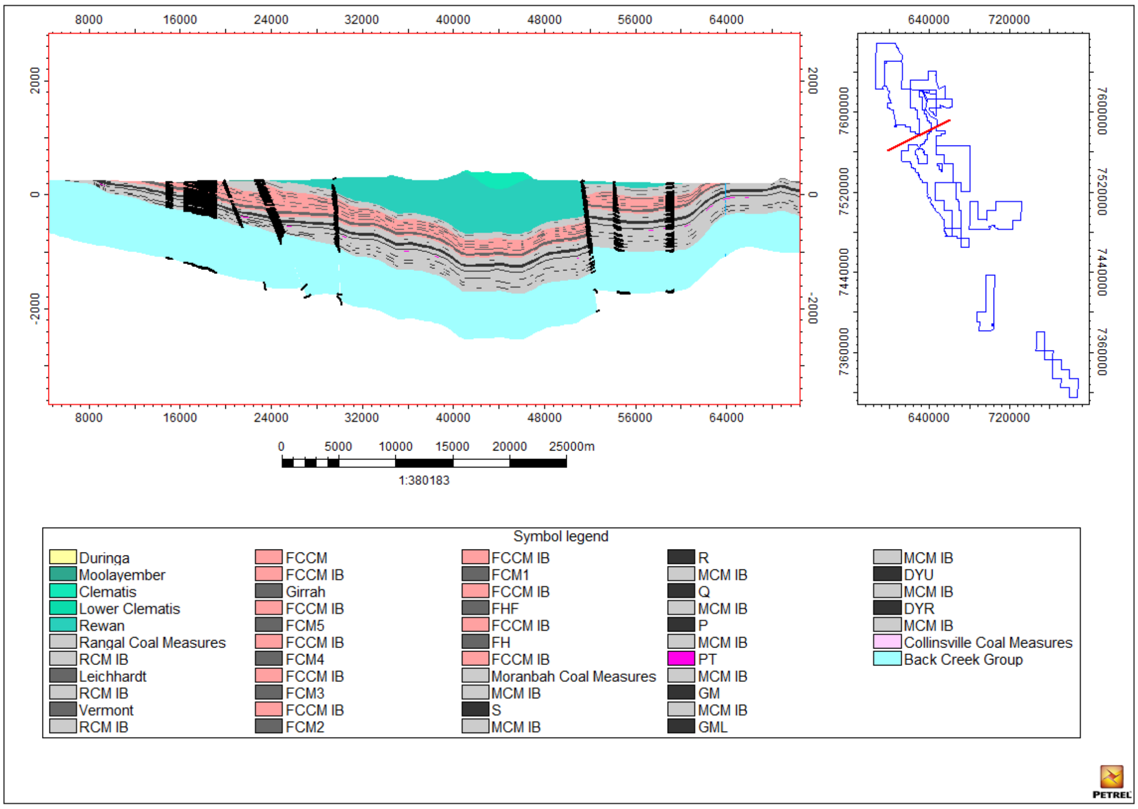


Figure 6 : Stratigraphy underlying MGP Area

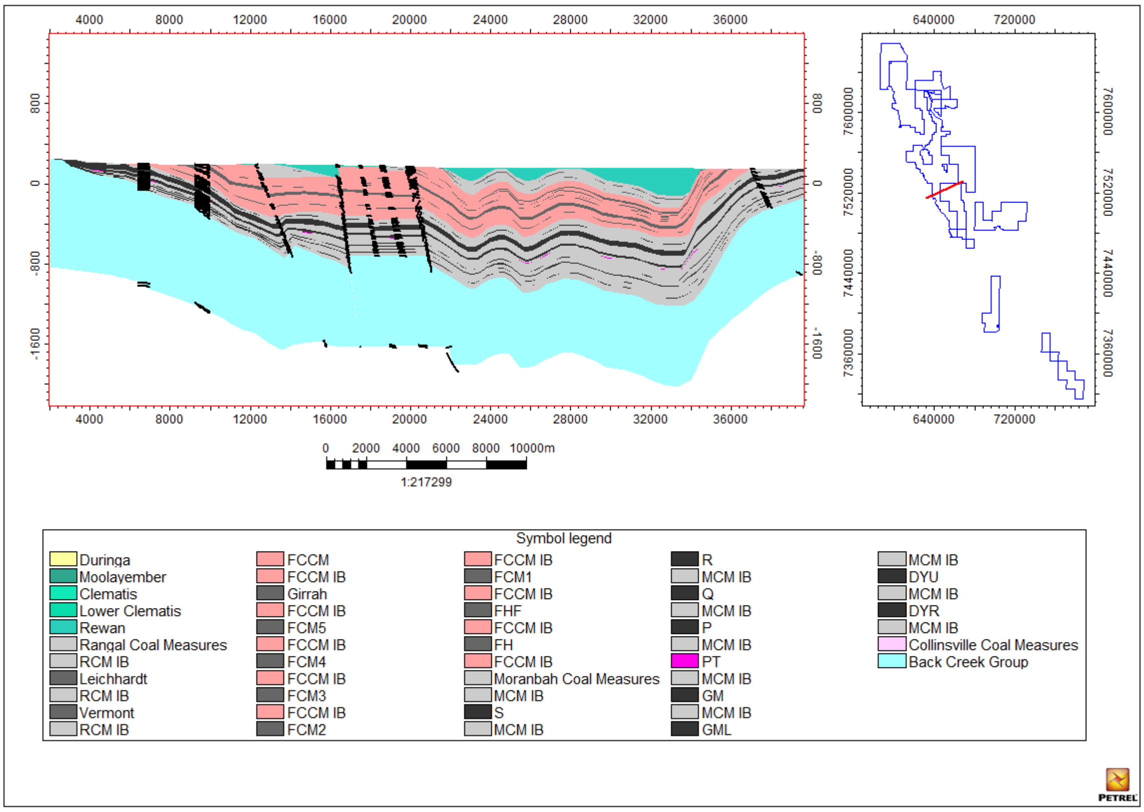


Figure 7 : Stratigraphy underlying ATP 1031

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 Formation		Mudstone, lithic sandstone, interbedded siltstone, mudstone, sandstone and thin coal seams.	0-200	Confining unit - GAB
	Clematis Sandstone		Cross-bedded quartz sandstone, some quartz conglomerate, minor reddish brown mudstone	0-300	Confined GAB aquifer
	Rewan Formation		Green lithic sandstone, pebble conglomerate, red and green mudstone, siltstone	200-800	Confining unit
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

The cross sections in Figure 4 to Figure 7 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 8.

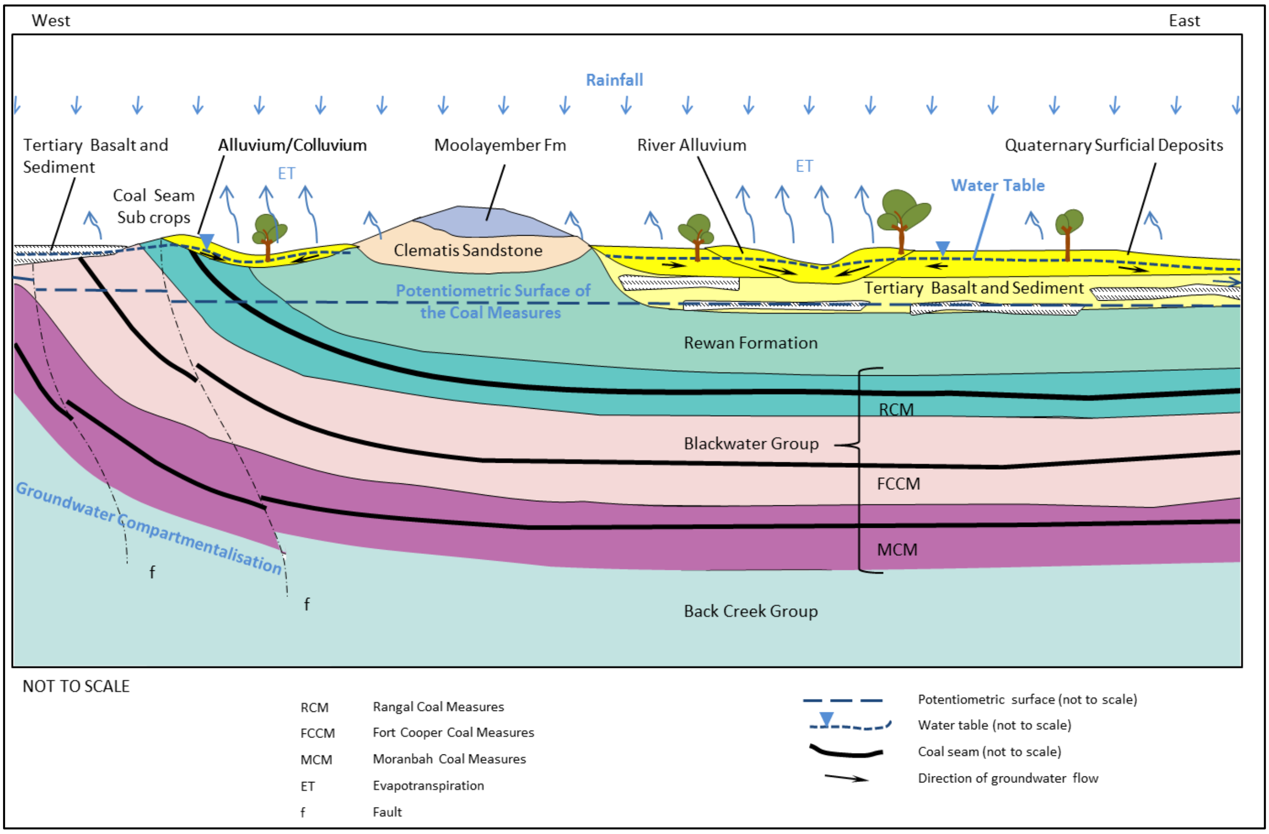


Figure 8: Conceptual Hydrogeological Model (Arrow Energy, 2012c)

A summary of the existing understanding of the hydrogeological setting as conceptualised in Figure 8 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:

- groundwater levels fluctuate between 6 to 10 meters below ground level (mbgl);
- 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;
- 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 brackish to 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:

- the average groundwater level around 52 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 classed as fresh to brackish;
- 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:

- groundwater levels range between 17 to 38 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 brackish to 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 aquifer 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:

- Rewan Formation:
    - the average groundwater level at around 25 mbgl;
    - highly variable in permeability and porosity and limited in lateral and vertical extent;
    - groundwater quality collected from the one monitoring bore in the Rewan Formation classed the groundwater as saline;
    - 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 and given the limited extent of this aquifer, groundwater supply is likely to be isolated;
- Clematis Sandstone:
    - the average groundwater level is around 52 mbgl;
    - highly variable in permeability and porosity and limited in lateral and vertical extent;
    - 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 targeting the sandstone is unknown.

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:

- Blackwater Group:
    - the recorded pressures associated with the Back Creek Group indicate artesian groundwater pressures;
    - 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/sub-cropping 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 saline;
    - groundwater resources associated with the Blackwater Group are typically contained in porous sandstones and fractured shale and siltstones;
    - confined by low permeability overburden and interburden as well as the overlying Rewan Formation where it exists.
- Back Creek Group
    - 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/sub-cropping 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);
    - confined by low permeability overburden and interburden as well as the overlying Rewan Formation where it exists;
    - groundwater quality is generally poor, however varies from being fresh to saline.

4 WATER MONITORING STRATEGY

4.1 Groundwater Monitoring Program

A water monitoring strategy is required for the CMA is shown in Figure 9 and Figure 10. 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 has been implemented. 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.

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

4.1.1 *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.

4.1.1.1 MGP Area

A total of 16 groundwater monitoring bores form the groundwater monitoring network for the MGP Area. Figure 9 provides an overview of the spatial distribution of the groundwater monitoring network and Table 1 lists the bores and their targeted formation.

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. Groundwater monitoring has been undertaken in these bores 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 MGP, 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 and monitors the deep CSG target (Moranbah Coal

Measures), Fort Cooper Coal Measures and the underlying Back Creek Group. The monitoring wells subjected to water quality sampling in the WMS prove sufficient in meeting the monitoring objectives as defined above.

Five monitoring bores were installed 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.

Note that due to nearby mining operations impacting water levels at M230W, M300W was chosen as a suitable replacement. The water levels observed in M230W are considered to have been influenced by nearby mining operations; a review of mine plan schedules indicated that "drive Number-1" traversed the area in proximity to M230W between Q3 and Q4-2017 indicating that the SWL decline were expected to be a result of the Anglo underground mine development. This was similar to the decline seen in M340W (as discussed in the 2017 Annual Review of the 2016 Bowen UWIR) where a decline in groundwater levels has made this monitoring borehole dry.

4.1.1.2 BGP

The network is comprised of 35 monitoring intervals at 22 separate locations (comprising 12 single sites and 10 nested sites of 23 monitoring intervals) from the approved groundwater monitoring network for the BGP area. Figure 10 provides an overview of the spatial distribution of the groundwater monitoring network. Table 11 displays the monitoring requirements of the BGP, along with the status of each location. Note that Table 11 displays the monitoring location name as per the 2019 Bowen Groundwater Monitoring and Management Plan (GMMP) which was approved by the Commonwealth Department of the Environment and Energy on 24 October 2019. All subsequent reporting is based off this nomenclature.

The network includes phased installation of the monitoring bores in advance of CSG development in the vicinity of the bores as detailed in Section 8.1.1.1 of the 2019 UWIR. At present, 9 monitoring points have been installed at seven locations as a part of the monitoring network; MB1-S/I/D, MB2, MB3, MB12, GW004, GW007 and AEN1063 as detailed below.

The design and layout of the groundwater monitoring network is underpinned by the 2021 numerical groundwater modelling that simulates the MGP and BGP groundwater abstraction and predicts the degree and extent of aquifer depressurisation in a spatial and temporal context. A geospatial analysis has been used to enable the magnitude, extent and timing of depressurisation to be related to the location of connected environmental features and existing water users, thereby providing an informed basis for establishing monitoring locations.

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

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

The layout of the groundwater monitoring network is specified separately for each of the BGP project phases, Red Hill Central development, Mavis Downs development and the remainder of the BGP FDP and takes into consideration their differences in gas development, both in a spatial and temporal context.

The monitoring bores used in developing the initial baseline will be augmented with additional monitoring bores to close out any monitoring/data gaps identified. The specifications, including the primary and secondary purpose of the bores, formations targeted and provisional installation years are shown in Table 11.

The installation schedule is phased according to the following:

- monitoring well locations with a primary purpose of baseline monitoring will be installed prior to the commencement of production in the corresponding development phase to enable the collection and interrogation of baseline data.
- monitoring well locations where baseline monitoring is not required will be installed immediately prior to the commencement of production in the corresponding development area.
- contingent locations will be installed only in circumstances where the criteria for contingency (specified in the notes to Table 11) are met.

Both field and laboratory-based quality monitoring will assist in aquifer characterisation and baselining, serving as a benchmark against which potential impacts can be assessed.

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

Table 11: BGP Monitoring Network

Monitoring location	Monitoring interval and target formation	Development area	Status/Indicative year of installation	Status
MB1	S – Quaternary / Tertiary I – RCM D – MCM	PL486	Current	Currently on monitoring. Groundwater level monitoring was required twice daily until 11/11/2020, which has been achieved. Going forward, a minimum of 6-monthly water level measurements are required for remainder of CSG production. Water quality sampling was required from MB1-D at biannual frequency for the first year, which has been achieved. Going forward annual monitoring is required.
MB2	MCM	PL486	Current	Currently on monitoring. Groundwater level monitoring was required twice daily until 31/10/2020, which has been achieved. Going forward, a minimum of 6-monthly water level measurements are required for remainder of CSG production. Online date is 16 February 2019 however data was lost between 30 October 2019 and 9 January 2020.
MB3	MCM	PL486	Current	Currently on monitoring. Groundwater level monitoring was required twice daily until 31/10/2020, which has been achieved. Going forward, a minimum of 6-monthly water level measurements are required for remainder of CSG production. Online date is 16 February 2019 however data was lost between 30 October 2019 and 9 January 2020.
MB4	Unconfined alluvium	PL486	Contingent	Not currently required as criteria not yet triggered. Requirement for installation is based on (modelled) increased risk of depressurisation resulting from changes in the FDP, or MB1 groundwater level monitoring data indicate interconnectivity of MCM with overlying units.
MB5	Tertiary / Triassic	ATP1103	2020	Not currently required due to no development within 10km.
MB6	Quaternary / Tertiary	ATP742	Contingent	Not currently required as criteria not yet triggered. Requirement for installation is based on (modelled) increased risk of depressurisation resulting from changes in the FDP, or monitoring of other sites in the northern development area indicate the potential or likelihood of preferential groundwater flow occurring across formations by way of geological faults.
MB7	S – Tertiary D – RCM	ATP742	2029	Not currently required due to no development within 10km.
MB8	Quaternary / Tertiary	ATP742	2030	Not currently required due to no development within 10km.
MB9	S – Quaternary / Tertiary I – RCM D – MCM / FCCM	ATP1103	2029	Not currently required due to no development within 10km.
MB10	Tertiary	ATP1103	2030	Requires installation immediately prior to commencement of pumping from Wards Well pilot wells.
MB11	S – Quaternary / Tertiary or Rewan Formation D – RCM	ATP1103	2029	Not currently required due to no development within 10km.
MB12	Quaternary / Tertiary	ATP1103	Current	Existing Fitzroy Mining monitoring bore (EFGW5D) being utilised to obtain groundwater level monitoring data in place of MB12. EFGW5D is located approximately 345m from the proposed location for MB12. Monitoring commenced in July 2018. Groundwater level monitoring will include 6-monthly water level measurements for remainder of CSG production.
MB13	S – Quaternary / Tertiary (if present) D – Blackwater Group (RCM / FCCM / MCM)	ATP1103 ATP1103	Contingent - 2028	MB13S not currently required due to no development within 10km. Requirement for installation of MB13D is based on monitoring of MB13-S and/or other monitoring points in the southern development area indicates the potential or likelihood of preferential groundwater flow occurring across formations by way of geological faults, or ongoing modelling or revised development indicates a greater risk of depressurisation impact at this location.
MB14	S – Quaternary / Tertiary I – RCM D – MCM / RCCM	ATP1103 ATP1103 ATP1103	2029	Not currently required due to no development within 10km.
MB15	S – Unconfined alluvium I – Tertiary / Triassic	ATP1103 ATP1103	2029	Not currently required due to no development within 10km.
MB16	Tertiary	ATP1103	2029	Not currently required due to no development within 10km.
MB17	S – Unconfined alluvium I – Rewan Formation	ATP 1103 (in proximity to Lake Elphinstone)	Contingent	Not currently required as criteria not yet triggered. Requirement for installation is based on if revised modelling indicates a risk of depressurisation impacts to Lake Elphinstone, or if impacts are detected at MB11-S.
Supplementary monitoring bores				
AEN1214	Rangal Coal Measures	ATP742	Current	Manual measurements recorded every 6-months. Awaiting access and monitoring agreement for deployment of logger.
AEN1063	Blackwater Group	ATP1031	Current	On monitoring as of November 2020. Suitable replacement for proposed AEN1036 as on same property and drilled to the same formation.
AEN1234	Quaternary alluvium	ATP1103	Current	Suitable replacement for proposed AEN1050. Manual measurements recorded every 6-months. Awaiting access and monitoring agreement for deployment of logger.
GW004	Alluvium Fort Cooper Coal Measures	ATP1103	Current	On monitoring as of November 2020. Replaces GW001 due to logger failure.
GW007	Alluvium Fort Cooper Coal Measures	PL486	Current	On monitoring as of November 2020.

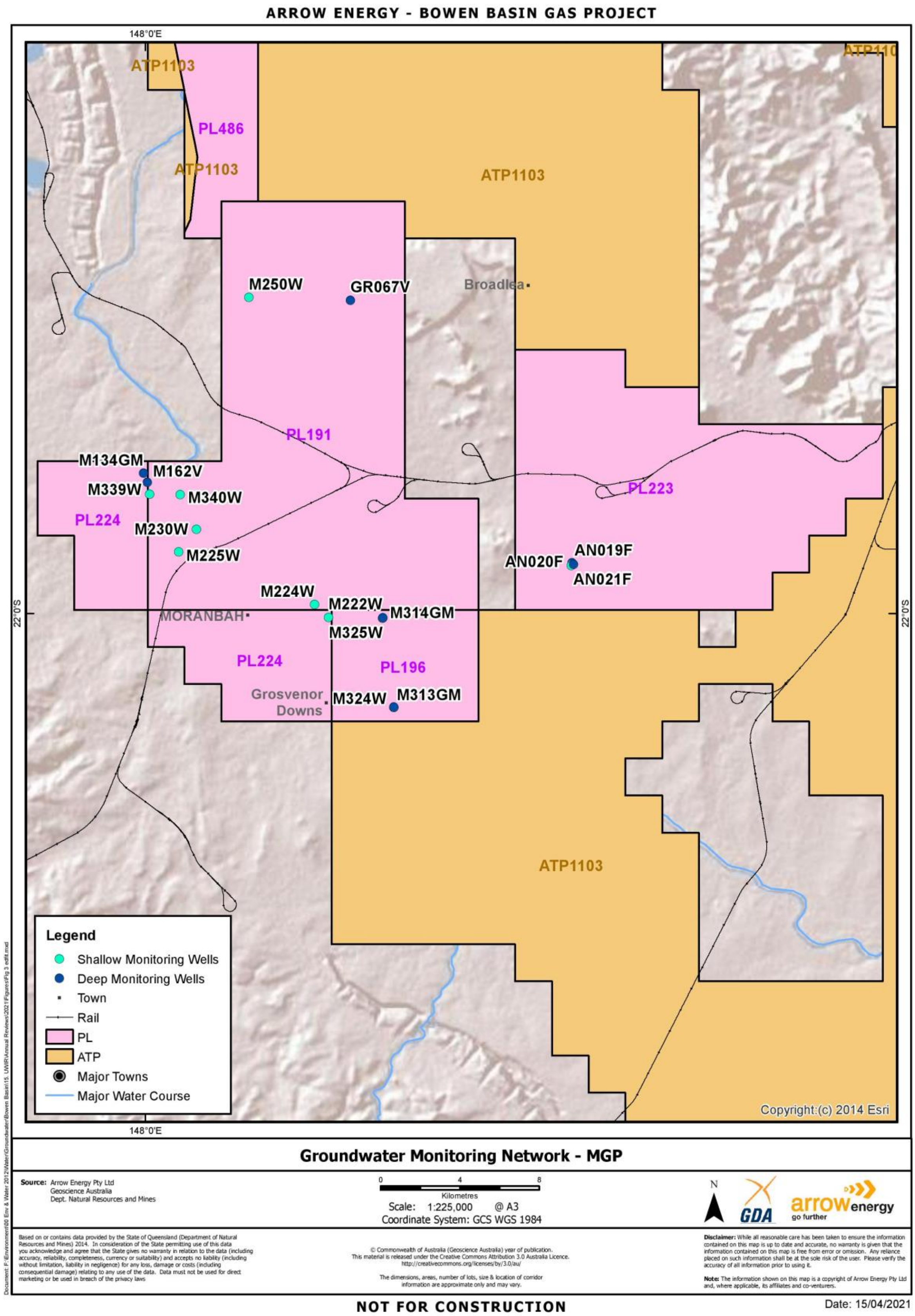


Figure 9: Groundwater Monitoring Network – MGP

arrow energy
go further

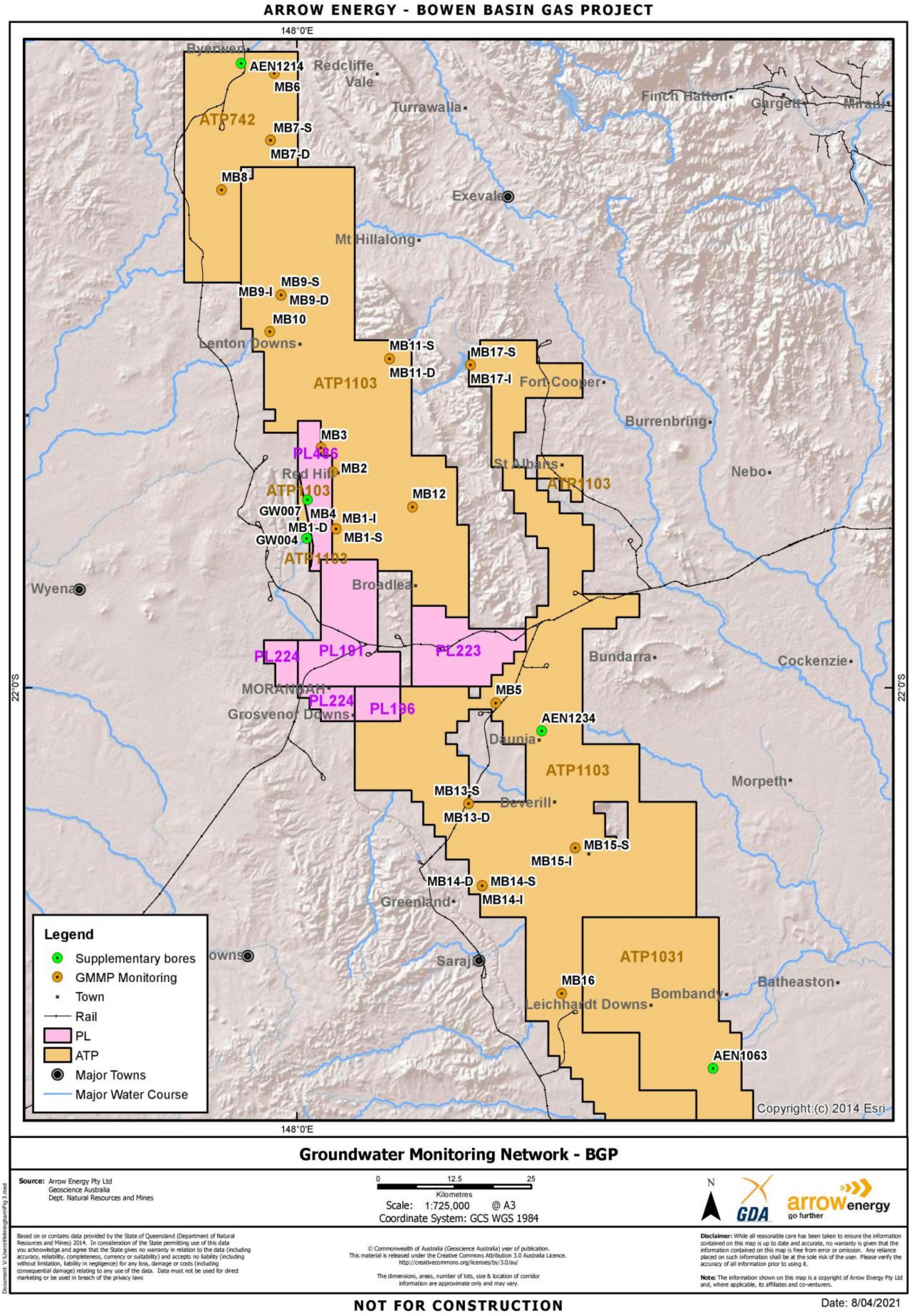


Figure 10: Groundwater Monitoring Network – BGP

4.1.2 *Groundwater Monitoring Frequency*

The groundwater monitoring frequency for the WMS bores are shown in Table 12 and Table 13.

Table 12: MGP WMS Groundwater Monitoring Frequency

Bore	Shallow/Deep	Monthly Water Level	6 Monthly Water Quality	6 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 to June 2021	
M300W	Shallow			November 2021 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	Deep	November 2015 to November 2016		January 2016 Onwards	No Water Quality Monitoring

Table 13: BGP WMS Groundwater Monitoring Frequency

Bore	Shallow/Deep	Twice Daily Water Level (logger)	6 Monthly Water Quality	6 Monthly Water Level (manual)	Annual Water Quality
MB1[1]	Deep	November 2019 to November 2020		November 2019 onwards	November 2019 onwards
MB1-I	Deep	November 2019 to November 2020		November 2019 onwards	November 2019 onwards
MB1-S	Shallow	November 2019 to November 2020		November 2019 onwards	N/A
MB2	Deep	October 2019 to October 2020		October 2019 onwards	N/A
MB3	Deep	October 2019 to October 2020		October 2019 onwards	N/A

[1] Note that due to the wellhead configuration and the MB1 monitoring point, manual readings through the wellhead are not possible with the pump installed.

Bore	Shallow/Deep	Twice Daily Water Level (logger)	6 Monthly Water Quality	6 Monthly Water Level (manual)	Annual Water Quality
MB12	Shallow	July 2018 onwards	N/A	July 2019 onwards	N/A
GW004A	Shallow	November 2020 onwards	N/A	N/A	N/A
GW004B	Shallow	November 2020 onwards	N/A	N/A	N/A
GW007A	Shallow	November 2020 onwards	N/A	N/A	N/A
AEN1214	Shallow	N/A		Awaiting access agreement	N/A
AEN1234	Shallow	N/A		Awaiting access agreement	N/A
AEN1063	Shallow	N/A		November 2020 onwards	N/A

For any future WMS bores (MGP and BGP), groundwater quality monitoring is proposed to be undertaken on a six-monthly basis for a period of 12 months and thereafter 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 DES as prescribed in Section 9. 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.

4.1.3 *Groundwater Monitoring Procedure*

Groundwater monitoring will be conducted in accordance with Arrow Energy's (Arrow's) Water Quality Sampling Manual. This procedure has been prepared with reference to; the DES's (2009) Monitoring and Sampling Manual 2018, 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 series water quality sampling Australian Standards and the Groundwater Sampling and Analysis – A Field Guide (Sundaram et al, 2009).

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.

4.1.4 *Groundwater Monitoring Parameters*

The proposed field parameters and the laboratory analytical schedule for groundwater samples are listed in Table 14 and Table 15 below respectively.

Table 14: Field Parameters Monitoring Suite

Parameter	
Temperature (^{o}C)	Redox Potential (Eh)
Electrical Conductivity (EC)	Dissolved Oxygen (DO)
pH	

Table 15: Chemical Parameters Monitoring Suite

Parameter	
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)
Dissolved Methane (CH_2)	Metals (dissolved): arsenic (As), barium (Ba), boron (B), chromium (Cr), cobolt (Co), Copper (Cu), Iron (Fe), Lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), zinc (Zn)

4.1.5 *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.

4.1.6 *Baseline Assessment Program*

The *Water Act (Qld) 2000* requires petroleum tenure holders to carry out baseline assessments as indicated in Section 394. 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 11 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. The water bores within the IAA contour area have all been field inspected as a part of the baseline assessment process. Based on this, there are no remaining water bores that require a bassline assessment.

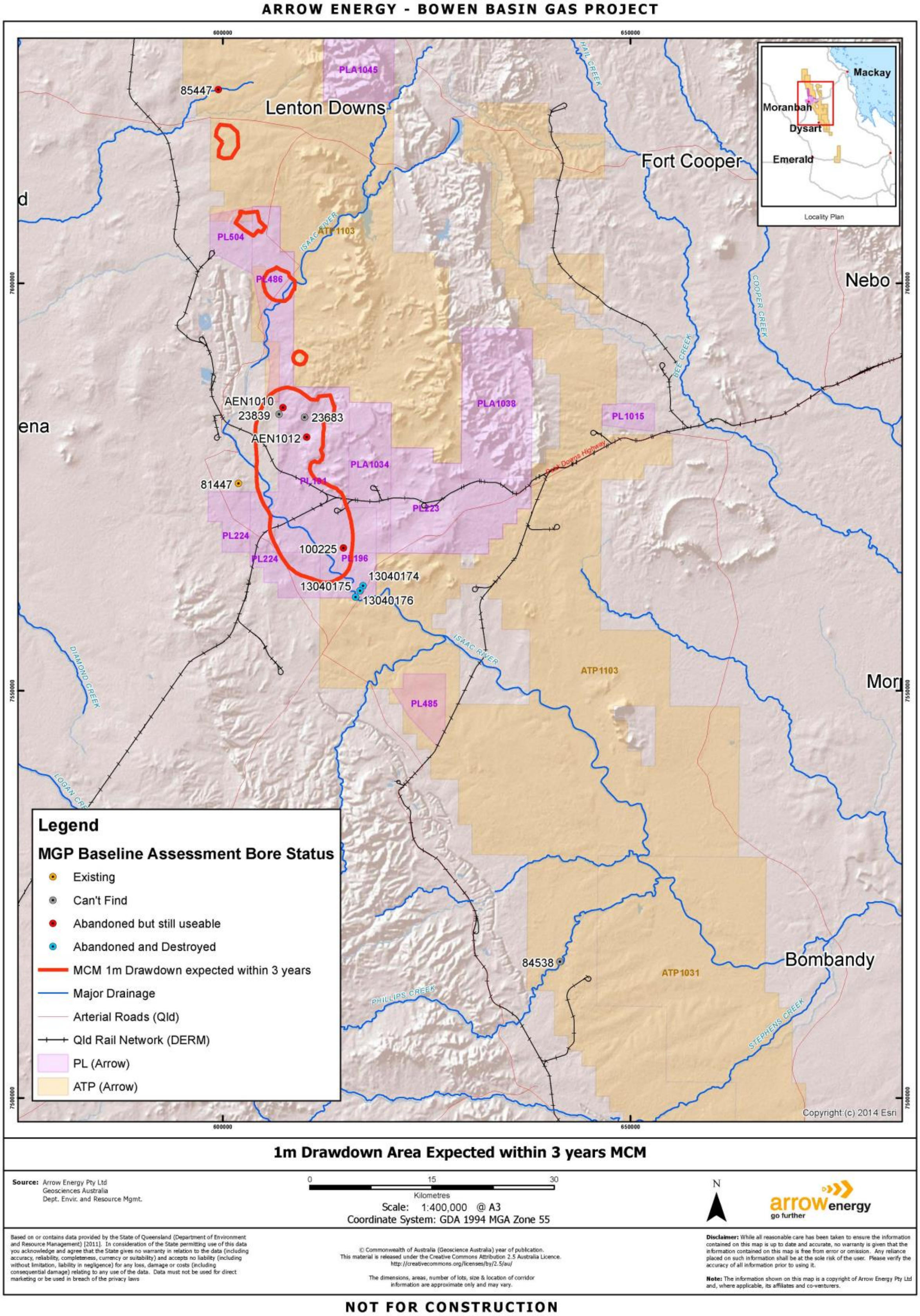


Figure 11: 1 m Drawdown Area Expected with 3 years for MCM

4.2 Water Production Monitoring

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

5 ARROW MONITORING RESULTS

Groundwater monitoring has been undertaken by Arrow in accordance with the UWIR WMS groundwater monitoring network located in the MGP Area. The locations of these bores are shown in Figure 9. This site-specific data is presented in more detail in the following sections and new data (groundwater levels and water quality) provide an update to the current understanding of the conceptual hydrogeological model.

5.1 Groundwater Levels

5.1.1 *Shallow UWIR Monitoring Data Summary*

Groundwater level monitoring has been undertaken in the following shallow groundwater monitoring bores, which form part of the 2022 Bowen UWIR groundwater monitoring network for the MGP and BGP Area (Table 16 provides a summary of these bores).

- monitoring since June 2012 for bores M339W, M225W, M340W, M230W, M250W, M224W, M222W;
- monitoring since March 2016 for bores AN020F and AN021F;
- monitoring since January 2018 for bore MB12;
- monitoring since November 2019 for bores MB1-S and GW007A;
- monitoring since November 2020 for bores GW004A, GW004B, AEN1214, AEN1234 and AEN1063;
- monitoring since November 2021 for bore M300W.

Table 16: Shallow Groundwater Monitoring Bores

Bore ID	Network	Total Constructed Depth (m)	Screen Interval (mbgl)	Screened Formation
M339W	MGP	41.0	35.0 – 41.0	Weathered Tertiary Basalt
M225W	MGP	34.0	23.0 – 34.0	Weathered Tertiary Basalt
M340W	MGP	27.3	19.3 – 27.3	Weathered Tertiary Basalt
M230W[1]	MGP	32.0	29.0 – 32.0	Weathered Tertiary Basalt
M250W	MGP	56.5	44.5 – 56.5	Tertiary Sediment
M300W	MGP	30.0	24.0 – 30.0	Weathered Tertiary Basalt
M224W	MGP	32.5	26.5 – 32.5	Quaternary Alluvium
M222W	MGP	30.2	20.0 – 26.0	Weathered Fort Cooper Coal Measures
AN020F	MGP	77.0	70.0 – 72.0	Rewan Formation
AN021F	MGP	27.0	20.0 – 22.0	Tertiary Sediment
MB1-S	BGP	60	45.0 – 50.0	Fort Cooper Coal Measures – Girrah Seam
MB12	BGP	59.1	56.0 – 59.0	Rewan Formation
GW004A	BGP	13.5	7.5 – 13.5	Tertiary Sediment
GW004B	BGP	59	53.0 – 59.0	Fort Cooper Coal Measures
GW007A	BGP	7.5	1.5 – 7.5	Tertiary Sediment
AEN1214	BGP	37.32	-[2]	Rangal Coal Measures
AEN1234	BGP	102	48.2 – 102.0	Blackwater Group
AEN1063	BGP	52.6	39.6 – 45.7	Blackwater Group

[1]M230W was replaced by M300W due to mining impact impacting the water level
[2]Screened interval could not be determined due to pumping infrastructure

The groundwater level monitoring results are shown in Appendix A. Groundwater levels, are shown in Figure 12 to Figure 14 and are discussed below for the MGP and BGP areas.

MGP:

The groundwater levels in the MGP range from:

- 200.1 to 209.2 m Australian Height Datum (AHD) in the weathered Tertiary Basalt aquifer;
- 233.2 to 242.3 m AHD in the Tertiary Sediment aquifer;
- 207.8 to 211.7 m AHD in the Quaternary Alluvium aquifer;
- 202.4 to 206.3 m AHD in the Fort Cooper Coal Measures aquifer; and
- 237.2 to 238.6 m AHD in the Rewan Formation.

All bores located within close proximity to the Isaac River display similar depths to groundwater. This is shown in Figure 15.

A review of the groundwater levels in bore M224W, installed in the Quaternary Alluvium and within 300 m of the Isaac River was compared against data obtained from the Isaac River stream gauge (130414A). The graphically presented river level data (Figure 15) indicates a gradual decline in flow periods from mid-2013 to the end of 2014 and an increase in flow periods linked to rainfall events into 2018. The only shallow monitoring bore indicating a possible hydraulic link to the river level fluctuations, is bore M224W. The conceptual hydrogeological model reports a linkage between rainfall events and river level flow periods to groundwater levels. The current data set does however not indicate a strong link and the outcome is still inconclusive. Insufficient data available to suggest and allow changes to the current conceptual model.

The groundwater levels in the monitoring bores completed into the weathered tertiary basalt (M339W, M225W, M340W and M230W) and located in close proximity to the Isaac river, no direct hydraulic connection to the Isaac river fluctuations. The water level in monitoring bore M339W has been very stable of the last 7 years. The water level in M225W has continued to recover and M230W has gradually dropped over the last 4 years, not in sequence to the river fluctuations. The water level in M340W has dropped below the completed depth of the monitoring bore due to the impact of the underground mining directly below the area.

The groundwater levels for bores M250W, AN021F and AN020F are higher due to the respective surface elevation in the areas being approximately 50 to 60m, 30 to 40m and 85 to 95m, respectively, above the other bores. As indicated in Table 16, M250W and AN021F are installed in the Tertiary Sediment and located approximately 10 km north and east of the other groundwater monitoring sites along the Isaac River, while MB12 is constructed within the Rewan Formation and located approximately 26km northeast of the other groundwater monitoring sites along the Isaac River.

There is no predicted IAA or LAA for unconsolidated aquifers for the MGP and BGP; as modelled drawdown does not exceed the bore trigger threshold of 2 metres.

Groundwater level monitoring indicates:

- actual groundwater levels monitored in bore M339W have remained steady over the monitoring period.
- the water levels in M222W and M225W have continued to steadily rise since monitoring began in 2012.
- Figure 14 displays cumulative rainfall departure and groundwater levels at groundwater monitoring bores M225W, M230W, M222W and M224W. Recharge to shallow aquifers due to above mean rainfall has continued to contribute to the rising trend in groundwater levels noted in M222W and M225W with a peak at the end of 2017. The water level in M230W has declined since this peak, likely due to nearby mining operations as discussed below.
- there is no predicted IAA or LAA for any aquifer underlying PL 223; hence modelled drawdown greater than the bore trigger threshold at the end of 2019 was not predicted in the 2019 Bowen UWIR to occur at the location of bores AN020F and AN021F. AN021F is installed in the Tertiary Sediment and has increased in water level since monitoring began. AN020F is installed in the Rewan Formation which is considered to be a regional aquitard. Groundwater levels monitored at AN020F have remained steady over the monitoring period.
- a decline in groundwater level by greater than the bore trigger threshold was noted at bore M224W between November 2017 and November 2019. As discussed in the 2019 Bowen UWIR, the water levels in this bore indicate a possible hydraulic link to the river level fluctuations. This is in-line with the conceptual hydrogeological model report in the 2019 Bowen UWIR, where there is linkage between rainfall events and river level flow periods to groundwater level. This decline greater than the bore trigger threshold between November 2017 and November 2019 is not considered to be due to the effects of CSG production.

- a decline in groundwater level by greater than the bore trigger threshold was noted at bore M230W between November 2017 and November 2019. The water levels observed in this bore are considered to have been influenced by nearby mining operations; a review of mine plan schedules indicated that "drive Number-1" traversed the area in proximity to M230W between Q3 and Q4-2017 indicating that the SWL decline were expected to be a result of the Anglo underground mine development. This was similar to the decline seen in M340W (as discussed in the 2017 Annual Review of the 2016 Bowen UWIR) where a decline in groundwater level has made this monitoring borehole dry. Both monitoring bores are in the same area, as shown in Figure 9. Accordingly, the decline is not considered to be due to the effects of CSG production. Due to the impact of mining operations, this monitoring bore has been replaced by M300W but is included in this report for historical analysis.

Based on the graphically presented monitoring data in Figure 12, it is clear that there is no apparent influence of CSG production to the Quaternary alluvium, weathered Tertiary basalt, Tertiary sediment, weathered Fort Cooper coal measures and Rewan aquifers in which these bores are installed. This data supports the groundwater modelling predictions in the 2021 Bowen groundwater model.

BGP:

Groundwater levels, as is shown in Figure 13, range from:

- 227.9 to 64.75 m Australian Height Datum (AHD) in the Tertiary Sediment aquifer;
- 209.5 m AHD in the weathered Fort Cooper Coal Measures aquifer, and
- 286.4 m AHD in the Rewan Formation.

Based on the presented monitoring data in Figure 13, there is no apparent influence of CSG production to the Tertiary Sediment, Fort Cooper Coal Measures and Rewan aquifers in which these bores are installed. This is expected given no water production has commenced in the BGP.

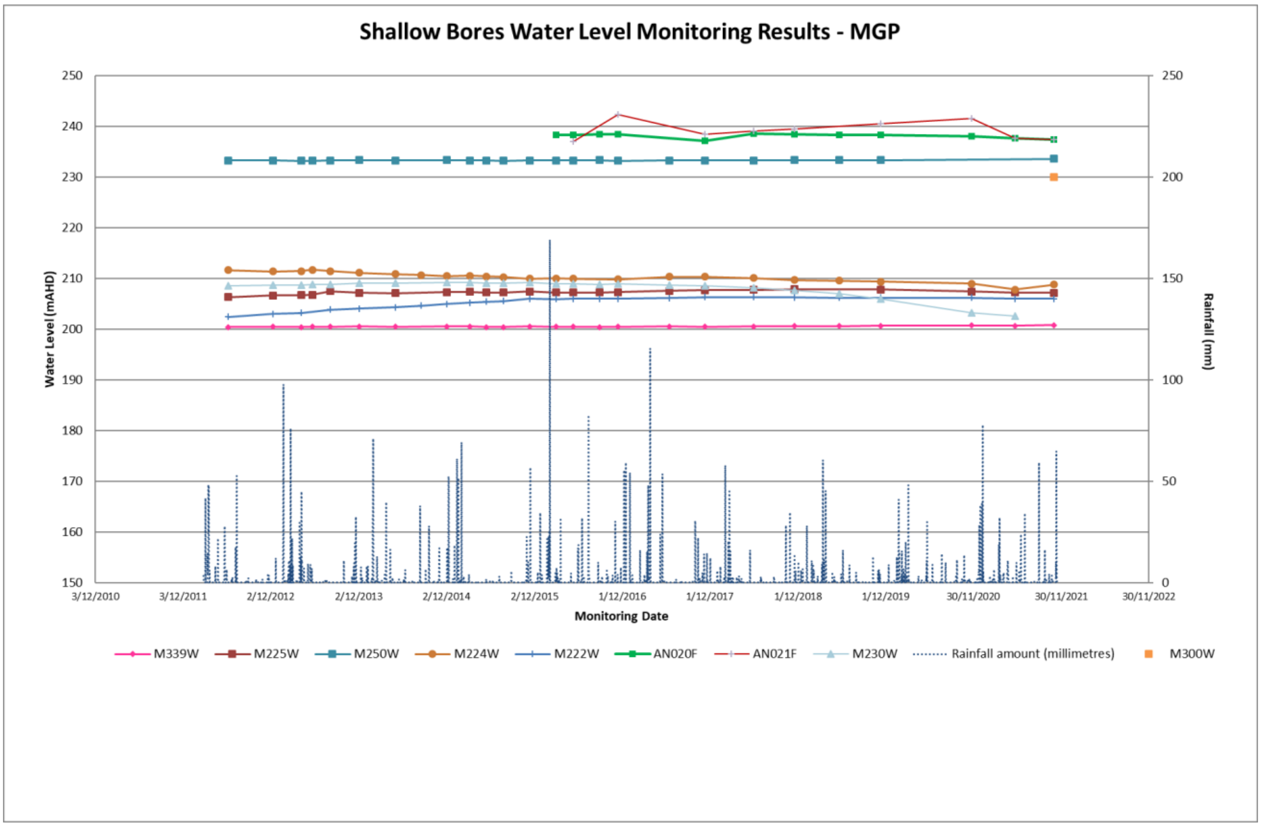


Figure 12: Shallow Bores Water Level Monitoring Results – MGP

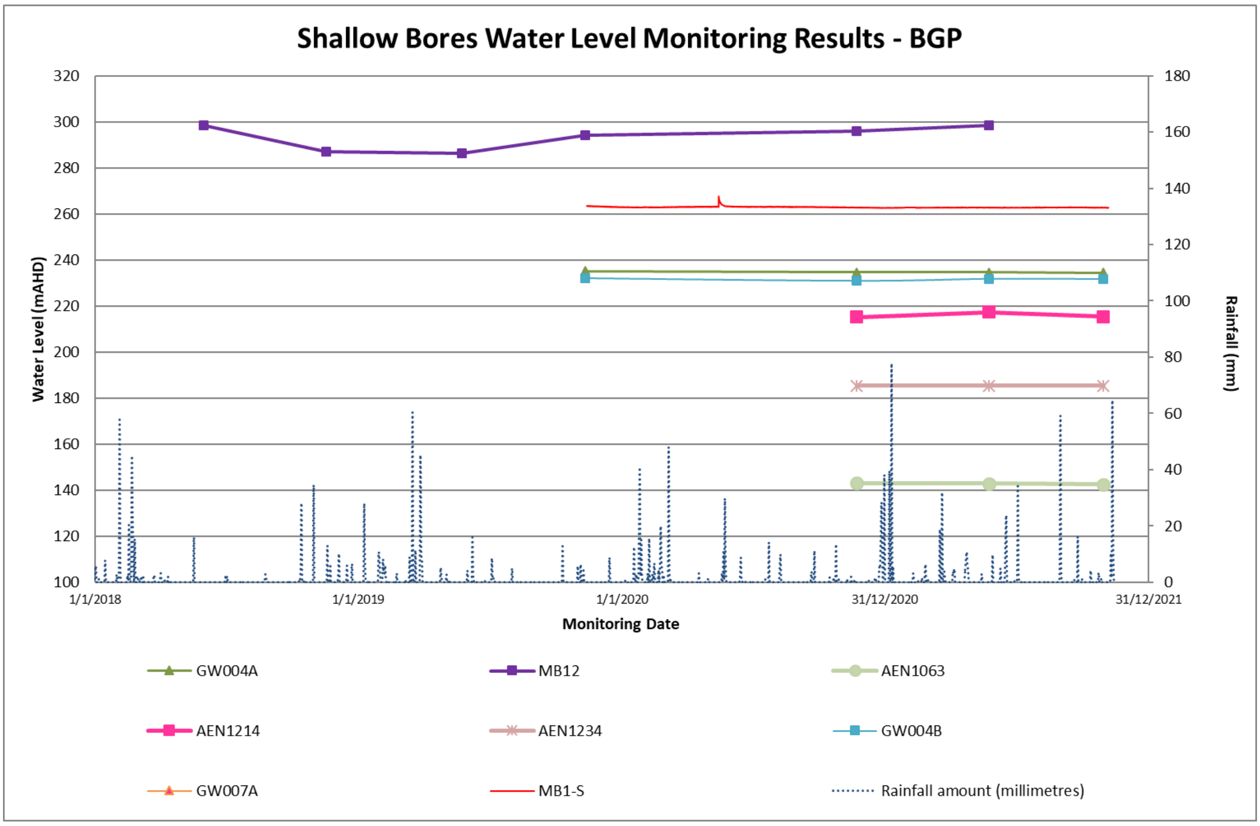


Figure 13: Shallow Bores Water Level Monitoring Results – BGP

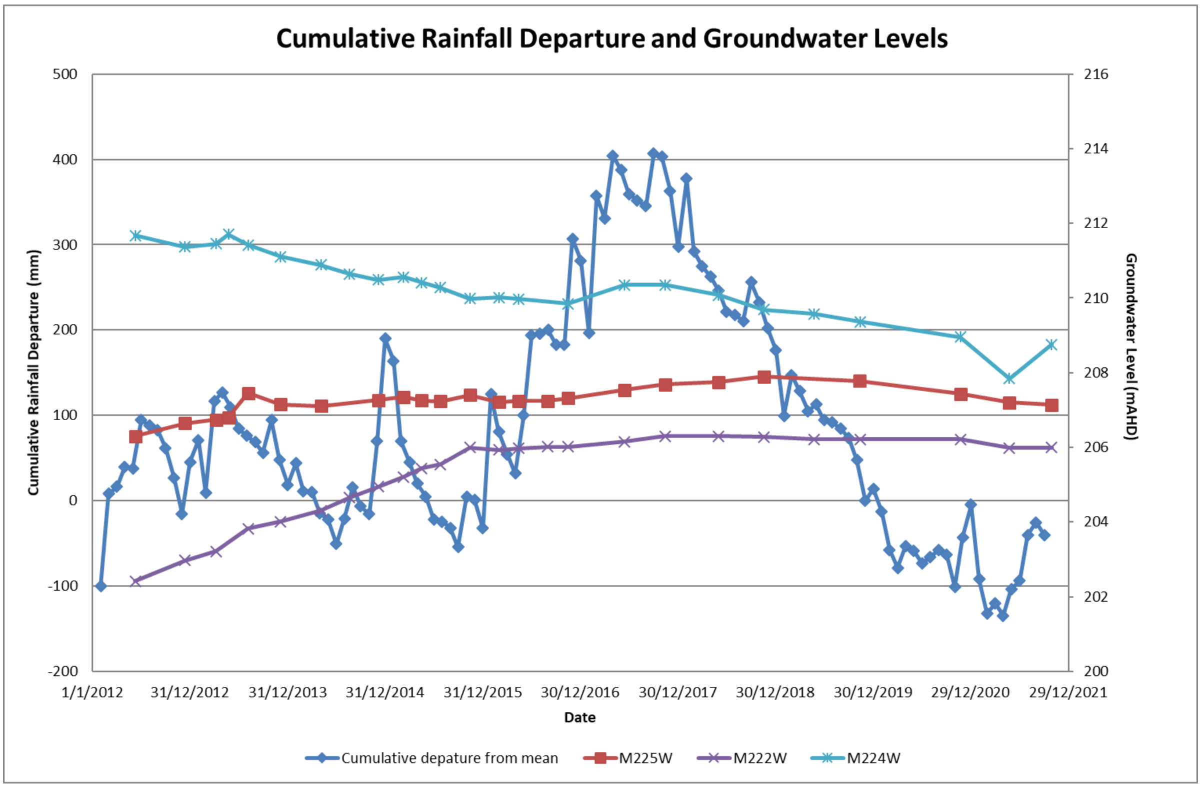


Figure 14: Cumulative Rainfall Departure and Groundwater Levels

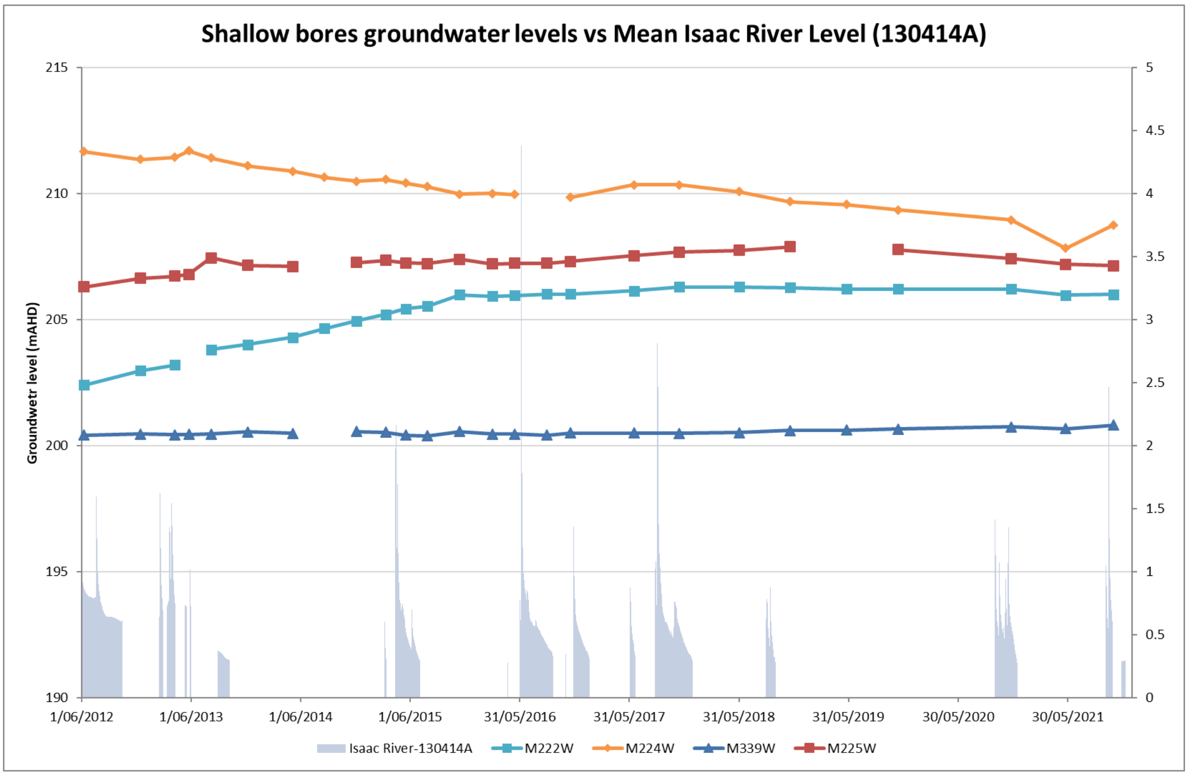


Figure 15: Shallow Groundwater levels vs mean Isaac River levels

.

5.1.2 *Deep UWIR Monitoring Data Summary*

Groundwater level monitoring has been undertaken in the following deep groundwater monitoring bores which form part of the 2022 Bowen UWIR groundwater monitoring network. Table 17 provides details for these bores.

- monitoring since November 2011 for MB1-D and since November 2019 for MB1-I;
- monitoring since September 2015 for bore MB2;
- monitoring since September 2013 for bore MB3;
- monitoring since September 2014 for bores M313W, M314W, M324W;
- monitoring since February 2015 for bore M325W;
- monitoring since November 2015 for bores AN019F
- monitoring since December 2015 for bore M162V;
- monitoring since February 2016 for bore GR067V; and
- monitoring since November 2019 for bore GW007B.

Table 17: Deep Groundwater Monitoring Bores

Bore ID	Network	Total Constructed Depth (m)	Screen Interval (mbgl)	Screened Formation
M313W	MGP	532.4	313.0 – 316.5 507.0 – 510.0	Moranbah Coal Measures (QA Seam) Back Creek Group
M314W	MGP	560.5	210.5 – 213.5 551.5 – 553.5	Moranbah Coal Measures (QA Seam) Back Creek Group
M324W	MGP	240.0	163.0 – 166.0 187.0 – 190.0	Fort Cooper Coal Measures Moranbah Coal Measures (QA Seam)
M325W	MGP	202.3	180.5 – 182.0	Fort Cooper Coal Measures
AN019F	MGP	290.0	269.0 – 271.0	Fort Cooper Coal Measures
M162V	MGP	276.0	252.0 – 256.0	Moranbah Coal Measures
GR067V	MGP	610.9	543.2 – 610.9	Moranbah Coal Measures
MB1	BGP	550	336 -340 423.9-506.6	Fort Cooper Coal Measures Moranbah Coal Measures
MB2	BGP	834	701.1-814.7	Moranbah Coal Measures
MB3	BGP	796.3	712.3 – 717.9	Moranbah Coal Measures
GW007B	BGP	181.5	175.5 – 181.5	Fort Cooper Coal Measures

MGP:

The groundwater level monitoring results are shown in Figure 16. Observed groundwater levels or calculated potentiometric water levels ranged from:

- 209.8 to 216.8m AHD in the BCG;
- 49.6 to 207.7m AHD in the FCCM; and
- -129.1 to 204.2 m AHD in the MCM.

The monitoring bores discussed below have been selected due to identification of noticeable trends:

- decreases in water levels at GR067V of up to 150 metres, noted in April and August 2016, are due to depressurisation activities in this bore associated with the conversion of the bore to a monitoring point. The recovery curve has subsequently stabilised and a standing water level of 204 mAHD is evident.
- monitoring data from M325W has not been compared to the bore trigger threshold because water levels have exhibited a consistently increasing pressure trend since monitoring commenced in 2014. As presented in Figure 16, the available pressure data for M325W indicates groundwater levels in the FCCM have increased past the

previously-observed peak of 69.99m AHD (recorded in 22/05/2016) and recovered to 97.4m AHD by 30/10/2021. As the starting water level of the bore is unknown and cannot be determined, including the ongoing increase in water level in the bore, the bore trigger threshold has not been applied to the monitoring bore.

- monitoring data from M314W indicates a decline within both the MCM and BCG zones. The MCM decline can be attributed due to the nearby production of GM050V. Due to the separation between the MCM and BCG zones, the drawdown in the BCG is unlikely due to CSG activities. The decline in the BCG water level can possibly be attributed to a decrease in the CRD as evident in Figure 14.
- the decline in groundwater levels in M313W and M324W (MCM) exceeded the bore trigger threshold of 5 m (19) due to the proximity and hydraulic communication with production well GM052V, 300m to the southwest and within the MCM. The monitoring data from the MCM monitoring bore M324W is also presented in Figure 19 and indicates hydraulic communication with the production well.
- the current production from M134GMV within the MCM, located 470m to the northwest of monitoring bore M162V, has resulted in the bore trigger threshold of 5m being exceeded (Figure 19). The information suggests the water pressures will continue to decline in the area in line with the CSG production.

In Figure 18 the graphically presented pressure data indicates pressure changes of less than the 5m bore trigger threshold and the figure provides a more detailed presentation of the FCCM and BCG pressures. The recorded FCCM pressures (Figure 18) in bores M324W and AN019F, located 11 km apart, reflect similar trends. The pressures in both bores have gradually decreased. Decline in water levels noted for the FCCM are observed to correlate to the water production in CSG wells and consequential drawdown in the underlying MCM. This suggests that there is some transmission of impacts from the MCM to the shallower FCCM. Whilst there is some decline in water levels in the deeper Back Creek Group aquifer, it does not clearly correlate to the water production in the CSG wells and ongoing monitoring will confirm this. Based on this, monitoring data suggests that impacts are contained within the MCM and FCCM.

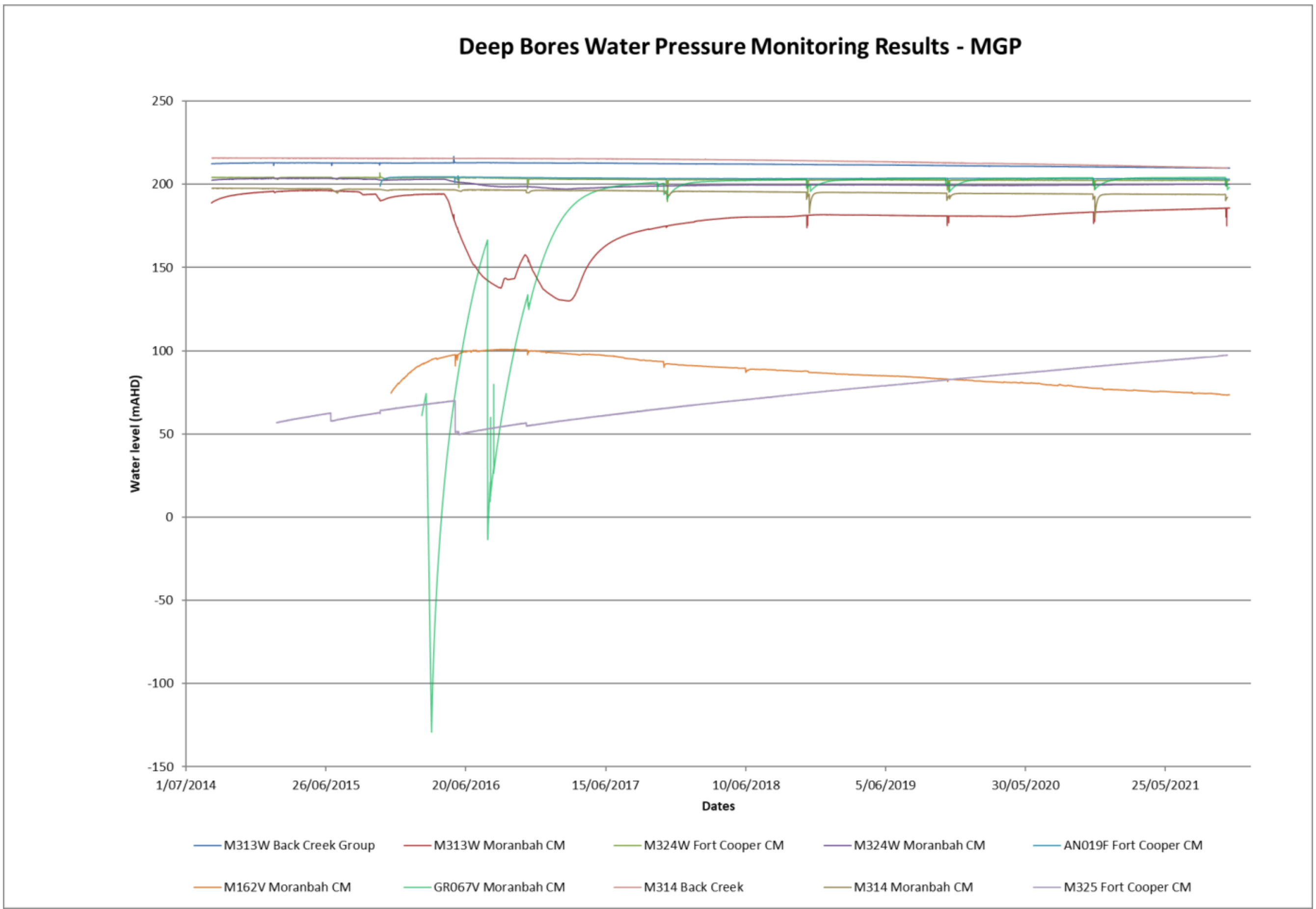


Figure 16: Deep Bores Water Pressure Monitoring Results – MGP

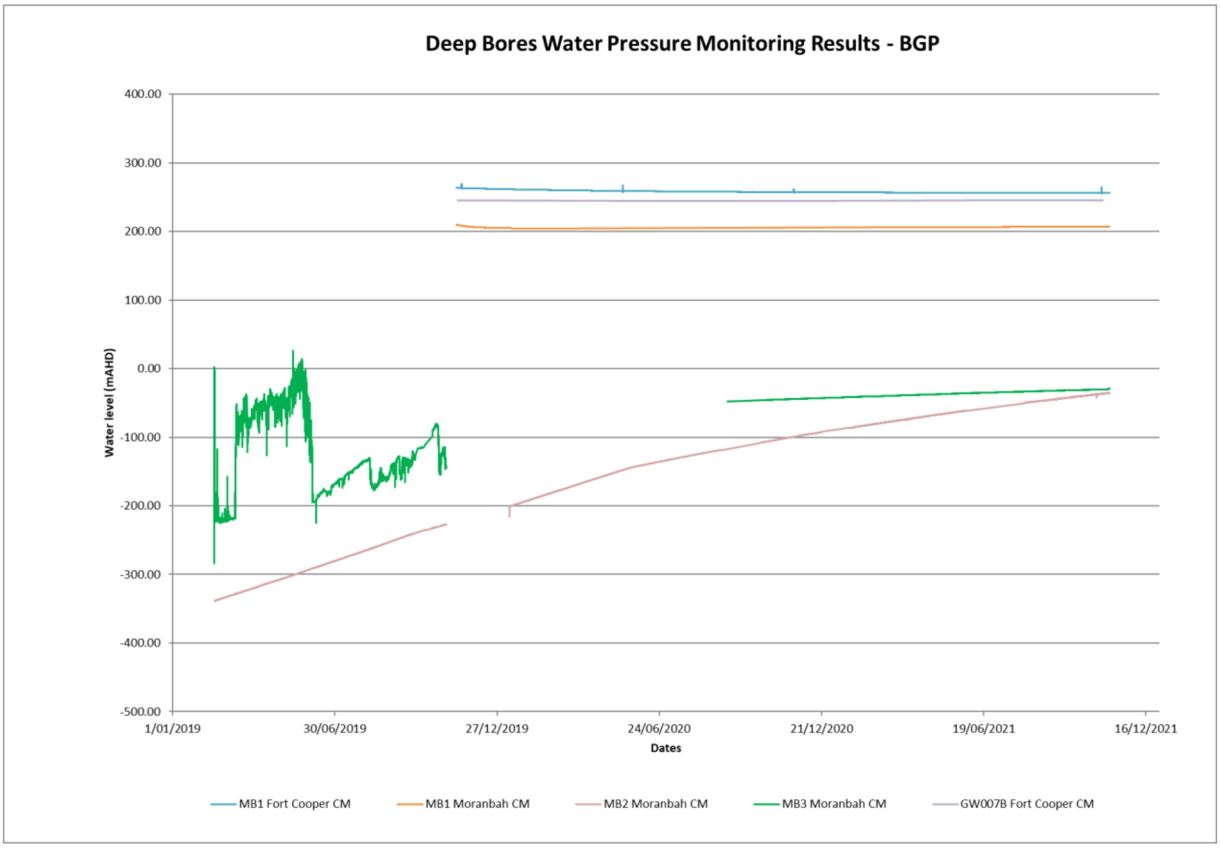


Figure 17: Deep Bores Water Pressure Monitoring Results – BGP

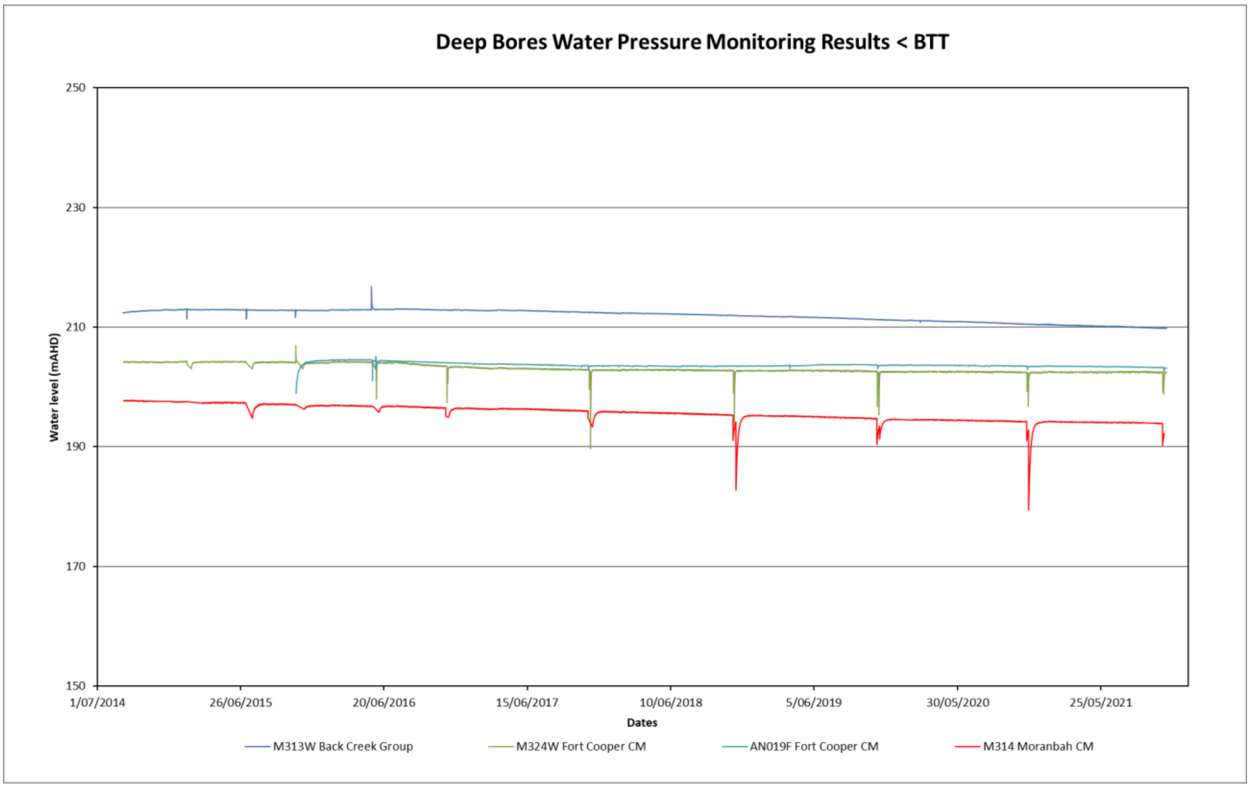


Figure 18: Deep Bores with Level Changes Less Than the Bore Trigger Threshold

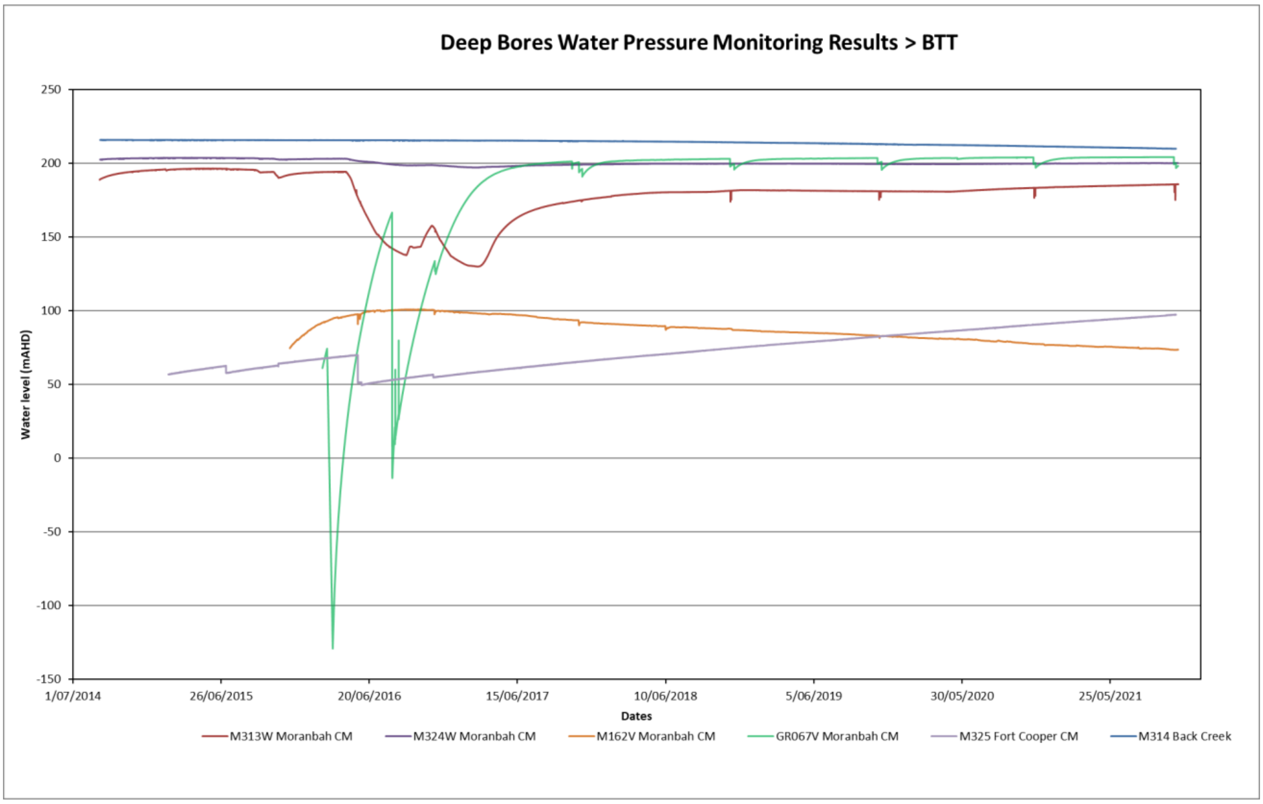


Figure 19: Deep Bores with Level Changes Greater Than the Bore Trigger Threshold

5.2 Groundwater Flow

A review of vertical gradients was undertaken for two monitoring locations in the MGP area and one monitoring location in the BGP area. Monitoring at each site included:

- Site 1: From deepest to shallowest; Back Creek Group (M314W), Moranbah Coal Measures (M314W), Fort Cooper Coal Measures (M325W) as well as data from monitoring approximately 3 km north west in the weathered Fort Cooper Coal Measures (M222W) and Quaternary Alluvium (M224W).
- Site 2: From deepest to shallowest; Back Creek Group (M313W), Moranbah Coal Measures (M313W), Moranbah Coal Measures (M324W) and Fort Cooper Coal Measures (M324W).
- Site 3. From deepest to shallowest, MCM, FCCM and FCCM (Girrah seam), in MB1.

Figure 20 shows the vertical gradients for Site 1 and the latest data indicates the FCCM aquifer, at bore M325W, has the lowest water level. The collected and graphically displayed data indicate a very steady and continued recovery of approximately 34m in M325W. With the exception of Site 1, there is an apparent gradient toward the MCM (the target coal seams for CSG production from the MGP) i.e. upward from the BCG and downward from the Quaternary Alluvium, to the FCCM and then to the MCM.

The water levels in monitoring bore M222W which is constructed into the FCCM show a rising trend in response to above average rainfall recharge. Water levels in M224W constructed in the Quaternary Alluvium show that trends in water levels are linked to flows in the nearby Isaac River.

A decline in water levels have been observed in M314W within MCM and the BCG. The water level trends between the MCM and shallow aquifer seem to indicate no vertical hydraulic links exist at this location.

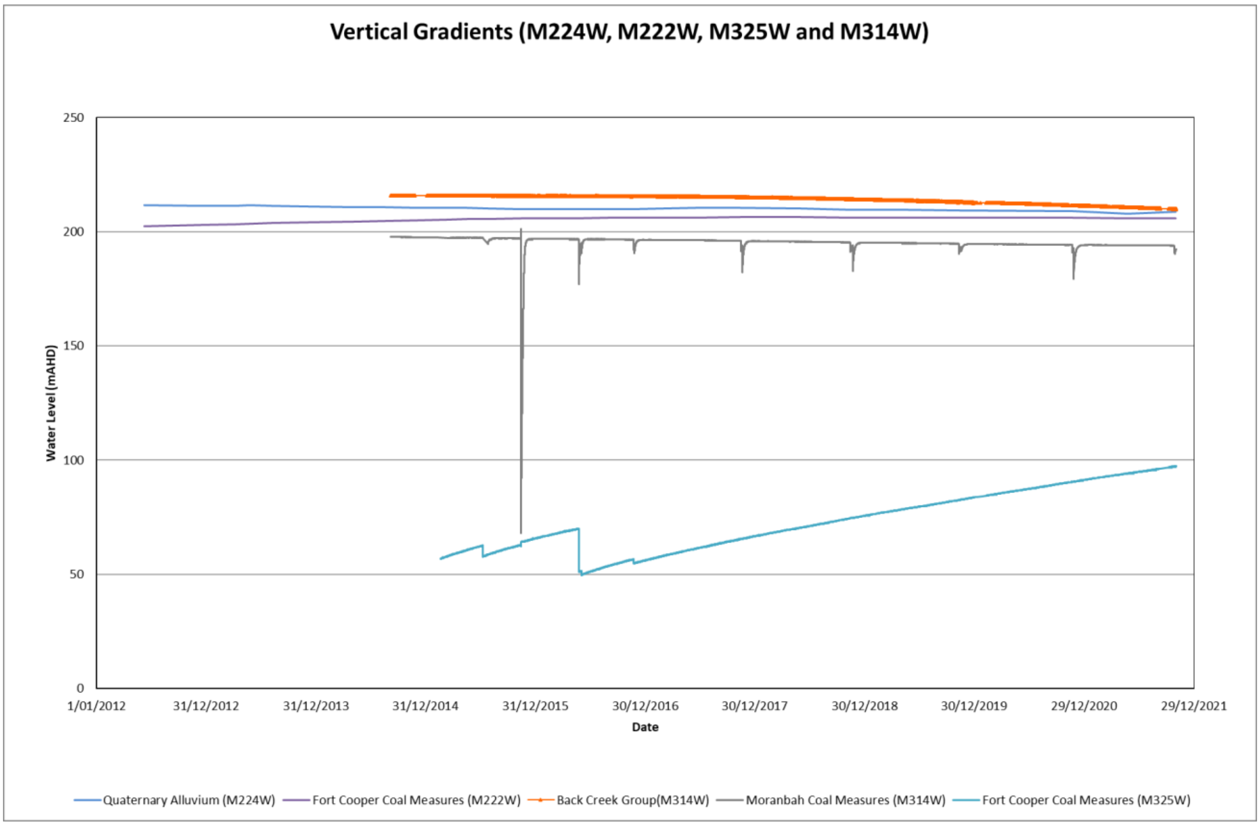


Figure 20: Site 1 - Review of Vertical Gradients for M222W, M224W, M314 and M325W

Figure 21 shows the graphically displayed vertical gradients for Site 2 and based on the presented data, water levels in the MCM monitoring bores have continued to recover following the cessation of production in GM052V.

Drawdown as a result of water production in CSG wells to the MCM aquifer is evident at site M313W and M324W but since the production ceased in April 2017, the water level recovery is evident in both monitoring boreholes. Monitoring data for the FCCM and BCG at this site indicates a slight decline in water levels. Decline in water levels noted for the FCCM are observed to correlate to the water production in CSG wells and consequential drawdown in the underlying MCM. This suggests that there is some transmission of impacts from the MCM to the shallower FCCM. Whilst there is some decline in water levels in the deeper Back Creek Group aquifer, it does not clearly correlate to the water production in the CSG wells and ongoing monitoring will confirm this. Based on this, monitoring data suggests that impacts are contained within the MCM and FCCM.

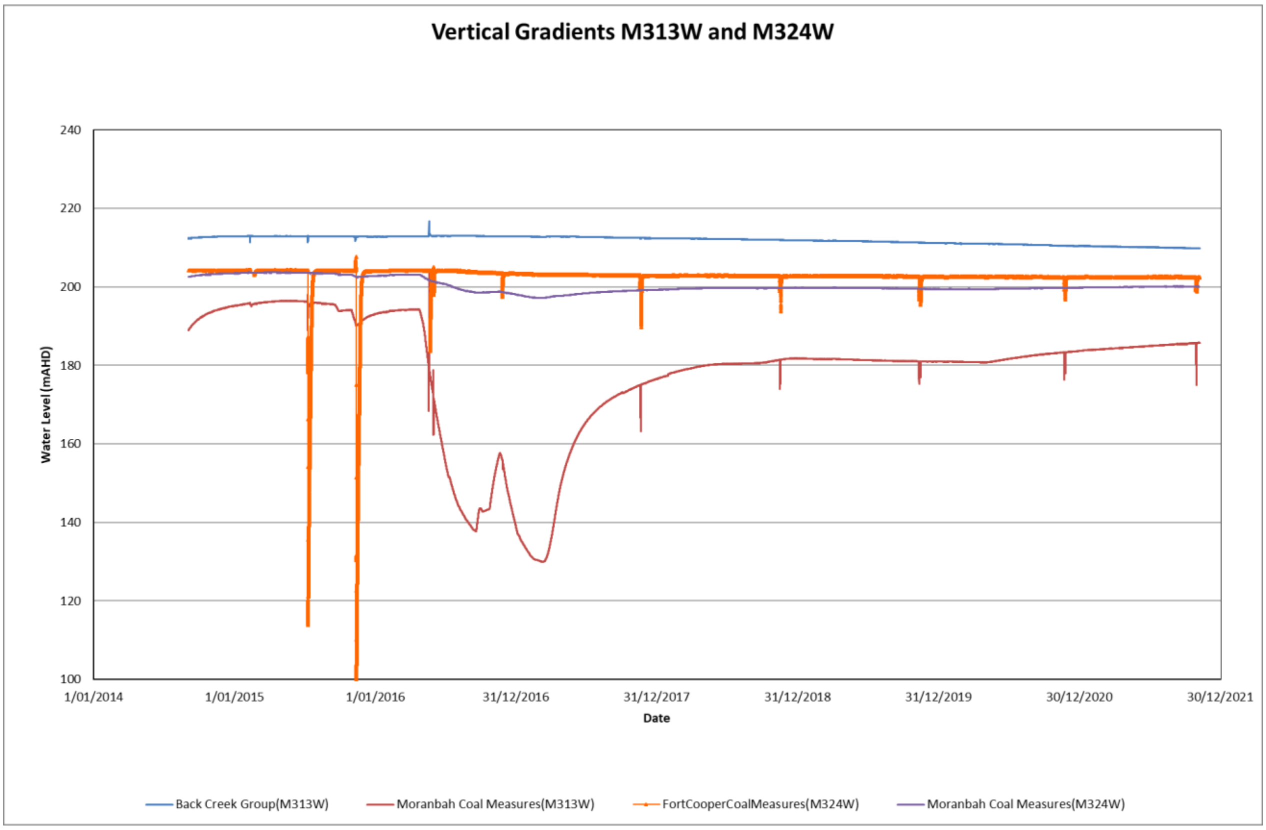


Figure 21: Site 2 - Review of Vertical Gradients for M313W and M324W

Figure 22 shows the graphically displayed vertical gradients for Site 3 (MB1) and based on the presented data, a decrease in water levels in the MCM is visible in 2016, with a smaller decrease seen in the FCCM. Prior to this decrease, the FCCM displayed similar water levels to the Quaternary Alluvium. This decline in water levels can be attributed to the workover conducted on MB1 to equip the borehole for multi-zone monitoring. During the workover process, a slug of water was introduced to ‘kill’ the well and due to the low permeability of the FCCM and MCM, a decline in water level was seen. As of the end of 2021, the water levels in all three zones are stabilising, with the MCM zone displaying an increase in water levels.

The sharp pressure increases in the data can be attributed to sampling events of MB1, where the pressure is bled off the borehole during sampling.

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

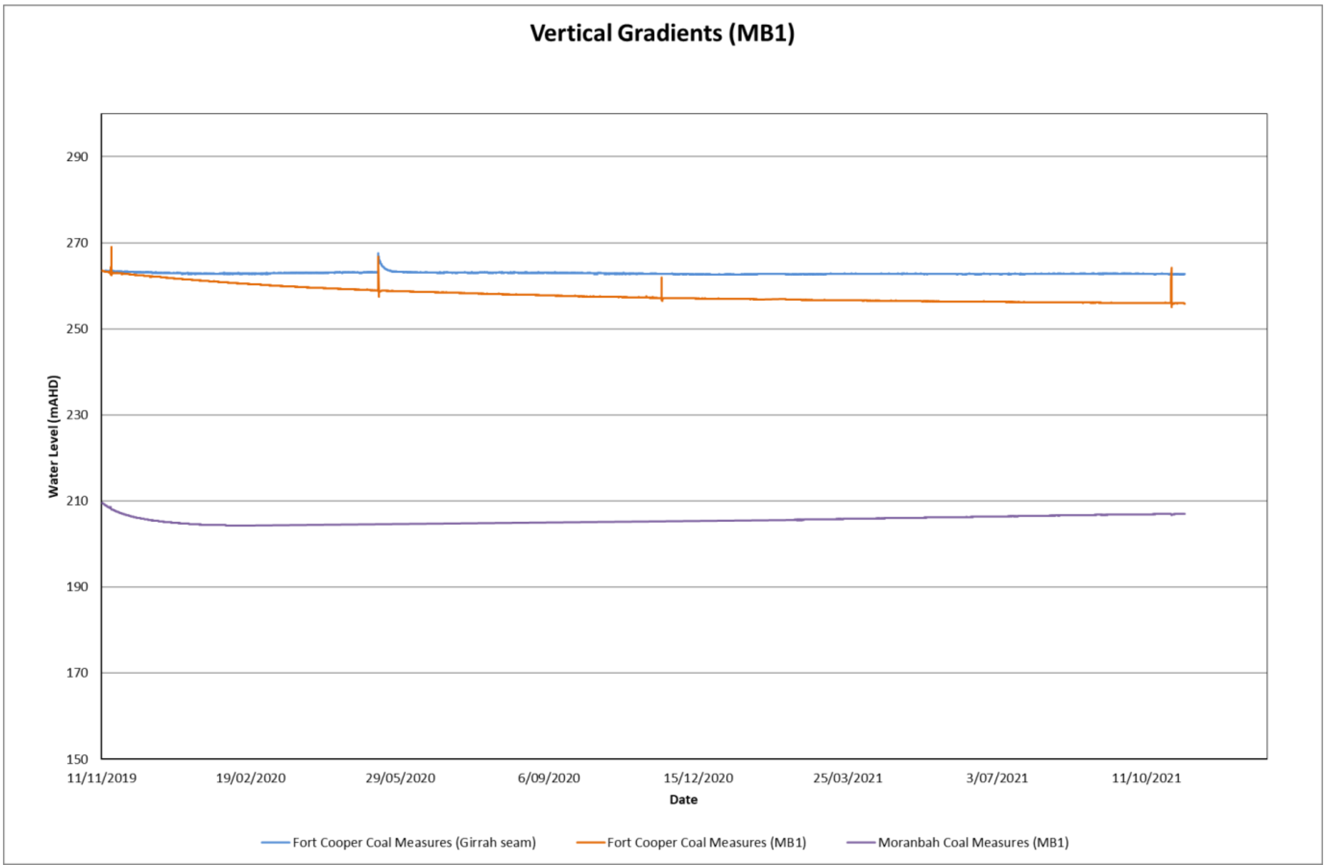


Figure 22: Site 3 - Review of Vertical Gradients for MB1

5.3 Groundwater Quality

5.3.1 *Shallow aquifer water quality*

Groundwater quality monitoring for PL 191, 196, 223 and 224 has been undertaken in eight shallow groundwater monitoring bores since June 2012. It should be noted that one shallow groundwater monitoring bore AN021F, has held insufficient water for sampling and no sampling has been able to be undertaken at this site. An adjacent bore AN020F, drilled and completed into the Rewan Formation, has been sampled since 13 May 2016 as the replacement.

Table 18 provides a summary of water quality results obtained from bores targeting the shallow aquifers (M339W, M225W, M340W, M230W, M250W, M224W, M222W and AN020F). 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 a high degree of variation which is likely to be attributable to the spatial heterogeneity of the hydrogeological system. Review of this data indicates that there are no notable trends. It should be noted that there is a separate groundwater monitoring program, required by the EA, to monitor potential impacts of CSG related infrastructure, which is outside the scope of this report.

In general, the salinity ranges[2] for the underlying units can be described as follows:

- 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

[2] Environmental Protection Agency (EPA) of South Australia

- groundwater quality of the weathered coal measures is saline
- groundwater quality of the Rewan Formation is saline

The groundwater quality monitoring results are shown in Appendix B.

Table 18: Water Quality – Shallow Monitoring Bores

Parameter	Units	Quaternary Alluvium		Tertiary Basalt		Tertiary Sediment		Weathered Coal Measures		Rewan Formation	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Field pH		5.73	7.48	6.28	8.49	5.42	7.76	5.92	8.16	6.2	7.58
Electrical Conductivity	µS/cm	4240	31600	5300	42769	2170	2650	9090	11400	9590	11200
Total Dissolved Solids	mg/L	2360	27000	3000	29000	1300	1620	5190	9600	6210	9070
Hydroxide Alkalinity (OH-) as CaCO3	mg/L	<1	<5	<1	<5	<1	<5	<1	<5	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	<1	<5	<1	94	<1	<5	<1	<5	<1	<1
Bicarbonate Alkalinity as CaCO3	mg/L	101	360	380	827	53	116	243	457	5	126
Total Alkalinity as CaCO3	mg/L	101	360	380	827	53	116	243	457	5	126
Sulphate	mg/L	541	6200	60	1140	54	106	78	177	<1	1
Chloride	mg/L	1020	14000	1490	17000	660	794	3140	4100	3750	4030
Calcium - Dissolved	mg/L	172	1000	55	297	12	20	290	448	51	460
Magnesium - Dissolved	mg/L	107	1400	85	792	38	52	340	513	169	203
Sodium - Dissolved	mg/L	543	6200	891	13000	344	510	932	1400	1450	2160
Potassium - Dissolved	mg/L	5	17	12	150	9	13	9	14	21	29
Aluminium - Dissolved	mg/L	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01	0.36	<0.01	<0.01
Arsenic-Dissolved	mg/L	<0.001	0.008	<0.001	0.003	<0.001	<0.01	<0.001	0.011	<0.001	<0.001
Beryllium-Dissolved	mg/L	<0.00001	0.193	<0.0005	<0.005	<0.0005	<0.001	<0.000001	<0.001	<0.001	<0.001
Barium-Dissolved	mg/L	0.045	0.2	0.05	0.283	0.047	0.11	0.184	3.9	3.42	5.34
Cadmium-Dissolved	mg/L	<0.0005	0.0002	<0.0001	0.0012	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium-Dissolved	mg/L	<0.001	0.015	<0.001	0.01	0.001	0.076	<0.001	0.002	<0.001	<0.001
Cobalt-Dissolved	mg/L	<0.001	0.027	<0.001	0.005	<0.0001	0.005	<0.001	0.035	<0.001	0.001
Copper-Dissolved	mg/L	<0.005	0.017	<0.001	0.07	<0.001	0.005	<0.001	0.036	<0.001	0.01
Lead-Dissolved	mg/L	<0.001	<0.01	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese-Dissolved	mg/L	0.313	8.1	<0.005	0.611	0.007	0.095	1.1	1.86	1.17	2.28

Parameter	Units	Quaternary Alluvium		Tertiary Basalt		Tertiary Sediment		Weathered Coal Measures		Rewan Formation	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Molybdenum	mg/L	<0.001	0.003	<0.001	0.008	<0.001	0.002	0.002	0.004	<0.001	0.01
Nickel-Dissolved	mg/L	<0.00005	0.17	0.005	0.361	0.006	0.088	<0.001	0.125	<0.001	0.01
Selenium	mg/L	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	3.19	14	1.52	8.98	0.686	0.725	6.67	8.96	11	11.3
Vanadium-Dissolved	mg/L	<0.001	0.002	<0.001	0.042	<0.001	<0.01	<0.001	<0.01	<0.01	<0.01
Zinc-Dissolved	mg/L	0.008	0.302	<0.005	2.27	<0.005	0.131	<0.005	0.719	<0.005	<0.005
Boron	mg/L	0.13	0.39	0.42	2.96	0.61	0.76	0.3	0.34	0.09	0.2
Iron	mg/L	0.2	10.1	<0.05	0.59	<0.05	0.43	0.05	21.1	1.68	14.3
Mercury-Dissolved	mg/L	<0.00005	<0.0001	0.00008	0.001	<0.00005	<0.0001	<0.0001	<0.00005	<0.0001	<0.0001
Fluoride, F	mg/L	0.2	0.9	0.09	2	0.13	0.6	0.4	1	<0.1	0.1
Phosphate as P in water	mg/L	0.007	0.79	0.026	12.6	0.01	1.3	0.11	2.09	<0.01	0.11

5.3.2 *Deep aquifer water quality*

Table 19 provides a summary of water quality results obtained from bores targeting the deep aquifers (M313W, M314W, M324W, M325W, AN019F, GR067V, M162V, M134GMV and MB1-D). 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. Overall, a review of this data indicates that there are no notable trends. In general, this data shows that:

- groundwater quality of the Fort Cooper Coal Measures aquifer is fresh to saline[3]
- groundwater quality of the Moranbah Coal Measures is fresh to saline

The water level in monitoring bore M162V dropped below the pump intake and sampling was unable to be undertaken at this site. A replacement sampling bore (M134GMV) located 480 m north that was completed to approximately the same depth intersecting the MCM seam was selected to be used in the interim until water levels recover within M162V. Sampling was conducted in M134GMV up to November 2020, however the water level had again dropped below the pump intake for the November 2021 sampling round. A replacement sampling bore (GM031V) located 1.4m south was selected to be used until water levels recover in M162V.

Table 19: Background Water Quality – Deep Monitoring Bores

Parameters	Units	Fort Cooper Coal Measures		Moranbah Coal Measures	
		Min	Max	Min	Max
Field pH		6.79	11.8	7.27	9.42
Electrical Conductivity	µS/cm	1170	15700	1710	16000
Total Dissolved Solids	mg/L	707	9910	1160	9810

[3] Environmental Protection Agency (EPA) of South Australia

Parameters	Units	Fort Cooper Coal Measures		Moranbah Coal Measures	
		Min	Max	Min	Max
Hydroxide Alkalinity (OH-) as CaCO3	mg/L	<1	456	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	<1	157	<1	456
Bicarbonate Alkalinity as CaCO3	mg/L	<1	1380	159	2380
Total Alkalinity as CaCO3	mg/L	159	1380	159	2420
Sulphate, SO4	mg/L	<1	68	<1	134
Chloride, Cl	mg/L	188	4920	198	5850
Calcium - Dissolved	mg/L	2	276	6	209
Magnesium - Dissolved	mg/L	<1	256	<1	62
Sodium - Dissolved	mg/L	199	2590	212	3490
Potassium - Dissolved	mg/L	12	73	9	1450
Aluminium - Dissolved		<0.01	<0.01	-	-
Arsenic-Dissolved	mg/L	<0.001	0.005	<0.001	0.013
Beryllium-Dissolved	mg/L	<0.001	<0.001	<0.001	<0.001
Barium-Dissolved	mg/L	0.005	12.2	0.236	23
Cadmium-Dissolved	mg/L	<0.001	<0.001	<0.001	0.001
Chromium-Dissolved	mg/L	<0.001	0.004	<0.001	0.018
Cobalt-Dissolved	mg/L	<0.001	0.004	<0.001	0.01
Copper-Dissolved	mg/L	<0.001	0.582	<0.001	7.08
Lead-Dissolved	mg/L	<0.001	0.459	<0.001	2.19
Manganese-Dissolved	mg/L	<0.001	0.304	0.008	0.446
Molybdenum	mg/L	0.006	0.114	0.001	0.089
Nickel-Dissolved	mg/L	<0.001	0.02	<0.001	0.036
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.639	8.18	1.18	10.8
Vanadium-Dissolved	mg/L	<0.01	<0.01	<0.01	0.02
Zinc-Dissolved	mg/L	<0.005	2.16	<0.005	0.568
Boron	mg/L	0.24	1.17	0.46	2.4
Iron	mg/L	<0.05	2.94	0.1	3
Mercury-Dissolved	mg/L	0.42	0.42	<0.0001	0.87
Fluoride, F	mg/L	0.2	4.5	0.4	2.6
Phosphate as P in water	mg/L	0.04	0.59	0.44	17.4

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 BGP Area and submitted to DES. The results of the assessments undertaken as part of these are presented in the following sections. The completed baseline assessments have been submitted to the Office of Groundwater Impact Assessment (OGIA).

5.4.1 *MGP Area*

A BAP was submitted for the MGP Area and approved by the DES on 3 July 2012. The baseline assessment process included undertaking field assessments, sourcing information from mining companies and undertaking desktop assessments. A total of 42 assessments including registered (39) and unregistered bores (3) have been undertaken which identified:

- 5 bores which could not be found (12%)
- 12 bores were abandoned and destroyed (29%)
- 13 bores were abandoned but still useable (29%)
- 12 bores have been verified to exist (29%)

All bores in the baseline assessments were classified in accordance with the status as defined in the groundwater database by DRDMW. The exception to this was where 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 in Figure 23. Based on this data, the majority of existing bores are located on PL223, which suggests that groundwater use is limited in the MGP area.

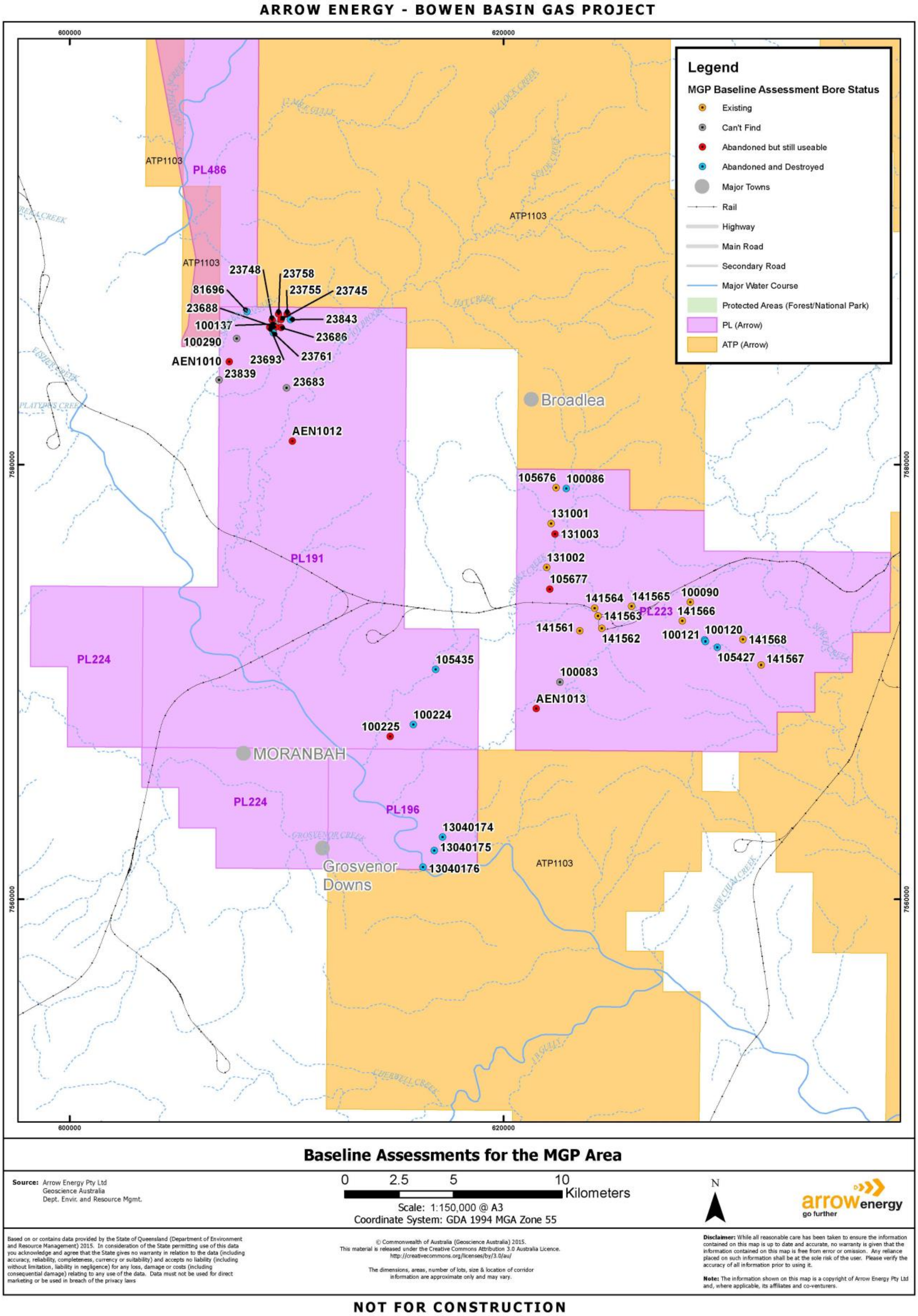


Figure 23: Completed Baseline Assessments for MGP

5.4.2 *ATP 1103*

A BAP was submitted for ATP1103 and approved on 12 November 2013. Based on the information presented in the DRDMW 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 133 assessments, including registered (76) and unregistered bores (57), have been undertaken on ATP1103. The results concluded that:

- 30 bores could not be found (23%)
- 6 bores are abandoned and destroyed (5%)
- 29 bores are abandoned but still useable (22%)
- 68 bores have been verified to exist (51%)

The locations of these bores are shown in Figure 24.

.

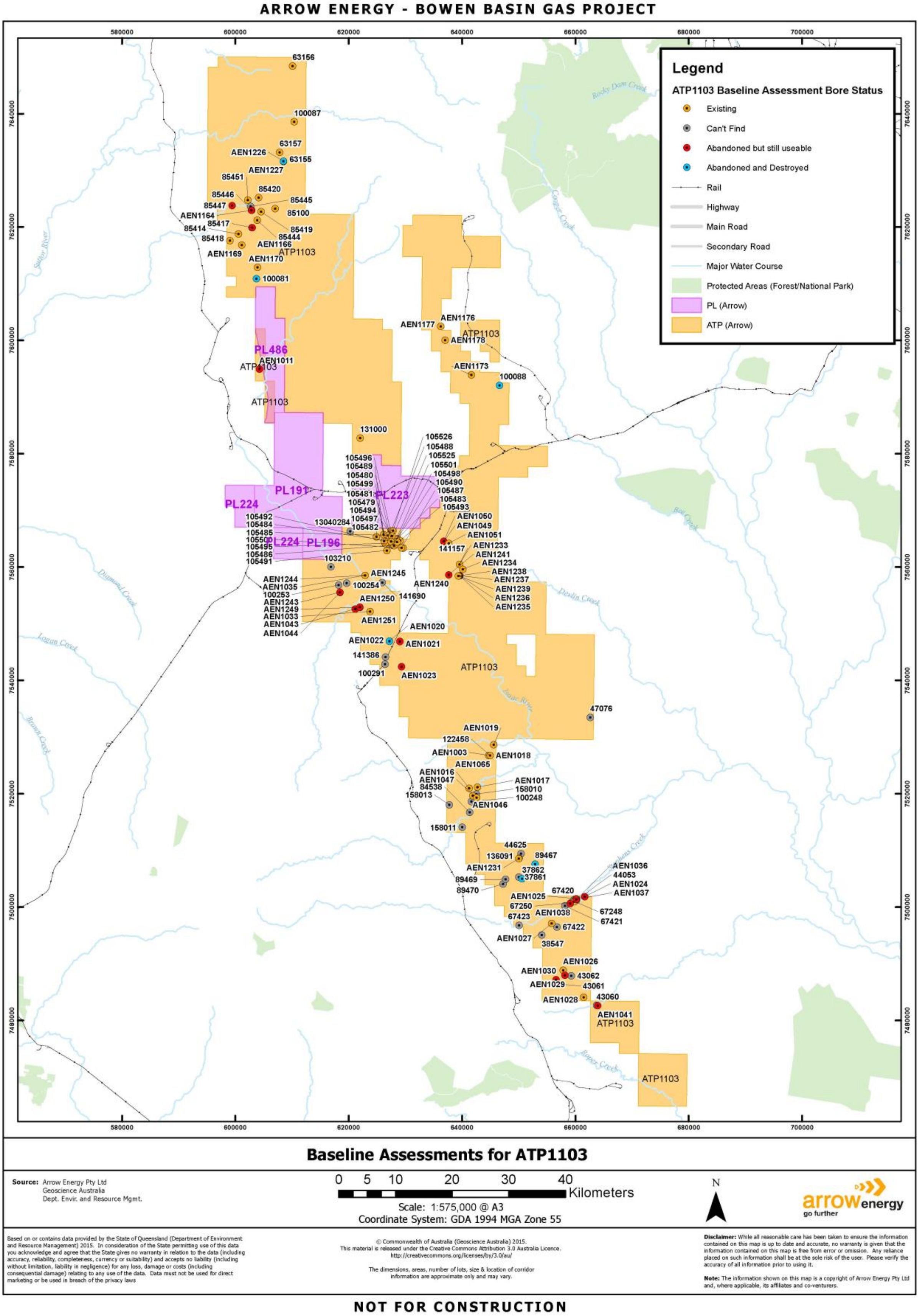


Figure 24: Completed Baseline Assessments for ATP 1103

5.4.3 *ATP 1031*

A BAP was submitted for ATP1031 and approved on 16 April 2013. Based on the information presented in the DRDMW 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, 49 assessments, including registered (39) and unregistered bores (10), have been undertaken on ATP1031. The results concluded that:

- 24 bores could not be found (49%)
- 5 bores are abandoned and destroyed (10%)
- 11 bores are abandoned but still useable (22%)
- 9 bores have been verified to exist (18%)

The locations of these bores are shown in Figure 25.

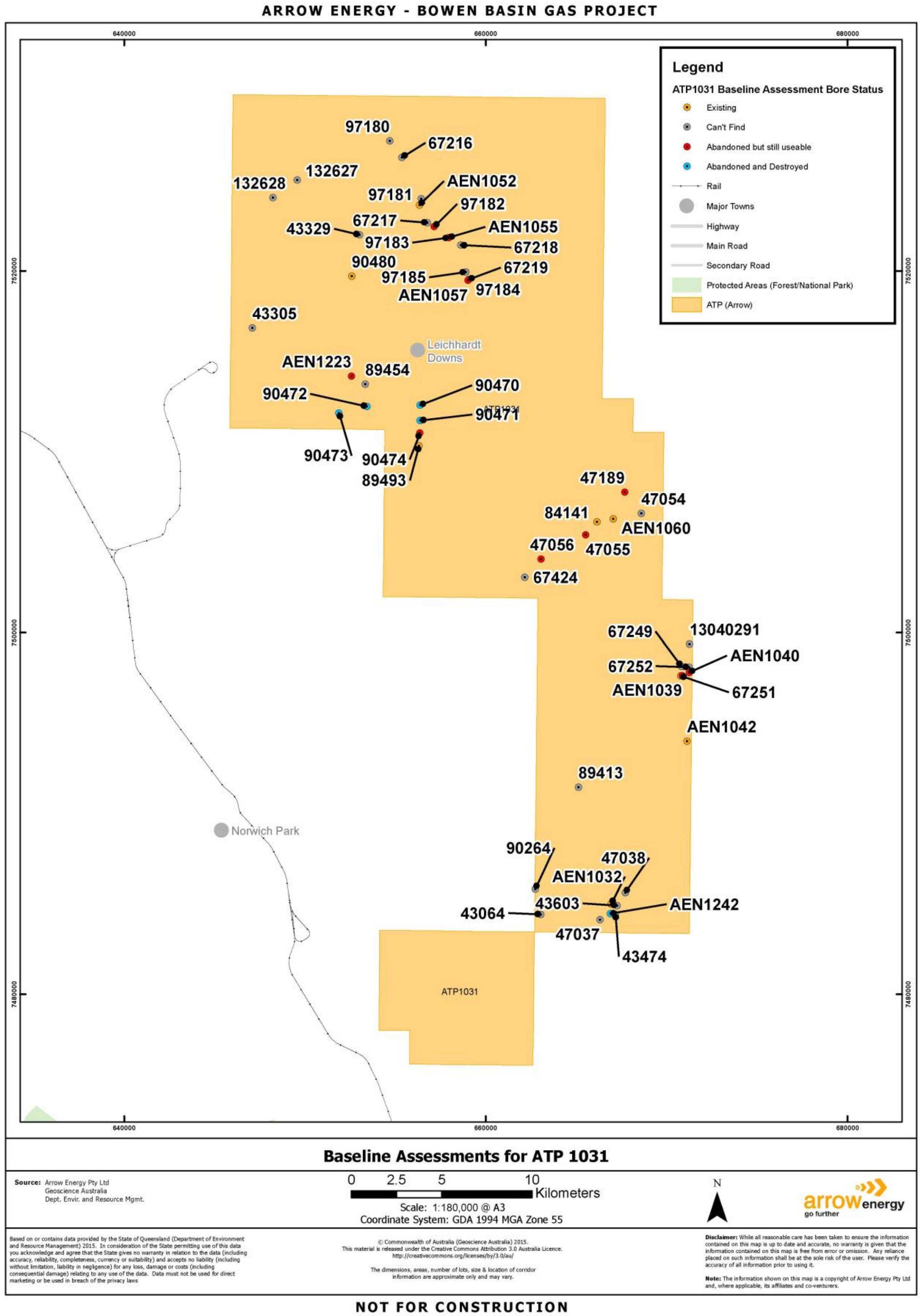


Figure 25: Completed Baseline Assessments for ATP 1031

5.4.4 *ATP 742*

A BAP was submitted for ATP742 and approved on 22 October 2015. Based on the information presented in the DRDMW 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 9 assessments have been undertaken on ATP742. The results concluded that:

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

The locations of these bores are shown in Figure 26.

5.4.5 *Future Baseline Assessments*

Ongoing assessments will be carried out as outlined in the baseline assessment plans for each tenure.

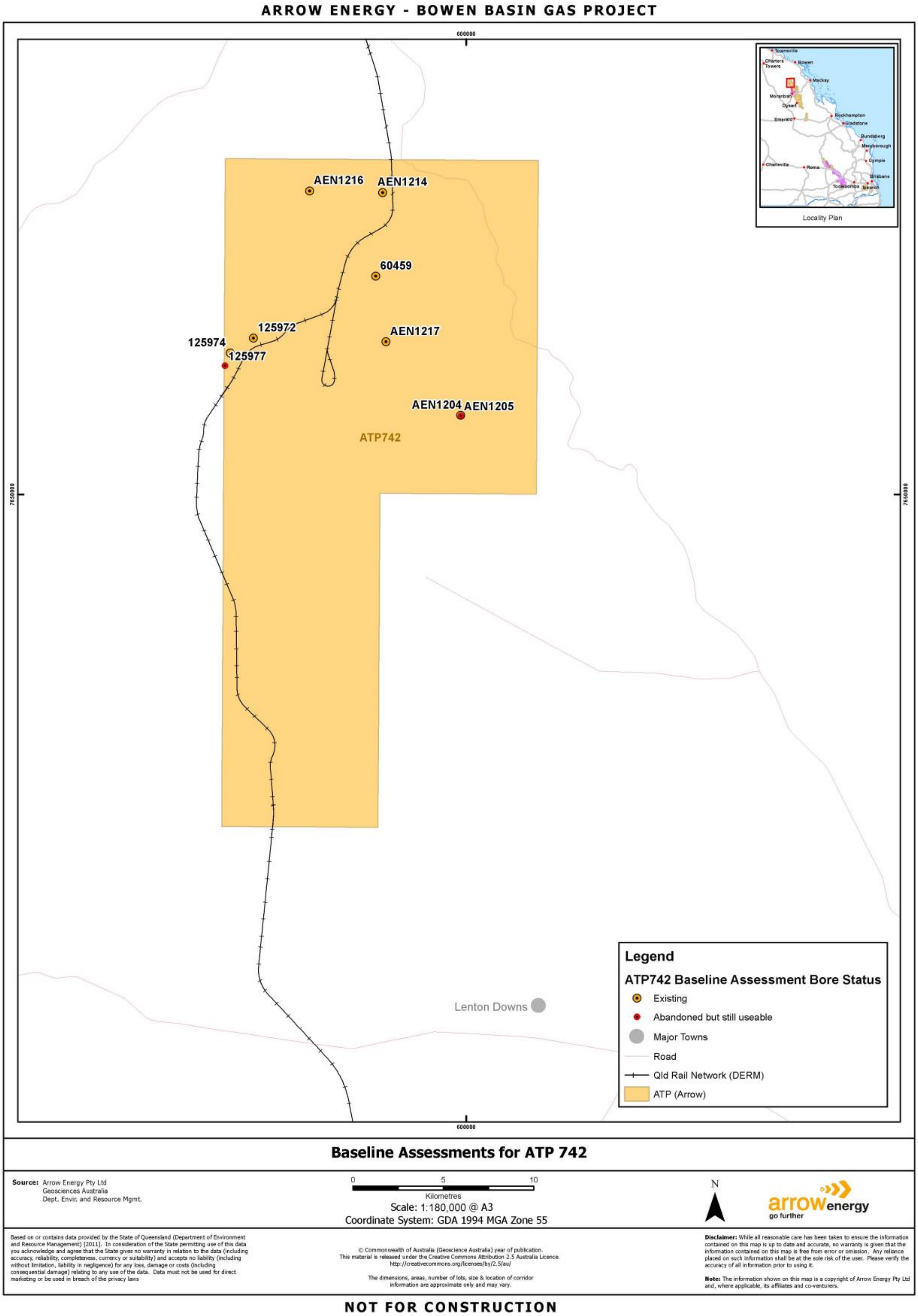


Figure 26: Completed Baseline Assessments for ATP 742

6 UPDATED CONCEPTUAL HYDROGEOLOGICAL MODEL

A conceptual hydrogeological model was developed as part of the EIS and SREIS and was updated as part of the 2016 UWIR 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.

6.1 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 20: Data Comparison

Existing Conceptual Model	Change since previous UWIR and supporting data
Shallow aquifers are recharged mainly through direct infiltration of rainfall, overland flow and surface water flow. The extent of recharge to water table aquifers from rainfall, overland flow and surface water are site and location specific.	No change
Shallow aquifers are hydraulically connected to surface water systems. The assumption has been made that water table aquifers in some locations are in connection with rivers/streams (generally losing stream).	No change
Rewan Formation is considered to be a regional-scale confining unit (aquitard). The coal seams are further confined by low permeability overburden and interburden. The pressure data presents evidence of limited interconnectivity between deep aquifers. Depressurisation impacts notable within the coal measures in monitoring bores located within 350m 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.	No change
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.	No change
Groundwater quality of the Quaternary Alluvium aquifer is highly variable ranging from brackish to saline.	No Change
Groundwater quality of the Tertiary Basalt aquifer is variable ranging from brackish to saline.	No change

Existing Conceptual Model	Change since previous UWIR and supporting data
Groundwater quality of the Tertiary sediment aquifer is considered fresh to brackish.	No change.
Groundwater quality of the Permian aquifers is considered to range from fresh to brackish.	Groundwater quality of the Permian aquifers is considered to range from fresh to saline.

6.2 Groundwater Users

Baseline assessments have been undertaken by Arrow as discussed in Section 4.1.6. This data provides information on groundwater users within the Project Area and suggests that groundwater use is limited in the MGP and BGP area.

6.3 Conclusion

Groundwater monitoring data obtained to date was focussed around the MGP Area, with increasing data from the BGP monitoring network. Whilst the above monitoring 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 2018 groundwater model assessed the regional scale groundwater impacts of Arrows MGP Area and BGP area. This model has been updated and re-calibrated to take into consideration the available new data. There are no other material changes to the hydrogeological understanding of the Project Area since the development of the previous UWIR.

7 UWIR NUMERICAL GROUNDWATER MODEL UPDATE

Arrow Energy Pty Ltd (Arrow) undertook to update the existing numerical groundwater model prepared by consultants Australian Groundwater & Environment (AGE) related to the Arrow Moranbah and Bowen Gas Expansion Project (MGP and BGP) for use with the Bowen Underground Water Impact Report (UWIR) and the Bowen Groundwater Management and Monitoring Plan (GMMP).

The Moranbah Gas Project has been producing gas for the domestic market since 2004, operated by Arrow and part owned by AGL. In 2012, Arrow submitted an Environmental Impact Statement to develop the Bowen Gas Project, followed by a Supplementary Report to the EIS in 2014. Arrow submitted the UWIR (Arrow Energy, 2016), outlining potential immediate and long-term groundwater impacts to groundwater levels due to CSG production.

7.1 Model Development

The original Northern Bowen Basin numerical groundwater model was developed by Ausenco Norwest for Arrow Energy in 2012 to predict and delineate areas where predicted groundwater level drawdowns exceed the Queensland Department of Environmental and Heritage Protection (DEHP) threshold criteria. The model was built in MODFLOW-SURFACTTM using the Groundwater Vistas 6 software package. A uniform mesh of 1500 m x 1500 m cells was simulated over 18 model layers (Norwest, 2012).

AGE (2018) updated the Ausenco Norwest model in 2017 by remeshing the model to increase the resolution of the mesh around the MGP area, to better delineate groundwater structures, and to increase the layer resolution within the Moranbah Coal Measures (MCM), increasing the total count to 22 layers. Pilot point multipliers were added to the aquifer/aquitard hydraulic and storage parameter fields and the model was calibrated to groundwater head data from January 2014 to November 2017. Updated measured and predicted production data from Arrow Energy was provided on a monthly basis, per production bore and used to revise the MODFLOW well input package (AGE, 2017).

A further refinement (AGE 2020) was undertaken in 2020 to refine the mesh in the Red Hill area, and refine the stress periods. The following cell dimensions were adopted for the Red Hill production area:

- 150 m cells within the Red Hill Production area, and
- 150 m cells centred at the location of each monitoring well.

The stress period setup refinement for the sector model was as follows:

- 31 December 2003- steady state stress period, pre-mining initial conditions.
- January 2004 to May 2030 – 318 monthly stress periods.

Stress periods after this time remained the same as the prior model iteration. Details of these refinements are provided in Appendix C.

This groundwater model describes a new simulation with the model using an amended field development plan for the MGP and BGP.

7.1.1 *Model Structure*

The model domain is approximately 157 km wide (west to east direction) and 395 km long (north to south direction) as shown in Figure 27.

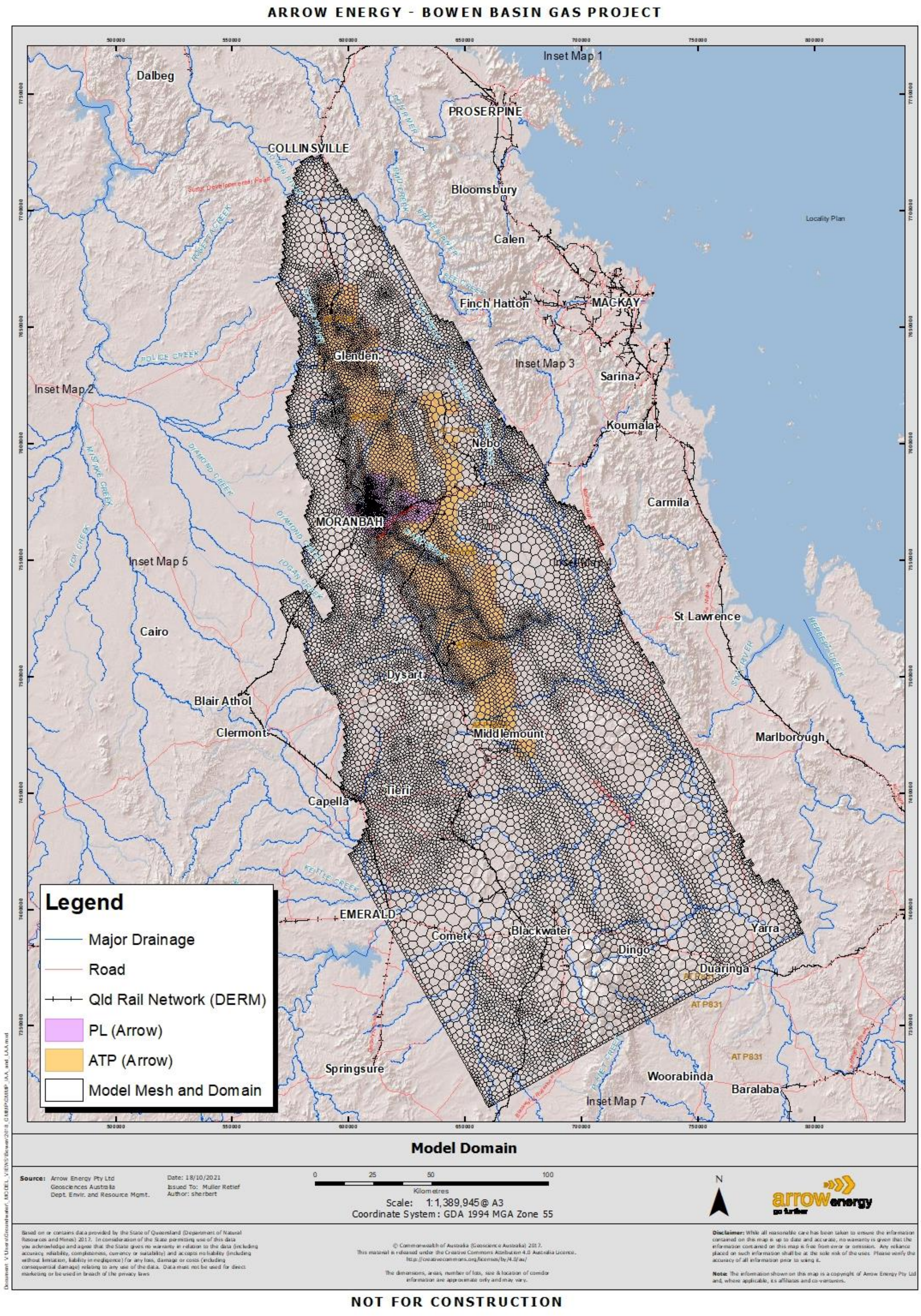


Figure 27: Model Domain

The model domain was discretised and arranged into 22 layers comprising up to 18,082 cell nodes in each layer with the dimensions of the cells varying according to the features that required representation. The following cell dimensions were adopted:

- MGP area: ~200 x 200 m hexagonal cells aligned to in seam wells;
- BGP area: ~1500 x 1500 Voronoi/rectangle cells centred on downhole CSG production wells;
- faults: ~1000 x 1000 centred on either side of fault trace;
- surficial aquifer systems (e.g. basalt): ~1000 x 1000m centred either side of aquifer extents; and
- major drainage systems: ~500 x 500m centred along river lines proximal to the MGP.

Overall, the model comprised 188,516 cells across the 22 layers. Groundwater layer types were prescribed as convertible layers, with unsaturated flow represented using the 'upstream weighting' function. Model layer elevations were based on a regional geological model

Table 21: Model Layers

Model Layer	Formation/Group	Unit
1	Quaternary Alluvium, weathered materials	Surficial Coverage
2	Tertiary sediments (Duringa), Basalts (Anakie) & Moolayember	Tertiary, Triassic
3	Clematis Sandstone	Triassic
4	Rewan/Rangal Coal Measures	Triassic
5		Leichardt seam
6	Rangal Coal Measures (RCM)	Interburden
7		Vermont seam
8		FCCM
9	Fort Cooper Coal Measures (FCCM)	FCCM
10		FCCM
11		Q Seam
12		Interburden
13		P seam
14		Interburden
15		GM seam
16	Moranbah Coal Measures (MCM)	Interburden
17		GML seam
18		Interburden
19		DYU seam
20		Interburden
21		DYR seam
22	Collinsville, Back Creek Group	Permian basement

Boundary conditions included Recharge (RCH), Evapotranspiration (EVT), General Head Boundary (GHB), River (RIV), and Basic (BAS) packages.

7.1.2 *Specific Storage*

Since 2017, several papers have been released highlighting likely physical upper and lower bounds relating to specific storage. Specific storage represents the volume of water a portion of an aquifer (or aquitard) releases from storage, per unit change in hydraulic head, under fully saturated conditions. It is also known as 'elastic storage' as water can only be released from the decompression of the water, or compression of the aquifer.

To determine the magnitude and range for elastic storage, it is necessary to first understand the compressibility of water, the compressibility of the aquifer matrix which contains the groundwater and the compressibility of the individual aquifer grains themselves.

Pells (2017) presented the following equation for specific storage based on poroelastic theory as part of a review of a proposed underground coal mine in NSW: $S_s = \rho_w g[(1+v)(1-2v)K(1-v) + \theta\beta_w]$.

Where ρ_w is the density of water, g is the gravitational constant, β_w is water compressibility, *v* is Poisson's ratio, *K* is the bulk modulus, β_w is water compressibility, and θ is total porosity.

Rau et al (2018) described their work calculating uniaxial specific storage from undrained poroelastic properties, namely bulk modus, loading efficiency and the *Biot-Willis* coefficient. Specific storage was then derived using Loading efficiency (LE), derived from Barometric efficiency, the confined bulk modulus (K_{vu}) and the Biot-Willis coefficient (α), as: $S_s = \rho_w g \alpha K_{vu} LE(1-\alpha LE)$.

Rau tested the methodology using field datasets collected at two sites with sand and clay dominated lithologies. Rau undertook a theoretical analysis using the equation outlined above to derive the physical limits of 2.3 x 10^{-7} m^{-1} and 1.3 x 10^{-5} m^{-1}.

Although the theoretically derived bounds presented in Rau (2018) use different combinations of elastic moduli to the Pells (2017) equation, and the relationships between the parameters possess inherent uncertainty at their upper and lower bounds, the results are consistent with the Pells (2017) relationship.

Assessment of specific storage in the model was undertaken (AGE 2020) and suggests that on average a lower specific storage maybe more appropriate. The use of a lower storage value leads to some increases in the area of impact, however, a lower storage also leads to faster recoveries of pressures post production.

7.2 Calibration

The updated groundwater model was calibrated with a pre-development steady state run and a transient run (2000–2017) using available groundwater level records and documented production rates.

The steady state and transient model simulated water levels in all available monitoring bores within the hydrostratigraphic units. A total of 529 monitoring points were used to calibrate the model, comprising:

- 47 Arrow Energy transient monitoring locations; and
- 482 government and landholder monitoring locations (steady state).

Figure 28 presents the observation bores that were used in the calibration.

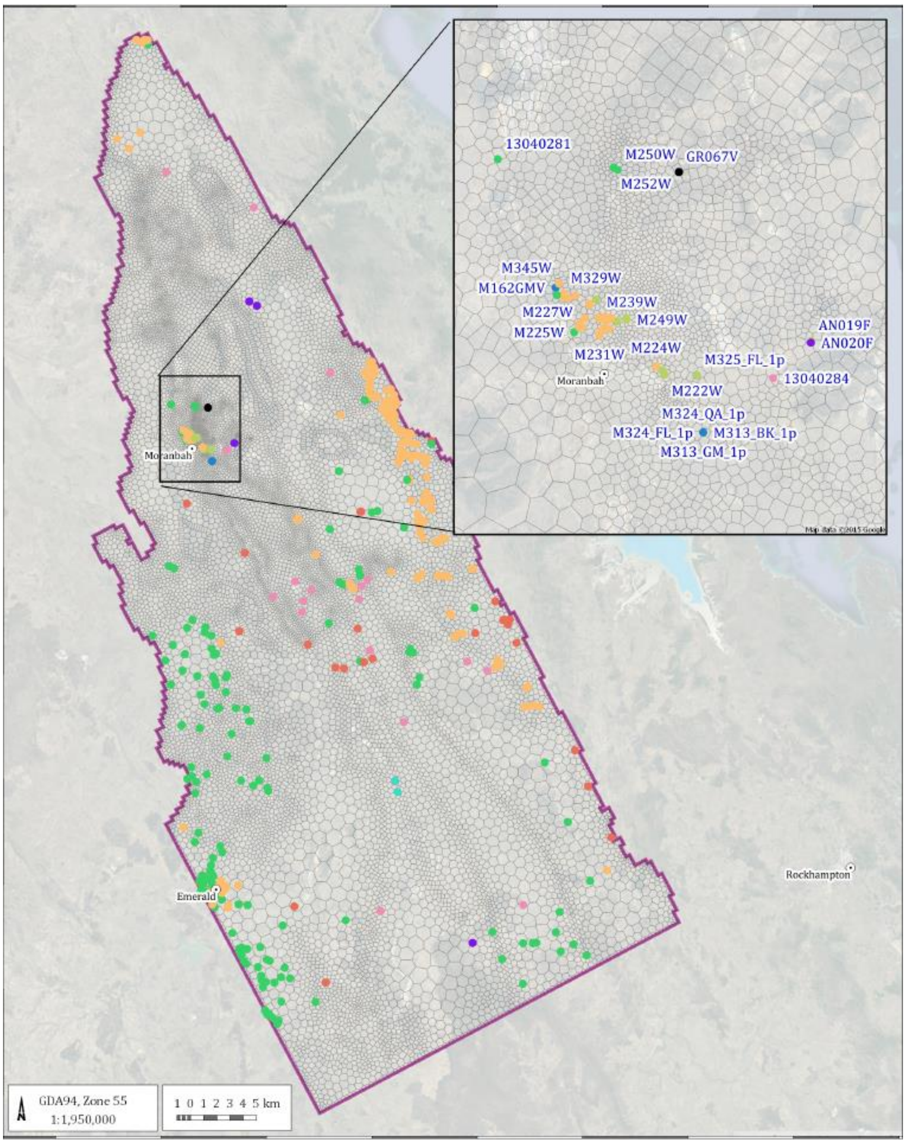


Figure 28: Observation Locations

Throughout the observation dataset the frequency of observations vary between bores, hence the number of available records for each bore varies. To overcome this, the observation data was weighted to normalise the error on a bore by bore basis. Weighting to each bore was applied by using the following equation:

$$weight\ per\ observation\ record = 1\ \sqrt{n}$$

n = number of observation records at a monitoring location.

A number of bores are likely to be impacted by longwall, board and pillar and open cut mining in the region. Where possible, the weighting of these observations was reduced as to not significantly impact the integrity of the calibration and uncertainty analysis.

Three bores M162GMV, GR067 and M325 were not included in the calibration statistics since these bores appear to show local drawdown due to sampling, and/or erroneous measurements.

The root mean square (RMS) error calculated for the calibrated model was 5.8 m. The total measured head change across the model domain was 377.7 m, with a standardised unweighted RMS (SRMS) of 1.54%, indicating a good match for the type of system being modelled.

7.2.1 *Water Budget*

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0%. The maximum percent discrepancy at any time step in the simulation was also 0%. This value indicates that the model is stable and achieves an accurate numerical solution.

7.3 Field Development Plan

Arrow Energy has historical and future Field Development Plans (FDP) for the MGP and a FDP for PL486, and the rest of the BGP. Well locations are shown in Figure 29.

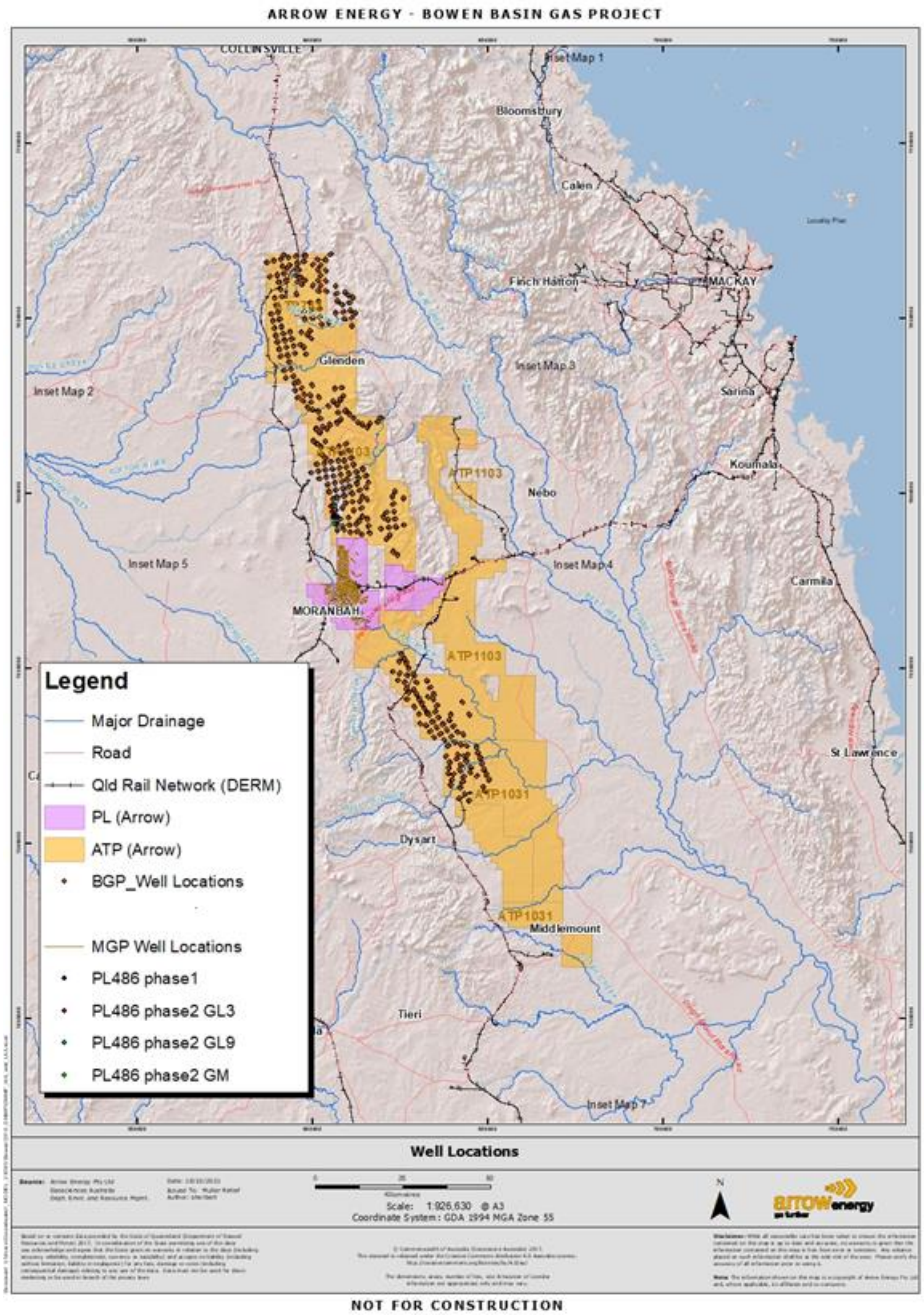


Figure 29: Field Development Well Locations

The FDP scenario was run against a base case without CSG production to assess the impact due to Arrow Energy CSG production.

The Bowen regional model does not contain the impacts to coal mining on groundwater.

The water production for the development scenario is summarised in Figure 30.

The MGP has reducing water production rates whilst the large volume of water production is predicted for post 2030 after start of the larger Bowen field development.

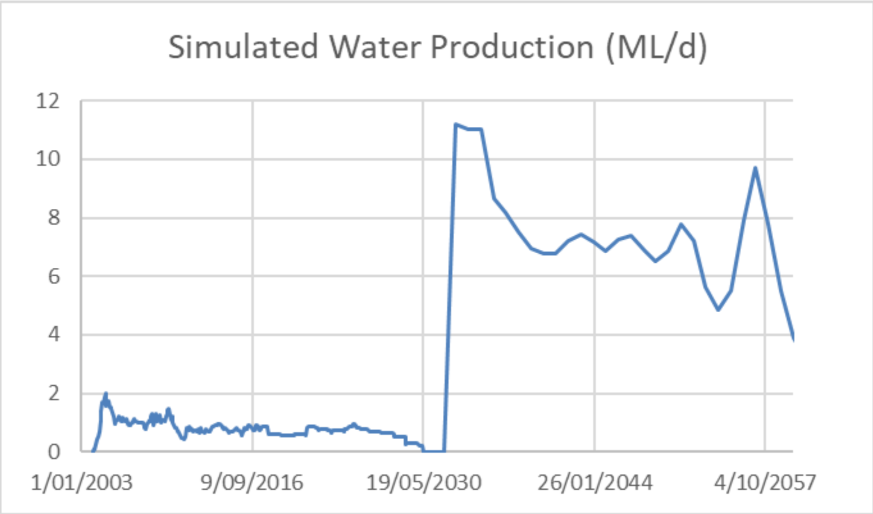


Figure 30: Field Development Well Locations

7.4 Predictions of Impacts

The cumulative and incremental drawdowns are presented for a scenario with MGP production until 2025 and ongoing BGP production until 2060.

Model predictions indicate that drawdown greater than trigger thresholds will be restricted to the MCM and RCM.

The method to derive cumulative drawdowns for the UWIR scenario are described below:

- for each scenario the cumulative drawdowns are calculated by subtracting the heads from the scenario with no CSG production' (NC scenario) from the heads in a scenario with CSG production.
- all drawdowns represent maximum drawdowns queried across the entire simulation period and recorded for each cell, drawdowns therefore represent a composite result from the entire simulation.

The extent of maximum drawdown for the Moranbah (MCM) and Rangal Coal Measures (RCM) has been presented as a composite of the cumulative drawdown from each coal seam in the coal measure to present the area of maximum drawdown across all coal seam layers within that coal measure. This provides a conservative overestimate of the extent of impact and this mirrors the method used by OGIA to derive LAAs in the coal measures in the Surat CMA.

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

7.4.1 *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 (January 2022). The trigger thresholds are specified in the *Water Act (Qld) 2000* and are 5 m for consolidated aquifers (such as sandstone) and 2 m for unconsolidated aquifers (such as sands). Table 22 shows the layers with an IAA exceeding the trigger threshold.

Table 22: IAA Exceeding the trigger threshold

Unit	IAA trigger threshold exceeded
Moranbah Coal Measures	Yes
Rangal Coal Measures	Yes

Drawdown less than the bore trigger threshold was identified in layers 1 and 2.

Figure 31 shows the IAA for the consolidated aquifers and the impacts associated with the MGP Area are restricted to the MCM. With the exception of GR067V in the north and AN019F and AN020F to the east, all the UWIR monitoring bores are within the IAA area footprint of the MCM. No existing landholder bores completed into the MCM and RCM aquifer are within the IAA area.

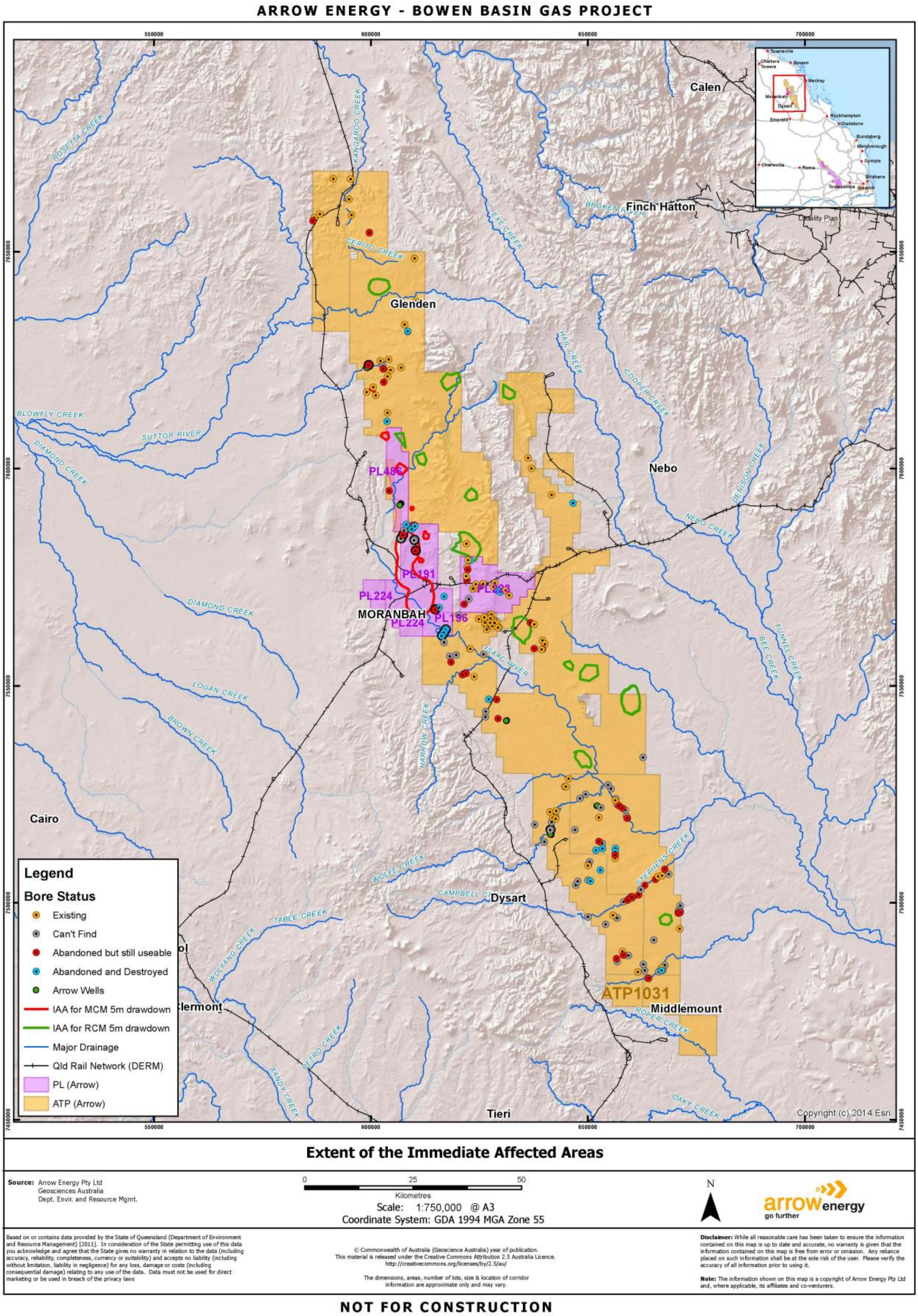


Figure 31 : Extent of the Immediately Affected Areas

7.4.2 *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 (Qld) 2000*. They are 5 m for consolidated aquifers (such as sandstone) and 2 m for unconsolidated aquifers (such as sands). The timeframe within which the LAA has been determined is up until 2181.

Figure 32 presents the extent of the LAA for the MCM and the RCM. The LAA for the MCM shows a very similar footprint to the IAA for the MCM overlying the MGP Area. The LAA for the MCM also extends 103km north and up to 67km south based on the BGP.

The footprints of the LAA for the RCM do not fall within the MGP area but are located to the direct north and further south within the BGP. The RCM footprints are generally located more to the east of the MCM footprint due to RCM located above the MCM and the formation dips is to the east as indicated in the figure and covers a significantly smaller area than the MCM.

Future production testing volumes cannot be provided given that they are undertaken for exploration and appraisal purposes. Based on available data, the impacts predicted for the IAA is the same as the LAA for production testing wells as depicted in Figure 31 above.

The methodology for developing forecast water production data for the MGP is based on a Decline Curve Analysis (DCA) discussed in Section 2.2, and the accuracy of the prediction is subject to uncertainties in the measurement and reporting of the historical water rates.

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 MCM in comparison to the RCM. This is associated with proposed production from the MCM in the BGP as well as the MGP.
- 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 and Rangal coal measures
- there is no predicted LAA in any other consolidated aquifers.

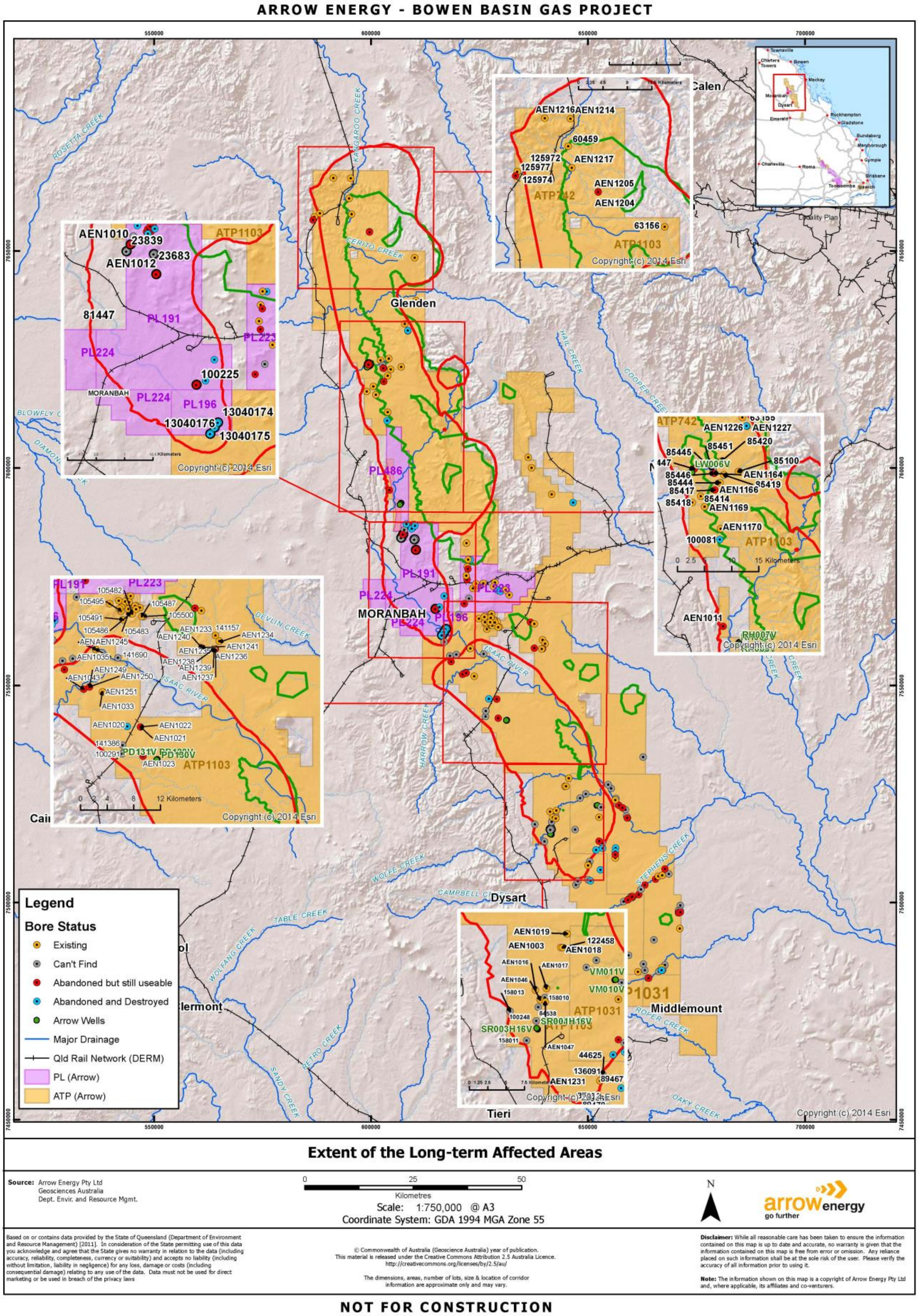


Figure 32 : Extent of the Long-term Affected Areas

8 ENVIRONMENTAL VALUES

This section identifies and describes the groundwater related environmental values in the Bowen Basin based upon studies undertaken for the Bowen Gas Project EIS/SREIS and the Bowen Gas Project CSG Groundwater Management and Monitoring Plan (GMMP). It then assesses the potential for impact to those environmental values to have occurred or to occur.

8.1 Requirements

In central Queensland groundwater is used for a variety of uses and can potentially support groundwater dependent ecosystems and have cultural value. The enhancement of these values and the protection of groundwater are required in the EPP (water). The EPP (water) provides a framework for identifying the environmental values. For the purposes of this assessment the 'values' as defined in the EPP (water) are those groundwater systems within the potential impact area that are sufficiently important to be protected or enhanced.

This section therefore addresses the following legislative requirements under the Water Act 2000:

da) a description of the impacts on environmental values that have occurred, or are likely to occur, because of any previous exercise of underground water rights;

db) an assessment of the likely impacts on environmental values that will occur, or are likely to occur, because of the exercise of underground water rights

i. during the period mentioned in paragraph (a)(ii); and
ii. over the projected life of the resource tenure;

8.2 Environmental Values in the area

In the EIS/SREIS process the groundwater related environmental values that were assessed included:

- Biological integrity of aquatic ecosystems;
- Suitability for recreational use (primary recreation);
- Suitability for minimal treatment before supply as drinking water;
- Suitability for use in primary industries; and
- Cultural and spiritual values.

8.2.1 *Aquatic Ecosystems*

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

- 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
- 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 are considered to be spring vents, spring complexes 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. DES 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).

Based on this data, the springs (Palustrine springs) identified proximal the Project Area are found to the west and south-west and are located greater than a 100 km south of ATP 1103. Predicted impacts to the identified Palustrine 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 and located outside the BGP project area:

- upper reaches of the Connors River, Funnel Creek, Denison Creek and Lotus Creek approximate 40km east of the BGP;
- mid reaches of the Connors River and Funnel Creek, approximately 45km east of the BGP; and
- lower reaches of the Isaac River approximately 37km from the BGP

The locations of these watercourse springs, and where the water level is predicted to decline in 0.2m in the shallow and deep aquifer (based on 2021 model), are shown in Figure 33. As indicated on the map, the maximum 0.2 m drawdowns for the shallow aquifers are isolated occurrences with limited spatial extent. In addition to this, in some instances 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.

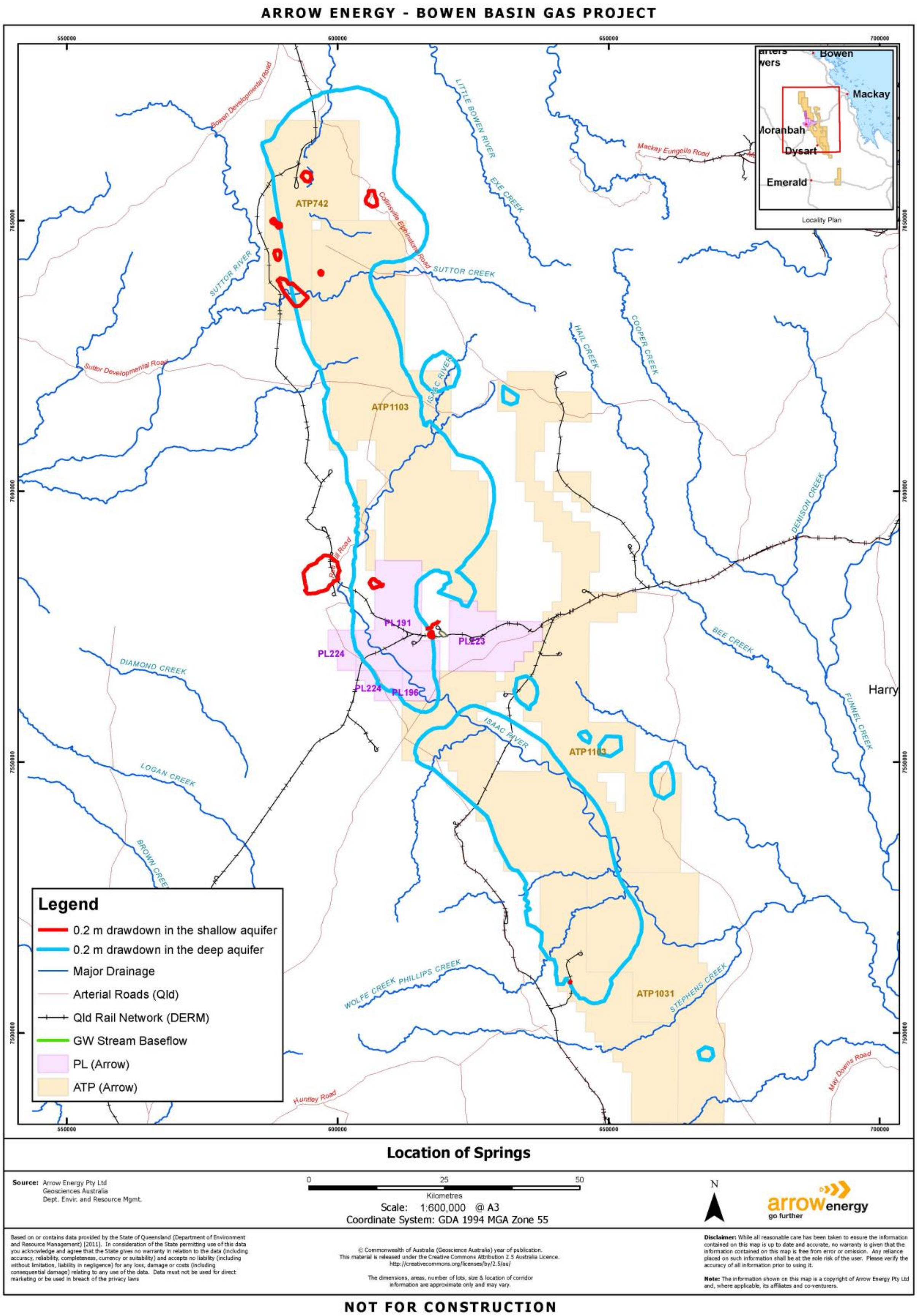


Figure 33: Springs and Drawdown in Shallow and Deep Aquifer

The identification of landscapes that may contain groundwater dependent ecosystems (GDEs) is documented in detail in the BGP EIS/SREIS and included known and potential GDEs as mapped in the Atlas of Groundwater Dependent Ecosystems (GDE Atlas).

The types of GDEs that have been considered include:

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

A site inspection was carried out end 2015 to visually inspect the areas identified in the GDE Atlas and to further refine these locations, a site visit was conducted in November 2015 to inspect locations identified as having the potential to support GDEs. Following the site visit, a detailed analysis of the potential for GDEs to be present across the project area was completed and findings summarised below:

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

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

The current field development plan (FDP) and the 2021 groundwater model assessment did not identify any potential spring GDEs or non-spring GDEs at risk of impact from the proposed FDP. The predicted 0.2m watertable drawdown contour in shallow aquifers does not intersect any locations identified as potential sites.

Lake Elphinstone is categorised as a Matter of National Environment Significance (MNES) wetland and located immediately outside Arrow tenure and described as having a high potential for interaction with the surface expression of groundwater. The predicted 0.2m watertable drawdown contour in the shallow aquifers does not intersect the area.

If required, the monitoring network described herein can be adapted and applied to spring and non-spring GDEs should such features be identified, or if monitoring indicates a potential for the field verified riparian vegetation to be affected by groundwater drawdown in connected underlying aquifers, at any stage in the future, as additional information becomes available, or changes to the FDP are proposed. As indicated no drawdown in excess of 0.2m in proximity to spring vents, spring complexes or watercourse springs, springs GDEs or non-spring GDEs, have been identified to exist in the area. A Spring Impact Management Strategy will not be prepared as part of this UWIR.

8.2.2 *Recreational Use*

The category of suitability for recreational use is not applicable to in-situ groundwater. As noted above there are also no registered groundwater springs in the area. Groundwater seepage from the alluvium into water courses can provide short duration baseflow into rivers and creeks immediately after heavy rains of flooding, however, after large flood events suitability of these water for recreation will be limited by other factors.

8.2.3 *Drinking water*

Fresh groundwater occurs in discrete locations with limited extent within the Bowen Basin associated with basalts, alluvial deposits and water courses, specifically the alluvium of Cooper Creek, Denison Creek, Funnel Creek and Connors River. Such water is accessed by groundwater bores. In addition, the Braeside borefield supplies water to coal mines, the Coppabella township and a number of rural properties. Such water is accessed by groundwater bores.

The remaining aquifer areas are generally too saline and/or sodic for use as drinking water with minimal treatment.

8.2.4 *Primary Industry*

Water bores may be used for agricultural uses such as stock watering where water quality permits. In the Bowen Basin water quality suitable for stock watering is generally found in basalts and alluvial systems. Other shallow groundwater is too saline for most agricultural uses, whilst in deep aquifers such as the coal measures the groundwater is saline and has limited uses. Areas of alluvium and basalts in the Bowen Basin therefore represent the primary areas with potential for this environmental value.

8.2.5 *Cultural and Spiritual Value*

Based upon the Bowen Gas Project EIS/SREIS studies there are no registered groundwater springs or seeps that supply surface water bodies in the Project area. Cultural heritage studies were carried out during the EIS and identified four significant sites with potential association with groundwater based on their description as 'wells'. Three of these sites are located with the project area (Figure 34).

From the above discussion it is concluded the environmental values with potential to exist in the Bowen Basin UWIR area include:

- Biological integrity of aquatic ecosystems in or dependent upon alluvial aquifers;
- Drinking water with minimal treatment in alluvial aquifers or basalts
- Agricultural uses such as stock watering; and
- Cultural and Spiritual Value

The potential for activity reported in the Bowen Basin UWIR to have impacted or to impact these environmental values in the future is discussed below.

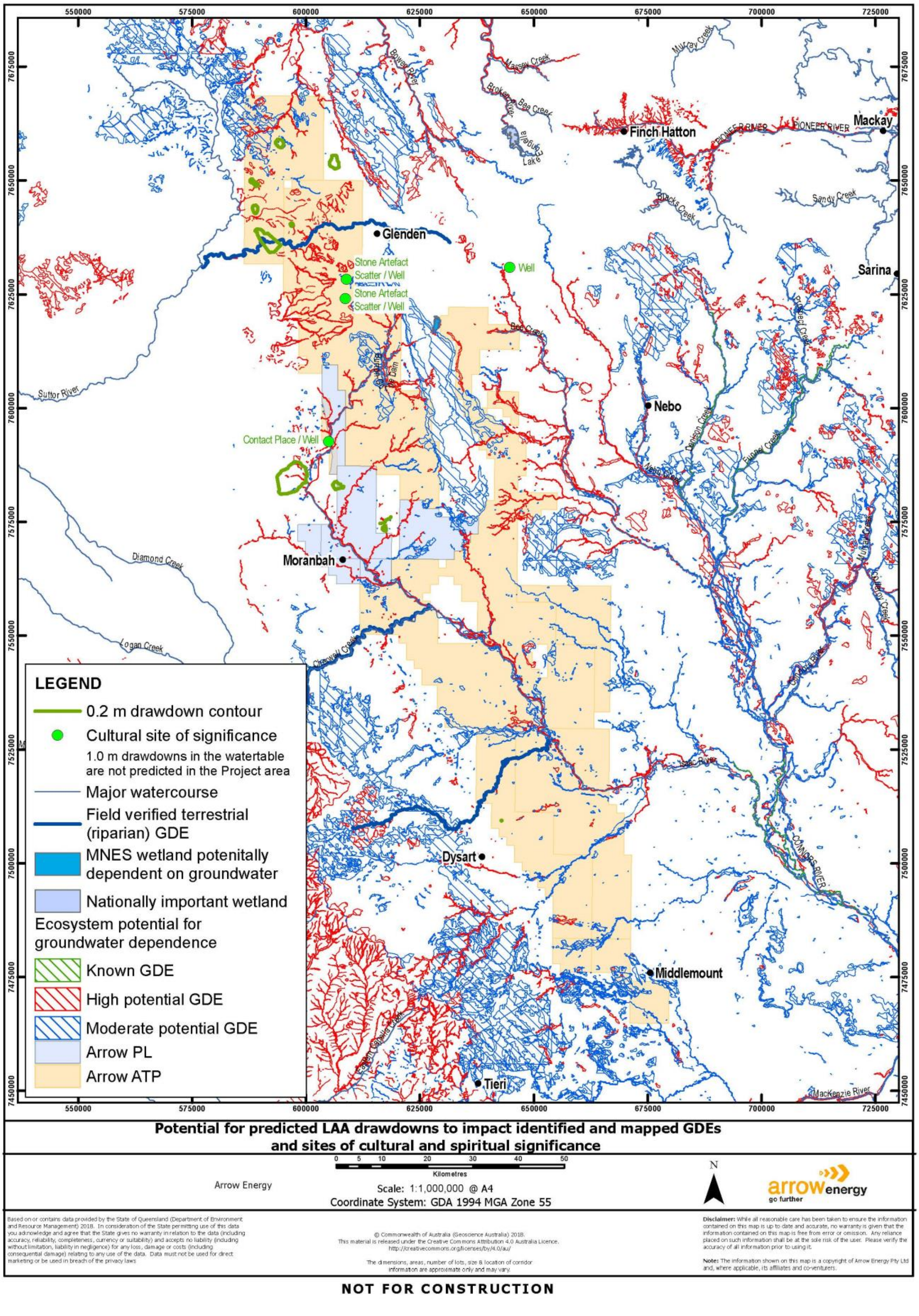


Figure 34: GDE and sites of cultural and spiritual significance

8.3 Potential Impacts to Environmental Values

The potential for impacts to environmental values to have occurred or to occur are discussed below.

8.3.1 *Aquatic Ecosystems*

No springs are recorded in the project area.

Aquatic ecosystems occur around alluvial aquifers along water courses. Predictions of impacts to the shallow alluvials indicate that no impacts of 1m occur in the watertable aquifers. Impacts of up to 0.2 m occur in the long term and not the short term. Long term impacts shown in Figure 33 below indicate that areas of 0.2m drawdown overlap watercourses and potential associated alluvial areas adjacent to the Isaac River 18 Km north of Moranbah. However, this overlaps an open pit coal mine footprint and the potential for propagation of CSG impacts to impact these already modified systems is considered to be low.

Similarly predicted impacts of up to 0.2m North West of Glenden and west of Glenden occur on the footprint to open cut coal mines adjacent to Cerito Creek and the Suttor River. The potential for propagation of CSG impacts to impact these already modified systems is considered to be low.

Where predicted impacts to shallow alluvials coincide with coal mining operations the potential for subsidence effects from proposed CSG activity to impact these environmental values is low. Potential subsidence impacts are described further in Section 8.4.

No impacts to terrestrial GDEs in excess of the trigger threshold of 1m are predicted in the water table aquifer.

Based on the information above there is negligible to minimal risk for potential CSG impacts to have occurred or to occur to these environmental values.

8.3.2 *Drinking water*

As described above the areas with potential environmental value as drinking water include alluvium of Cooper Creek, Denison Creek, Funnel Creek and Connors River and the alluvial sediments used by the Braeside borefield. Modelling indicates impacts to shallow alluvials are only predicted to occur a long time in the future. Figure 29 of the UWIR shows that areas of predicted drawdown that occur in these shallow alluvials in the long term do not coincide with the Braeside borefield, Cooper Creek, Denison Creek, Funnel Creek or the Connors River.

As such there is negligible to minimal risk for potential impacts to have occurred or to occur to this environmental value.

8.3.3 *Primary Industry*

Areas of alluvium and basalts in the Bowen Basin represent areas with potential for this environmental value. Figure 31 and Figure 32 of the UWIR show the extent of predicted impacts in the short term and long term.

Where these bores source water for primary industry and are predicted to be impacted by the project, baseline assessments are undertaken to assess if those bores abstract groundwater from the zones with predicted impacts. Where these bores are found to be in the immediately affected area Arrow Energy will comply with the make good obligations.

8.3.4 *Cultural and Spiritual Value*

Cultural heritage carried out during the EIS identified three significant sites with potential association with groundwater based on their description as 'wells' located with the project area (Figure 34). Comparison of these locations with potential areas of drawdown in the water table aquifer shows these sites are not predicted to be impacted by drawdown.

As such there is negligible to minimal risk for potential impacts to have occurred or to occur to this environmental value.

8.4 Subsidence

The potential for subsidence due to CSG that could occur in areas of significant depressurisation are discussed below based upon studies from the Bowen Gas Project EIS and SREIS.

Based on the literature assessment it was considered that the risk of land subsidence was negligible, but nevertheless could not be entirely ruled out, and it was recognised that the major pressure reductions would occur in geological formations comprising consolidated rock. Subsequently a review of ground movement data collected over the Moranbah Gas Project area was assessed in the SREIS as an analogue to potential impacts that could occur in the BGP.

Interpreted ground movement from satellite interferometry data showed movement over most of the study area was less than 10 mm (uplift or subsidence). Isolated cases with a greater rate of movement were identified and found to be consistent with site surface features in most cases. Average downward movement of 10 to 20 mm was identified in one area that correlated with both CSG extraction and coal mining activity.

The subsidence interpreted from satellite interferometry indicated the magnitude of the surface ground movement associated with CSG extraction in the Moranbah Gas Project is small, within the lower range of calculations used to estimate subsidence, broadly distributed so therefore less likely to induce differential subsidence and significantly less than that from longwall coal mining.

As discussed in the above sections areas of potential environmental value that coincide with the outer edge of CSG depressurisation impacts in the surficial zones also coincide with coal mines. In these instances the potential subsidence effects from CSG are assessed as being small and will be less than potential subsidence impacts from coal mining.

As such there is minimal risk from subsidence due to CSG to have impacted or to impact these environmental values.

9 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 8 have materially changed.

The program for the implementation of the strategy will be reported to DES 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. As required under section 378(1)(d) of the *Water Act (Qld) 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	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.
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).

Term	Meaning
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.
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.

Term	Meaning
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.
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.

Term	Meaning
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.

References

- AGE, Bowen Groundwater Management and Monitoring Plan Uncertainty Analysis (2018)
- Arrow Energy, Underground Water Impact Report for PLs 191, 196, 223, 224 (2012a)
- Arrow Energy, Underground Water Impact Report for ATP 1103 (2012b)
- Arrow Energy, Bowen Gas Project Environmental Impact Statement (2012c)
- Arrow Energy, Underground Water Impact Report for ATP 1031 (2014a)
- Arrow Energy, Bowen Gas Project Supplementary Report to the EIS (2014b)
- Arrow Energy, Underground Water Impact Report for PL 191, 196, 223, 224, 831, 742, 1031 and 1103 (2016a)
- Arrow Energy, Underground Water Impact Report for ATP 644 (2016b)
- Arrow Energy, Underground Water Impact Report for PL 191, 196, 223, 224 and 742, 1031 and 1103 (Arrow Energy 2019)
- Ausenco and Norwest, Groundwater Model Northern Bowen Basin Regional Model Impact Predictions (2012)
- Ausenco and Norwest, Parameter and Predictive Error/Uncertainty Assessment Northern Bowen Basin Regional Groundwater Model (2013)
- Geoscience Australia, Bowen Basin (2008)
- Mutton, A. J. (Compiler), 2003: Queensland Coals 14th Edition. Queensland Department of Natural Resources and Mines
- Pearce, B; Hansen, J; Hydrogeological Investigations of the Comet River Sub-Catchment, Central Queensland, Australia (2006a)
- Pearce, B; Hansen, J; Jackson, J; Hydrogeological Investigation of the Dawson River Sub-Catchment, Central Queensland, Australia (2006)
- Pearce, B; Hansen, J; Hydrogeological Investigations of the Fitzroy River Sub-Catchment, Central Queensland, Australia (2006b)
- Pearce, B; Hansen, J; Hydrogeological Investigations of the Isaac and Mackenzie River Sub-Catchment, Central Queensland, Australia (2006c)
- Pearce, B; Hansen, J; Hydrogeological Investigations of the Nogoa River Sub-Catchment, Central Queensland, Australia (2006d)
- Sundaram, B, Feitz, A & Caritat, P & Plazinska, A & Brodie, R & Coram, J & Ransley, T (2009). Groundwater Sampling and Analysis – A Field Guide. 2009.

APPENDIX A: SHALLLOW MONITORING BORE WATER LEVEL RESULTS

Bore Name	SWL (mAHD)																									
	9/06/2012	13/12/2012	8/04/2013	25/05/2013	6/08/2013	6/12/2013	5/05/2014	19/08/2014	5/12/2014	11/03/2015	17/05/2015	27/07/2015	13/11/2015	2/03/2016	13/05/2016	29/08/2016	15/11/2016	15/06/2017	12/11/2017	1/06/2018	17/11/2018	24/05/2019	12/11/2019	22/11/2020	24/05/2021	30/10/2021
M339W	200.426	200.456	200.43	200.451	200.462	200.546	200.49		200.56	200.533	200.416	200.398	200.556	200.466	200.456	200.426	200.500	200.507	200.498	200.520	200.600	200.620	200.660	200.750	200.680	200.820
M225W	206.298	206.641	206.737	206.8	207.455	207.152	207.11		207.27	207.349	207.257	207.23	207.402	207.215	207.245	207.248	207.316	207.54	207.685	207.75	207.9		207.78	207.43	207.2	207.14
M340W	207.621	208.973	208.118	208.216	208.261	208.507	208.6		208.7	208.771	208.753	208.805	208.918	208.869	208.9	208.761	205.946	203.032	dry							
M230W	208.495	208.705	208.715	208.837	208.865	209.062	209.07		209.2	209.204	209.106	209.058	209.145	208.884	208.922	208.863	208.992	208.629	208.591	208.214	207.7	206.94	205.95	203.17	202.6	
M300W																										200.1
GW004A																							235.162	234.692	234.542	234.442
GW007A																							dry			
M250W	233.288	233.248	233.238	233.232	233.248	233.308	233.26		233.33	233.289	233.25	233.221	233.25	233.243	233.258	233.328	233.237	233.283	233.273	233.29	233.32	233.34	233.34			233.61
AN021F															237.06		242.34		238.47	239.06	239.52		240.52	241.52	237.62	237.37
M224W	211.675	211.365	211.45	211.705	211.42	211.11	210.89	210.65	210.49	210.561	210.419	210.277	209.982	210.02	209.969		209.852	210.354	210.355	210.08	209.69	209.57	209.36	208.96	207.84	208.76
M222W	202.414	202.974	203.209		203.819	204.014	204.3	204.65	204.95	205.21	205.44	205.54	205.994	205.929	205.969	206.014	206.014	206.149	206.301	206.3	206.28	206.22	206.22	206.22	205.98	206
MB1S																							263.51	262.72	262.75	262.7
GW004B																							232.09	230.95	231.80	231.74
AEN1214																								215.12	217.32	215.32
AEN1234																								185.34	185.44	185.35
AEN1063																								143.12	142.845	142.53
MB12																				298.54	286.88	286.31	294.26	296.01	298.28	298.42
AN020F														238.37	238.366	238.48	238.44		237.18	238.61	238.39	238.36	238.36	237.99	237.62	237.37

APPENDIX B – WATER QUALITY RESULTS

SHALLOW MONITORING BORES

Monitoring Bore ID	Sample Date	Field pH	Electrical Conductivity	Total Dissolved Solids	Hydroxide Alkalinity (OH-) as CaCO3	Carbonate Alkalinity as CaCO3	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as CaCO3	Sulphate	Chloride	Calcium	Magnesium	Sodium	Potassium	Aluminium - Dissolved
			µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
M339W	11/12/2012	6.46	38000	26000	<5	<5	680	680	980	15000	150	670	10000	110	
M339W	4/04/2013	6.28	36000	22000	<5	<5	690	690	830	14000	160	700	9700	120	
M339W	21/05/2013	8.09	37000	29000	<5	<5	680	680	1100	17000	150	710	10000	120	
M339W	7/08/2013	6.42	37000	25000	<5	<5	660	660	990	15000	190	670	13000	150	
M339W	5/12/2013	6.6	39000	28000	<5	<5	660	660	1100	16000	160	740	11000	110	
M339W	11/05/2014	6.6	37900	24600	<1	<1	698	698	1020	13800	150	722	7740	100	<0.5
M339W	9/12/2014	6.46	39300	25400	<1	<1	706	706	893	13700	158	780	8220	138	<0.05
M339W	10/03/2015	6.53	39000	27100	<1	<1	644	644	932	13900	183	682	8360	98	
M339W	16/05/2015	6.67	37500	24200	<1	<1	647	647	1140	12200	167	668	7770	82	<0.01
M339W	27/07/2015	6.53	38200	25400	<1	<1	658	658	1020	13500	180	676	7600	90	<0.01
M339W	16/11/2015	6.43	32300	21200	<1	<1	714	714	987	12700	147	669	7170	81	<0.05
M339W	2/03/2016	7.56	39800	21200	<1	<1	712	712	1000	13400	160	747	8710	104	
M339W	13/05/2016		39000	24400	<1	<1	681	681	1020	13000	178	712	7850	89	<0.01
M339W	29/08/2016	8.37	41300	28200	<1	43	714	757	993	12600	170	688	7790	93	
M339W	15/11/2016	7.13	37100	22900	<1	<1	652	652	1050	12600	171	743	8440	92	<0.01
M339W	13/06/2017		38600	25100	<1	<1	726	726	964	13500	186	780	9040	105	<0.05
M339W	12/11/2017	6.99	39800	27100	<1	<1	708	708	923	13700	204	792	9570	102	
M339W	1/06/2018	6.58	39300		<1	<1	644	644	974	12900	181	772	8990	97	<0.05
M339W	17/11/2018	6.51	42769	26800	<1	<1	661	661	916	11600	174	750	7800	96	<0.05
M339W	27/05/2019	6.47	37398	26200	<1	<1	632	632	958	13600	174	769	8370	95	<0.05
M339W	12/11/2019	6.69	38760	23400	<1	<1	669	669	936	13800	142	680	7860	88	<0.05
M339W	22/11/2020	6.73	38200	26800	<1	<1	677	677	941	14000	154	708	8150	91	
M339W	30/10/2021	6.43	40600	28600	<1	<1	617	617	925	12900	168	729	8570	99	<0.05
M225W	3/04/2013	7.54	28000	17000	<5	<5	810	810	710	11000	150	510	7200	84	
M225W	21/05/2013	6.53	28000	21000	<5	<5	790	790	660	10000	150	520	7500	82	
M225W	8/08/2013	6.59	29000	20000	<5	<5	780	780	700	11000	160	480	7500	75	
M225W	5/12/2013	6.84	30000	21000	<5	<5	780	780	780	11000	180	490	9500	95	<0.5
M225W	6/05/2014	6.98	29900	19400	<1	<1	745	745	369	9940	142	495	5440	72	<0.01
M225W	5/12/2014	6.73	30500	20100	<1	<1	808	808	617	9880	151	523	6450	76	
M225W	11/03/2015	6.82	30100	20000	<1	<1	716	716	827	10200	163	508	6600	75	<0.01
M225W	17/05/2015	6.89	30200	19800	<1	<1	780	780	884	9850	161	518	6430	64	<0.01
M225W	28/07/2015	6.96	28700	19300	<1	<1	790	790	735	9660	157	478	5670	65	<0.05
M225W	16/11/2015	6.38	23700	17400	<1	<1	826	826	738	9870	134	485	5460	59	
M225W	2/03/2016	7.71	30500	19400	<1	<1	817	817	721	10300	153	541	6530	76	<0.01
M225W	13/05/2016	7.57	29600	18400	<1	<1	779	779	752	9390	158	532	6570	66	
M225W	29/08/2016	7.45	29600	17900	<1	<1	799	799	727	9750	158	532	6220	68	<0.01
M225W	15/11/2016	7.31	30200	19800	<1	<1	778	778	711	9620	169	567	6560	72	<0.01
M225W	13/06/2017		29900	18300	<1	<1	827	827	786	10800	150	492	6780	66	
M225W	12/11/2017	7.15	30700	20100	<1	<1	814	814	691	10400	144	507	5930	64	
M225W	31/05/2018	7.16	30100	19200	<1	<1	701	701	701	9900	169	578	6960	70	<0.05
M225W	21/11/2018	6.74	29700	19000	<1	<1	748	748	723	10200	159	566	6470	68	<0.05
M225W	25/05/2019	6.59	29500	19500	<1	<1	738	738	745	10700	159	541	6250	70	
M225W	7/11/2019	6.91	30400	21800	<1	<1	733	733	715	10200	149	566	6670	71	<0.05
M225W	19/11/2020	6.81	29700	20000	<1	<1	758	758	746	10600	179	518	6130	68	<0.05
M225W	25/10/2021	7.99	25600	21100	<1	<1	749	749	725	9950	168	567	6640	73	<0.05
M340W	11/12/2012	6.6	8600	5200	<5	<5	620	620	240	2900	57	110	2100	25	
M340W	4/04/2013	6.3	8300	5200	<5	<5	620	620	230	2600	62	120	1900	32	
M340W	22/05/2013	6.81	8400	5000	<5	<5	610	610	240	2700	59	120	1900	25	
M340W	7/08/2013	6.63	8600	5000	<5	<5	620	620	230	2700	55	110	2000	26	
M340W	5/12/2013	6.63	9100	5700	<5	<5	610	610	260	2800	56	110	2200	27	
M340W	10/05/2014	6.74	10000	6500	<1	<1	661	661	246	3150	71	141	1920	25	<0.01
M340W	8/12/2014	6.69	11100	6390	<1	<1	708	708	257	3400	85	172	2050	33	<0.01
M340W	12/03/2015	6.81	11400	6500	<1	<1	689	689	269	3760	102	174	2240	32	
M340W	17/05/2015	6.82	11700	6900	<1	<1	679	679	383	3740	96	179	2060	27	<0.01
M340W	28/07/2015	6.68	11400	6280	<1	<1	668	668	319	3670	100	177	2120	29	<0.01
M340W	16/11/2015	6.38	10700	7320	<1	<1	727	727	322	3850	89	193	2180	28	<0.01
M340W	2/03/2016	8.43	12600	6400	<1	43	681	725	320	4060	101	203	2480	33	
M340W	13/05/2016	7.67	12400	7140	<1	<1	693	693	342	3790	100	200	2310	30	<0.01
M340W	29/08/2016	8.49	13000	7250	<1	94	636	730	345	3780	107	198	2340	30	
M340W	15/11/2016	7.44	13100	7430	<1	<1	668	668	371	4310	109	216	2420	31	
M340W	13/06/2017		11300	6590	<1	<1	651	651	353	3690	90	180	2180	27	<0.01
M230W	11/12/2012	7.15	5600	3300	<5	<5	420	420	64	1600	55	93	1200	18	
M230W	3/04/2013	6.66	5400	3200	<5	<5	420	420	66	1600	60	96	1000	19	
M230W	21/05/2013	7.01	5300	3300	<5	<5	410	410	60	1700	60	96	1100	18	
M230W	7/08/2013	7.05	5600	3000	<5	<5	400	400	77	1700	58	93	1100	16	
M230W	7/12/2013	6.96	5900	3700	<5	<5	390	390	83	1700	56	85	1200	15	
M230W	11/05/2014	6.99	6010	3910	<1	<1	426	426	82	1660	67	100	1040	14	<0.01
M230W	5/12/2014	7.05	6100	3120	<1	<1	418	418	73	1490	70	103	970	17	<0.01
M230W	12/03/2015	7	6080	3360	<1	<1	410	410	69	1730	74	100	1030	16	
M230W	17/05/2015	7	6180	3580	<1	<1	407	407	97	1550	75	106	985	14	<0.01
M230W	28/07/2015	7.05	6000	3210	<1	<1	404	404	87	1500	74	107	1050	16	<0.01
M230W	15/11/2015	6.62	6260	3440	<1	<1	419	419	82	1840	69	101	891	12	<0.01
M230W	2/03/2016	7.82	6350	3350	<1	<1	431	431	84	1760	68	104	995	17	
M230W	13/05/2016	7.78	6120	3500	<1	<1	419	419	80	1760	72	110	1050	16	<0.01
M230W	29/08/2016	7.48	6130	3450	<1	<1	417	417	79	1680	76	111	1050	18	
M230W	15/11/2016	7.51	6220	3500	<1	<1	414	414	83	1750	68	117	1100	15	
M230W	13/06/2017		6270	3470	<1	<1	442	442	78	1870	65	110	1100	15	<0.01
M230W	12/11/2017	7.5	6400	3710	<1	<1	420	420	79	1820	70	114	1070	15	
M230W	1/06/2018	6.95	6860	3960	<1	<1	380	380	99	1920	78	121	1170	17	
M230W	21/11/2018	6.83	7260	4140	<1	<1	401	401	104	2140	98	158	1300	17	
M230W	25/05/2019	6.74	7450	4410	<1	<1	397	397	117	2480	101	163	1350	18	
M230W	10/11/2019	6.88	7420	4770	<1	<1	403	403	110	2330	93	150	1260	18	
M230W	1/11/2020	6.9	7670	4630	<1	<1	416	416	110	2520	109	159	1280	18	
M230W	19/11/2021	7.21	7620	4390	<1	<1	415	415	113	2540	128	208	1580	22	
M300W	26/10/2021	7.61	32600	22400	<1	<1	531	531	550	10700	297	687	6430	79	<0.05
M250W	13/12/2012	5.42	2400	1400	<5	<5	61	61	54	700	14	39	380	11	
M250W	6/04/2013	5.77	2400	1600	<5	<5	69	69	69	660	17	45	490	13	
M250W	25/05/2013	5.86	2500	1600	<5	<5	67	67	83	730	18	46	510	13	
M250W	6/08/2013	5.82	2300	1300	<5	<5	72	72	81	730	19	43	450	11	
M250W	5/12/2013	5.92	2500	1600	<5	<5	60	60	84	710	14	39	480	12	
M250W	9/05/2014	5.64	2440	1590	<1	<1	76	76	76	682	13	43	393	12	<0.01
M250W	7/12/2014	5.65	2530	1380	<1	<1	58	58	76	717	13	45	432	11	<0.01
M250W	10/03/2015	5.5	2540	1580	<1	<1	58	58	92	768	19	42	420	10	
M250W	18/05/2015	5.75	2560	1420	<1	<1	55	55	92	763	17	44	398	10	<001
M250W	29/07/2015	5.48	2430	1430	<1	<1	59	59	89	729	15	44	387	11	<0.01
M250W	16/11/2015	5.72	2170	1300	<1	<1	72	72	76	664	12	38	344	9	<0.01
M250W	2/03/2016	6.54	2650	1490	<1	<1	53	53	92	787	15	45	408	12	
M250W	13/05/2016	6.74	2620	1530	<1	<1	116	116	95	774	18	52	461	11	<0.01
M250W	29/08/2016	7.76	2600	1440	<1	<1	64	64	81	678	14	44	396	10	
M250W	15/11/2016	6.36	2460	1400	<1	<1	60	60	86	715	12	46	411	10	<0.01
M250W	18/06/2017		2450	1360			63	63	80	708	12	42	402	10	<0.01
M250W	13/11/2017	7.23	2650	1620			55	55	106	794	20	50	465	11	
M250W	2/06/2018	5.8	2530					55	77	708	15	48	440	10	<0.01
M250W	22/11/2018	5.66	2510	1520	<1	<1	62	62	89	746	15	48	420	11	<0.01
M250W	26/05/2019	5.45	2480	1400	<1	<1	58	58	88	790	16	48	407	11	<0.01
M250W	7/11/2019	5.93	2510	1560	<1	<1	59	59	87	744	20	46	414	11	<0.01
M250W	21/12/2021	5.65	2420	1550	<1	<1	60	60	80	767	20	46	438	12	
M222W	16/06/2012	6.43	9520	6690	<1	<1	457	457	85	3140	326	355	1120	14	
M222W	14/12/2012	6.52	9300	6500	<5	<5	420	420	78	3500	290	340	1000	14	
M222W	5/04/2013	6.22	9100	6500	<5	<5	300	300	140	4100	320	440	1100	14	
M222W	26/05/2013	6.67	9400	7500	<5	<5	290	290	100	3200	350	450	1100	14	
M222W	9/08/2013	6.17	9200	6200	<5	<5	310	310	110	3400	340	400	1100	11	
M222W	6/12/2013	6.26	9700	9600	<5	<5	300	300	130	3300	440	380	1400	12	
M222W	10/05/2014	6.16	9480	6160	<1	<1	316	316	129	3420	363	428	1010	10	<0.01
M222W	19/08/2014	6.81	9090	8950	<1	<1	275	275	128	3450	365	448	1020	12	<0.01
M222W	4/12/2014	6.25	10200	7520	<1	<1	303	303	116	3330	361	451	1080	12	<0.01
M222W	11/03/2015	6.55	10000	6810	<1	<1	295	295	122	3450	395	395	999	10	
M222W	17/05/2015	6.32	9890	7160	<1	<1	304	304	165	3480	374	426	943	9	<0.01
M222W	27/07/2015	6.23	9670	6150	<1	<1	290	290	129	3420	385	434	956	10	<0.01
M222W	17/11/2015	6.1	10200	6820	<1	<1	296	296	124	3560	352	376	932	10	0.36
M222W	2/03/2016	7.19	10700	5190	<1	<1	318	318	118	3560	342	434	1040	12	
M222W	13/05/2016	7.22	9890	5740	<1	<1	282	282	177	3340	376	456	1040	10	<0.01
M222W	29/08/2016	8.16	10400	7370	<1	<1	280	280	155	3170	414	474	1080	10	
M222W	15/11/2016	6.62	10300	6300	<1	<1	292	292	140	3660	407	492	1170	11	<0.01
M222W	13/06/2017		10600	6320			310	310	145	3920	379	448	1140	11	<0.01
M222W	7/11/2017	6.82	10600	6800			271	271	126	3670	399	466	1080	10	
M222W	29/05/2018	6.29	11000					286	131	4020	417	478	1170	12	<0.01
M222W	18/11/2018	6.19	11000	6970	<1	<1	282	282	130	3630	406	494	1080	11	<0.01
M222W	24/05/2019	6.09	10700	7230	<1	<1	261	261	159	4000	432	506	1180	10	
M222W	10/11/2019	6.09	10700	8400	<1	<1	275	275	161	3780	404	470	1110	11	<0.01
M222W	20/11/2020	6.3	11100	8600	<1	<1	292	292	155	4090	448	513	1200	11	<0.01
M222W	28/10/2021	5.92	11400	9990	<1	<1	243	243	163	3800	438	481	1110	10	<0.01
M224W	16/06/2012	6.22	29500	22300	<1	<1	355	355	1600	9560	831	1260	4170	11	
M224W	15/12/2012	6.24	28000	22000	<5	<5	340	340	1500	14000	780	1100	4500	13	
M224W	7/04/2013	5.73	25000	20000	<5	<5	360	360	1300	11000	740	1000	4300	16	
M224W	25/05/2013	6.11	18000	14000	<5	<5	220	220	880	6200	610	680	2600	17	
M224W	6/08/2013	6.07	23000	17000	<5	<5	240	240	1200	9100	840	980	4500	12	
M224W	6/12/2013	6.15	28000	27000	<5	<5	280	280	6200	11000	1000	1400	6200	13	<.5
M224W	10/05/2014	6.24	27200	17700	<1	<1	253	253	1250	10200	779	1080	3690	11	<0.01
M224W	19/08/2014	6.34	27600	21000	<1	<1	192	192	1060	10800	822	1300	4590	13	<0.01
M224W	4/12/2014	6.14	31600	22900	<1	<1	186	186	842	9710	764	1320	4080	13	
M224W	12/03/2015	6.46	22900	16500	<1	<1	174	174	710	8850	661	842	3240	10	<0.01
M224W	17/05/2015	6.36	21000	16800	<1	<1	184	184	978	7200	640	768	2760	8	<0.01
M224W	27/07/2015	6.13	24700	17100	<1	<1	188	188	948	8670	712	984	3390	9	<0.01
M224W	17/11/2015	6.13	27700	17500	<1	<1	158	158	890	9930	613	870	3320	7	
M224W	2/03/2016	7.38	10800	5950	<1	<1	128	128	656	3350	316	360	1600	6	<0.01
M224W	13/05/2016	7.48	17900	11100	<1	<1	202	202	799	5860	512	664	2680	9	
M224W	29/08/2016	7.21	4240	2360	<1	<1	101	101	541	1020	172	107	543	5	
M224W	15/11/2016	6.77	17700	11700	<1	<1	192	192	802	6210	570	696	2650	8	<0.01
M224W	13/06/2017		17600	11000	<1	<1	238	238	1070	6490	676	630	2400	9	
M224W	07/11/2017	6.97	20400	14100	<1	<1	232	232	1000	7120	774	778	2650	10	
M224W	29/05/2018	6.28	27200					304	1240	10100	870	1090	4100	10	
M224W	18/11/2018	6.33	5490	3630	<1	<1	141	141	574	1270	264	137	669	5	<0.01
M224W	24/05/2019	6.53	12800	8730	<1	<1	152	152	907	4490	448	440	1960	6	<0.01
M224W	10/11/2019	6.12	18400	15200	<1	<1	141	141	644	6430	426	628	2760	6	<0.01
M224W	20/11/2020	6.13	20100	15600	<1	<1	137	137	575	7590	413	670	2980	5	<0.01
M224W	28/10/2021	6.22	22600	18800	<1	<1	209	209	718	7490	582	767	3150	7	<0.01
AN020F	13/05/2016	6.2	10800	6210	<1	<1	22	22	<1	3750	429	178	1550	29	<0.01
AN020F	15/11/2016	6.32	10600	7210	<1	<1	21	21	1	4030	439	174	1450	26	
AN020F	15/11/2017	7.39	10900	7010	<1	<1	47	47	<1	3790	456	182	1650	29	
AN020F	15/11/2018	7.05	11200	7280	<1	<1	126	126	<1	3800	460	203	1460	24	
AN020F	11/11/2019	7.58	10400	7310	<1	<1	20	20	<1	3830	457	174	1580	29	
AN020F	21/11/2020	7.03	10300	8090	<1	<1	5	5	<1	3990	51	<1	2160	21	
AN020F	30/10/2021	7.1	9590	9070	<1	<1	27	27	<1	3760	420	169	1540	28	

Monitoring Bore ID	Sample Date	Arsenic-Dissolved	Beryllium-Dissolved	Barium-Dissolved	Cadmium-Dissolved	Chromium-Dissolved	Cobalt-Dissolved	Copper-Dissolved	Lead-Dissolved	Manganese-Dissolved	Molybdenum	Nickel-Dissolved	Selenium - Dissolved	Strontium	Vanadium-Dissolved	Zinc-Dissolved	Boron - Dissolved	Iron - Dissolved	Mercury-Dissolved	Fluoride, F	Phosphate as P in water
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
M339W	11/12/2012	<0.001	<0.0005	0.056	0.0004	0.006	<0.001	0.007	<0.001	0.016		0.018			0.003	0.05			0.00008	0.45	0.1
M339W	4/04/2013	<0.001	<0.0005	0.057	0.0003	0.007	<0.001	0.005	<0.001	0.013		0.027			0.003	0.039			<0.00005	0.44	0.11
M339W	21/05/2013	<0.001	<0.0005	0.067	0.0005	0.004	<0.001	0.059	<0.001	0.012		0.014			0.003	0.068			0.00009	0.33	0.026
M339W	7/08/2013	<0.002	<0.0005	0.061	0.0004	0.003	<0.001	0.004	<0.001	0.007		0.014			0.003	0.078			<0.00005	0.29	0.19
M339W	5/12/2013	<0.001	<0.0005	0.055	0.0005	0.006	<0.001	0.007	<0.001	0.007		0.015			0.003	0.06			<0.00005	0.37	0.085
M339W	11/05/2014							<0.05		<0.01						<0.05			<0.0001		0.26
M339W	9/12/2014							<0.005		<0.005						0.04			<0.0001	0.4	0.08
M339W	10/03/2015	<0.005	<0.005	0.058		<0.005	<0.005	<0.005	<0.005	0.009		0.026			<0.05	0.053				0.8	
M339W	16/05/2015	<0.001	<0.001	0.124	0.0007	0.002	<0.001	0.009	<0.001	0.009		0.012			<0.01	0.128			0.0008	0.4	
M339W	27/07/2015	<0.001	<0.001	0.051	0.0004	<0.001	<0.001	0.001	<0.001	0.003		0.012			<0.01	0.016			0.001	0.5	
M339W	16/11/2015	<0.005	<0.005	0.053	<0.0005	<0.005	<0.005	0.01	<0.005	<0.005		0.014			<0.05	0.149			0.0006	0.4	0.1
M339W	2/03/2016	<0.001	<0.001	0.050		0.007	<0.001	0.002	<0.001	0.002		0.014			<0.01	0.046				0.4	0.24
M339W	13/05/2016	0.001	<0.001	0.055		0.01	<0.001	0.008	<0.001	0.005	0.003	0.014	0.01	8.48	<0.01	0.051	2.58	<0.05	<0.0001	0.4	0.62
M339W	29/08/2016	<0.005	<0.005	0.058		0.01	<0.005	0.005	<0.005	<0.005	<0.005	0.014	<0.05	8.98	<0.05	0.027	2.66	<0.05		0.5	0.07
M339W	15/11/2016	<0.001	<0.001	0.055	0.0001	0.002	<0.001	<0.001	<0.001	0.006	0.003	0.014	<0.01	8.36	<0.01	0.021	2.42	<0.05	<0.0001	0.5	0.15
M339W	13/06/2017							0.006		<0.005						<0.025	2.74	<0.05	<0.0001	0.5	
M339W	12/11/2017	<0.005	<0.005	0.062		0.008	<0.005		<0.005	<0.005	<0.005	0.015	<0.05		<0.05	<0.025	2.96	0.06		0.4	0.07
M339W	1/06/2018							<0.005		<0.005						<0.025	2.66	<0.05	0.001	0.4	0.09
M339W	17/11/2018	<0.005	<0.005	0.057		0.01	<0.005	<0.005	<0.005	<0.005	<0.005	0.013	<0.05		<0.05	<0.025	2.36	<0.05		0.09	
M339W	27/05/2019							<0.005		<0.005						0.029	2.91	<0.05	0.0009	<0.05	
M339W	12/11/2019	<0.005	<0.005	0.052		0.009	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05		<0.05	0.047	2.81	<0.05		0.11	
M339W	22/11/2020	<0.005	<0.005	0.058		0.01	<0.005	0.008	<0.005	<0.005	<0.005	0.013	<0.05		<0.05	0.026	2.64	<0.05		0.4	0.13
M339W	30/10/2021							<0.005		<0.005						0.028	2.39	<0.05	0.0002	0.4	0.14
M225W	3/04/2013	<0.001	<0.0005	0.063	0.0006	0.003	<0.001	0.01	<0.001	0.011		0.025			0.015	0.042			<0.00005	0.48	0.2
M225W	21/05/2013	0.001	<0.0005	0.140	0.0006	0.002	0.001	0.01	<0.001	0.21		0.034			0.009	0.053			<0.00005	0.37	0.11
M225W	8/08/2013	<0.001	<0.0005	0.120	0.001	0.002	0.001	0.03	<0.001	0.18		0.068			0.013	0.036			<0.00005	0.32	0.19
M225W	5/12/2013	<0.001	<0.0005	0.120	0.0007	0.002	0.002	0.009	<0.001	0.35		0.056			0.009	0.031			<0.00005	0.37	0.11
M225W	6/05/2014							<0.05		<0.01						0.059			<0.0001		0.1
M225W	5/12/2014							0.028		0.004						0.058			0.0001	0.5	0.27
M225W	11/03/2015	<0.005	<0.005	0.075		<0.005	<0.005	<0.005	<0.005	0.009		0.026			<0.05	0.096				0.8	
M225W	17/05/2015	0.001	<0.001	0.112	0.0012	0.001	<0.001	0.022	<0.001	0.161		0.048			0.01	0.029			<0.0001	0.4	
M225W	28/07/2015	0.001	<0.001	0.089	0.0006	<0.001	<0.001	0.011	<0.001	0.033		0.016			0.01	0.018			<0.0001	0.6	
M225W	16/11/2015	<0.005	<0.005	0.055	0.0006	<0.005	<0.005	0.012	<0.005	<0.005		0.022			<0.05	0.099			0.0001	0.6	0.18
M225W	2/03/2016	<0.001	<0.001	0.053		0.002	<0.001	0.02	<0.001	0.001		0.012			0.01	0.035				0.5	0.25
M225W	13/05/2016	<0.001	<0.001	0.062	0.0005	0.002	<0.001	0.006	<0.001	0.01	0.004	0.028	<0.01	4.25	0.01	0.036	2.48	<0.05	<0.0001	0.5	0.13
M225W	29/08/2016	<0.001	<0.001	0.065		0.002	<0.001	0.012	<0.001	0.006	0.004	0.022	<0.01	4.58	0.01	0.038	2.1	<0.05		0.6	0.22
M225W	15/11/2016	<0.001	<0.001	0.068	0.0006	0.002	<0.001	0.006	<0.001	0.008	0.006	0.058	<0.01	4.93	0.01	0.062	2.32	<0.05	0.0002	0.7	0.12
M225W	13/06/2017							0.013		0.005						0.018	1.92	<0.05	<0.0001	0.4	0.43
M225W	12/11/2017	<0.001	<0.001	0.060		0.003	<0.001		<0.001	0.008	0.004	0.253	<0.01		0.01	0.015	1.95	<0.05		0.5	0.17
M225W	31/05/2018							0.012		0.027						<0.025	2.07	<0.05	<0.0001	0.6	0.1
M225W	21/11/2018	<0.005	<0.005	0.103		<0.005	<0.005	0.07	<0.005	<0.005	<0.005	0.016	<0.05		<0.05	0.046	2.02	<0.05	0.0001	0.5	0.14
M225W	25/05/2019							0.041		0.022						0.031	1.98	0.08	0.0001	0.5	0.09
M225W	7/11/2019	<0.005	<0.005	0.067		<0.005	<0.005	<0.005	<0.005	0.008	<0.005	0.011	<0.05		<0.05	0.11	2.24	<0.05		0.5	0.09
M225W	19/11/2020	<0.005	<0.005	0.000		<0.005	<0.005	0.022	<0.005	0.062	<0.005	0.361	<0.05		<0.05	0.045	1.81	<0.05	<0.0001	0.5	0.18
M225W	25/10/2021	<0.005	<0.005	0.062		<0.005	<0.005	0.014	<0.005	<0.005	<0.005	0.026	<0.05		<0.05	0.032	2.07	<0.05		0.5	0.18
M340W	11/12/2012	<0.001	<0.0005	0.056	0.0002	<0.001	0.0002	0.005	<0.001	0.1		0.012			0.003	0.035			<0.00005	0.45	0.1
M340W	4/04/2013	<0.001	<0.0005	0.056	<0.0001	<0.001	0.002	0.004	<0.001	0.085		0.014			0.002	0.028			<0.00005	1.6	0.077
M340W	22/05/2013	<0.001	<0.0005	0.057	<0.0001	<0.001	0.002	0.005	<0.001	0.086		0.007			0.002	0.036			<0.00005	1.4	0.055
M340W	7/08/2013	<0.001	<0.0005	0.061	<0.0001	<0.001	0.002	0.002	<0.001	0.095		0.006			0.001	0.037			<0.00005	1.3	0.1
M340W	5/12/2013	<0.001	<0.0005	0.058	<0.0001	<0.001	0.002	<0.001	<0.001	0.1		0.013			0.001	0.021			<0.00005	1.5	0.063
M340W	10/05/2014							0.007		0.075						0.041			<0.0001		0.12
M340W	8/12/2014							0.008		0.081						0.076			<0.0001	1.8	0.08
M340W	12/03/2015	<0.001	<0.001	0.068		<0.001	0.002	0.003	<0.001	0.058		0.022			<0.01	0.013				1.7	
M340W	17/05/2015	<0.001	<0.001	0.194	<0.0001	<0.001	0.001	0.024	<0.001	0.051		0.009			<0.01	0.185			<0.0001	1.6	
M340W	28/07/2015	<0.001	<0.001	0.113	<0.0001	<0.001	<0.001	0.011	<0.001	0.049		0.038			<0.01	0.06			<0.0001	1.9	
M340W	16/11/2015	<0.001	<0.001	0.057	<0.0001	0.001	0.001	0.018	<0.001	0.047		0.01			<0.01	0.098			<0.0001	1.6	0.04
M340W	2/03/2016	<0.001	<0.001	0.060		<0.001	0.002	0.002	<0.001	0.044		0.01				0.018				2.0	0.08
M340W	13/05/2016	<0.001	<0.001	0.070	<0.0001	<0.001	0.001	0.012	<0.001	0.034	0.004	0.005	<0.01	2.95	<0.01	0.132	2.26	<0.05	<0.0001	1.8	0.05
M340W	29/08/2016	<0.001	<0.001	0.073		0.001	0.003	0.002	<0.001	0.06	0.004	0.008	<0.01	3.32	<0.01	0.005	1.83	<0.05		2.0	0.05
M340W	15/11/2016	<0.001	<0.001	0.075	<0.0001	0.002	0.002	<0.001	<0.001	0.056		0.006	<0.01		<0.01	0.014	2.14		<0.0001	1.6	0.08
M340W	13/06/2017							<0.001		0.611						<0.005	1.75	<0.05	<0.0001	1.9	12.6
M230W	11/12/2012	0.002	<0.0005	0.150	<0.0001	<0.001	<0.001	0.001	<0.001	0.097		0.005			<0.001	0.014			<0.00005	0.79	0.67
M230W	3/04/2013	0.002	<0.0005	0.170	<0.0001	<0.001	0.002	0.002	<0.001	0.26		0.01			<0.001	0.027			<0.00005	0.76	0.16
M230W	21/05/2013	0.002	<0.0005	0.180	<0.0001	<0.001	0.002	0.004	<0.001	0.18		0.014			<0.001	0.021			<0.00005	0.54	0.094
M230W	7/08/2013	0.002	<0.0005	0.180	<0.0001	<0.001	<0.001	0.003	<0.001	0.091		0.01			<0.001	0.033			<0.00005	0.46	0.27
M230W	7/12/2013	0.002	<0.0005	0.180	<0.0001	<0.001	0.002	0.003	<0.001	0.16		0.008			<0.001	0.017			<0.00005	0.63	0.11
M230W	11/05/2014							0.003		0.212						0.037			<0.0001		0.17
M230W	5/12/2014							0.001		0.317						0.06			<0.0001	0.7	0.3
M230W	12/03/2015	0.002	<0.001	0.195		<0.001	0.003	0.001	<0.001	0.251		0.131			<0.01	0.013				0.8	
M230W	17/05/2015	0.002	<0.001	0.283	<0.0001	<0.001	0.003	0.002	<0.001	0.243		0.01			<0.01	0.024			<0.0001	0.6	
M230W	28/07/2015	0.002	<0.001	0.237	<0.0001	<0.001	0.001	0.004	<0.001	0.146		0.012			<0.01	0.049			<0.0001	0.7	
M230W	15/11/2015	0.002	<0.001	0.175	<0.0001	0.002	<0.001	0.002	<0.001	0.046		0.06			<0.01	0.068			<0.0001	0.8	0.17
M230W	2/03/2016	0.001	<0.001	0.164		<0.001	0.001	0.002	<0.001	0.035		0.006			0.042	<0.01				0.7	0.19
M230W	13/05/2016	0.001	<0.001	0.184	<0.0001	<0.001	<0.001	0.001	<0.001	0.04	0.006	0.021	<0.01	1.52	<0.01	0.024	0.6	<0.05	<0.0001	0.7	0.1
M230W	29/08/2016	0.001	<0.001	0.186		<0.001	<0.001	0.007	<0.001	0.027	0.008	0.039	<0.01	1.68	<0.01	0.026	0.42	<0.05		0.7	0.1
M230W	15/11/2016	0.002	<0.001	0.186	<0.0001	<0.001	<0.001	0.002	<0.001	0.097	0.008	0.026	<0.01	1.71	<0.01	0.036	0.47	<0.05	<0.0001	0.6	0.08
M230W	13/06/2017							0.001		0.451						0.014	0.45	0.36	<0.0001	0.8	0.18
M230W	12/11/2017	0.002	<0.001	0.206		<0.001	0.005		<0.001	0.203	0.005	0.014	<0.01		<0.01	0.065	0.47	<0.05		0.7	0.23
M230W	1/06/2018							0.001		0.188						0.012	0.44	0.43	<0.0001	0.7	0.17
M230W	21/11/2018	0.002	<0.001	0.207		<0.001	0.003	<0.001	<0.001	0.186	0.003	0.009	<0.01		<0.01	0.047	0.48	<0.05	<0.0001	0.7	0.12
M230W	25/05/2019							0.001		0.213						0.012	0.56	0.39	<0.0001	0.7	0.14
M230W	10/11/2019	0.002	<0.001	0.206		<0.001	0.004	<0.001	<0.001	0.186	0.002	0.015	<0.01		<0.01	0.016	0.52	0.29		0.7	0.13
M230W	1/11/2020							<0.001		0.204						0.017	0.44	<0.05	<0.0001	0.6	0.14
M230W	19/11/2021	0.003	<0.001	0.283		<0.001	0.005	0.001	<0.001	0.286	0.004	0.262	<0.01		<0.01	0.025	0.71	0.59		0.7	0.13
M300W	26/10/2021							0.015		0.016						2.27	1.45	<0.05	<0.0001	0.7	0.13
M250W	13/12/2012	<0.001	<0.0005	0.1	<0.0001	0.002	<0.001	0.002	<0.001	0.027		0.008			<0.001	0.023			<0.00005	0.18	0.012
M250W	6/04/2013	<0.001	<0.0005	0.11	<0.0001	0.001	<0.001	0.002	<0.001	0.054		0.014			<0.001	0.02			<0.00005	0.14	0.01
M250W	25/05/2013	<0.001	<0.0005	0.1	<0.0001	0.003	<0.001	0.004	<0.001	0.015		0.007			<0.001	0.018			<0.00005	0.14	0.012
M250W	6/08/2013	<0.001	<0.0005	0.1	<0.0001	0.002	<0.001	0.002	<0.001	0.007		0.006			<0.001	0.016			<0.00005	0.13	0.079
M250W	5/12/2013	<0.001	<0.0005	0.083	<0.0001	0.002	<0.001	0.001	<0.001	0.019		0.01			<0.001	0.014			<0.00005	0.14	<0.005
M250W	9/05/2014							0.004		0.018						0.019			<0.0001		1.3
M250W	7/12/2014							<0.001		0.017						<0.005			<0.0001	0.2	0.08
M250W	10/03/2015	<0.001	<0.001	0.07		0.003	<0.001	<0.001	<0.001	0.013		0.01			<0.01	0.018				0.6	
M250W	18/05/2015	<0.001	<0.001	0.07	<0.0001	0.002	0.001	<0.001	<0.001	0.015		0.011			<0.01	0.019				0.2	
M250W	29/07/2015	<0.001	<0.001	0.078	<0.0001	0.003	0.001	<0.001	<0.001	0.028		0.01			<0.01	0.106			<0.0001	0.2	
M250W	16/11/2015	<0.001	<0.001	0.061	<0.0001	0.001	0.004	0.005	<0.001	0.076		0.048			<0.01	0.131			<0.0001	0.2	0.4
M250W	2/03/2016	<0.001	<0.001	0.047		0.002	<0.001	0.001	<0.001	0.014		0.01			<0.01	0.048				0.2	0.16
M250W	13/05/2016	<0.01	<0.001	<0.001		0.076	<0.0001	0.002	<0.001	0.011	<0.001	0.009	<0.01	0.725	<0.01	0.016	0.76	0.05	<0.0001	0.2	0.91
M250W	29/08/2016	<0.001	<0.001	0.055		0.002	0.001	0.001	<0.001	0.012	<0.001	0.01	<0.01	0.686	<0.01	0.008	0.61	<0.05		0.2	0.51
M250W	15/11/2016	<0.001	<0.001	0.05	<0.0001	0.002	0.001	<0.001	<0.001	0.012	<0.001	0.008	<0.01	0.698	<0.01	0.032	0.73	<0.05	<0.0001	0.2	0.47
M250W	18/06/2017							0.001		0.014						0.021	0.67	<0.05	<0.0001	0.2	0.44
M250W	13/11/2017	<0.001	<0.001	0.072		0.002	0.005	0.002	<0.001	0.095	0.002	0.043	<0.01		<0.01	0.111	0.7	<0.05		0.3	0.62
M250W	2/06/2018							<0.001		0.014						0.006	0.73	0.43	<0.0001	0.2	0.63
M250W	22/11/2018	<0.001	<0.001	0.057		0.002	0.001	0.001	<0.001	0.016	<0.001	0.01	<0.01		<0.01	0.072	0.68	<0.05	<0.0001	0.2	0.77
M250W	26/05/2019							0.001		0.021						0.031	0.74	<0.05	<0.0001	0.2	0.23
M250W	7/11/2019	<0.001	<0.001	0.059		0.002	0.004	<0.001	<0.001	0.043	0.001	0.088	<0.01		<0.01	0.035	0.74	<0.05		0.2	0.03
M250W	21/12/2021	<0.001		0.063		0.002	0.003	<0.001	<0.001	0.05	0.003	0.056			<0.01	0.054	0.59	<0.05		0.1	
M222W	16/06/2012	0.003	<0.000001	3.9	<0.0001	0.002	0.002	0.002	<0.001	1.17		0.125			<0.01	0.041			<0.0001	0.6	
M222W	14/12/2012	<0.001	<0.0005	1.2	<0.0001	<0.001	0.002	0.003	<0.001	1.3		0.005			<0.001	0.043			<0.00005	0.48	<0.005
M222W	5/04/2013	<0.001	<0.0005	0.26	<0.0001	<0.001	<0.001	0.002	<0.001	1.1		0.019			<0.001	0.037			<0.00005	0.68	<0.005
M222W	26/05/2013	0.001	<0.0005	0.24	<0.0001	<0.001	<0.001	0.002	<0.001	1.3		0.004			<0.001	0.007			<0.00005	0.47	<0.005
M222W	9/08/2013	0.003	<0.0005	0.23	<0.0001	<0.001	<0.001	0.001	<0.001	1.2		<0.001			<0.001	0.011			<0.00005	0.44	<0.005
M222W	6/12/2013	0.006	<0.0005	0.24	<0.0001	<0.001	<0.001	0.002	<0.001	1.7		0.001			<0.001	0.018			<0.00005	0.59	<0.005
M222W	10/05/2014							0.004		1.35						0.019			<0.0001		2.09
M222W	19/08/2014							0.001		1.54						0.036			<0.0001	0.4	0.18
M222W	4/12/2014							<0.001		1.45						0.115			<0.0001	0.8	0.74
M222W	11/03/2015	0.003	<0.001	0.248		<0.001	<0.001	<0.001	<0.001	1.27		<0.001			<0.01	0.02				1	
M222W	17/05/2015	0.011	<0.001	0.202	<0.0001	<0.001	<0.001	<0.001	<0.001	1.57		0.002			<0.01	0.021			<0.0001	0.7	
M222W	27/07/2015	0.004	<0.001	0.226	<0.0001	<0.001	<0.001	<0.001	<0.001	1.28		0.007			<0.01	<0.005			<0.0001	0.8	
M222W	17/11/2015	0.004	<0.001	0.22	<0.0001	<0.001	<0.001	0.001	<0.001	1.37		<0.001			<0.01	0.074			<0.0001	0.9	0.53
M222W	2/03/2016	0.003	<0.001	0.219		0.002	<0.001	<0.001	<0.001	1.27		0.017			<0.01	0.043				0.8	0.11
M222W	13/05/2016	0.009	<0.001	0.201	<0.0001	<0.001	<0.001	<0.001	<0.001	1.59	0.004	<0.001	<0.01	6.67	<0.01	<0.005	0.33	17.6	<0.0001	0.7	0.43
M222W	29/08/2016	0.01	<0.001	0.184		<0.001	<0.001	<0.001	<0.001	1.86	0.004	0.003	<0.01	8.96	<0.01	<0.005	0.32	21.1		0.8	0.55
M222W	15/11/2016	0.005	<0.001	0.252	<0.0001	<0.001	<0.001	<0.001	<0.001	1.59	0.003	0.002	<0.01	8.73	<0.01	0.015	0.34	13.6	<0.0001	0.8	0.19
M222W	13/06/2017							<0.001		1.55						<0.005	0.33	11.4	<0.0001	0.7	0.32
M222W	7/11/2017	0.005	<0.001	0.288		<0.001	<0.001	<0.001	<0.001	1.63	0.002	0.001	<0.01		<0.01	<0.005	0.3	14.5		0.8	0.43
M222W	29/05/2018							0.002		1.63						<0.005	0.32	15.5	<0.0001	0.7	0.46
M222W	18/11/2018	0.004	<0.001	0.268		<0.001	<0.001	<0.001	<0.001	1.48	0.002	<0.001	<0.01		<0.01	<0.005	0.34	11		0.6	0.12
M222W	24/05/2019							0.036		1.65						0.069	0.32	18.6	<0.0001	0.7	0.39
M222W	10/11/2019	0.007	<0.001	0.248		<0.001	<0.001	0.014	<0.001	1.56	0.003	0.028	<0.01		<0.01	0.059	0.32	17.1		0.7	0.41
M222W	20/11/2020							<0.001		1.72						0.013	0.33	0.05	<0.0001	0.7	0.67
M222W	28/10/2021							0.007		1.78						0.719	0.33	19.5	<0.0001	0.7	0.39
M224W	16/06/2012	<0.050	<0.00001	0.078	<0.0050	<0.010	0.011	<0.00005	<0.010	7.75		<0.00005			<0.10	0.06			<0.0001	0.9	
M224W	15/12/2012	0.003	<0.0005	0.11	<0.0001	<0.001	0.012	<0.001	<0.001	7.8		0.023			0.001	0.009			<0.00005	0.74	0.03
M224W	7/04/2013	0.002	<0.0005	0.2	0.0002	<0.001	0.015	<0.001	<0.001	8.1		0.04			<0.001	0.024			<0.00005	0.45	<0.005
M224W	25/05/2013	0.004	<0.0005	0.14	<0.0001	<0.001	0.007	<0.001	<0.001	4.8		0.083			0.002	0.008			<0.00005	0.23	<0.005
M224W	6/08/2013	0.005	<0.0005	0.13	<0.0001	<0.001	0.01	<0.001	<0.001	6.8		0.018			<0.001	0.027			<0.00005	0.37	0.052
M224W	6/12/2013	0.007	<0.0005	0.13	<0.0001	<0.001	0.012	<0.001	<0.001	8		0.015			<0.001	0.021			<0.00005	0.51	0.007
M224W	10/05/2014							<0.05		7.57						0.056			<0.0001		0.3
M224W	19/08/2014							<0.001		7.98						0.302			<0.0001	0.4	0.79
M224W	4/12/2014							<0.001		6.83						0.067			<0.0001	0.4	0.17
M224W	12/03/2015	0.004	<0.001	0.157		<0.001	0.016	0.006	<0.001	4.4		0.119			<0.01	0.044				0.6	
M224W	17/05/2015	0.006	<0.001	0.164	<0.0001	<0.001	0.021	0.001	<0.001	4.59		0.025			<0.01	0.05			<0.0001	0.3	
M224W	27/07/2015	0.008	<0.001	0.157	0.0001	<0.001	0.019	0.003	<0.001	4.51		0.17			<0.01	0.059			<0.0001	0.5	
M224W	17/11/2015	0.008	<0.001	0.163	<0.0001	<0.001	0.027	<0.001	<0.001	3.78		0.014			<0.01	0.101			<0.0001	0.4	0.11
M224W	2/03/2016	0.005	<0.001	0.065		<0.001	0.009	0.002	<0.001	1.36		0.021			<0.01	0.037				0.4	0.06
M224W	13/05/2016	0.008	<0.001	0.159	<0.0001	<0.001	0.011	0.005	<0.001	3.42	0.001	0.007	<0.01	11.4	<0.01	0.176	0.34	4.8	<0.0001	0.4	<0.05
M224W	29/08/2016	0.003	<0.001	0.06		<0.001	0.005	<0.001	<0.001	0.834	0.001	0.004	<0.01	3.19	<0.01	0.037	0.13	0.2		0.2	0.09
M224W	15/11/2016	0.008	<0.001	0.182	<0.0001	<0.001	0.017	<0.001	<0.001	3.75	0.002	0.02	<0.01	14	<0.01	0.21	0.24	5.39	<0.0001	0.4	0.07
M224W	13/06/2017							<0.001		4.04						0.052	0.22	7.91	<0.0001	0.3	0.08
M224W	07/11/2017	<0.001	0.193	<0.001		0.015	<0.001		<0.001	4.94	0.003	0.042	<0.01	<0.01	<0.01	0.044	0.22	10.1		0.4	0.3
M224W	29/05/2018							0.002		6.72						0.062	0.34	7.2	<0.0001	0.5	0.22
M224W	18/11/2018	<0.001	<0.001	0.045		<0.001	0.003	0.017	<0.001	0.313	<0.001	0.014	<0.01		<0.01	0.103	0.16	0.52		0.2	0.03
M224W	24/05/2019							0.001		1.68						0.032	0.29	1.12	<0.0001	0.4	0.13
M224W	10/11/2019	0.006	<0.001	0.126		<0.001	0.026	0.002	<0.001	1.58	0.001	0.045	<0.01		<0.01	0.059	0.39	4.43		0.3	<0.05
M224W	20/11/2020							<0.001		1.64						0.042	0.39	0.2	<0.0001	0.3	0.09
M224W	28/10/2021							<0.001		5.23						0.038	0.38	14.2	<0.0001	0.5	0.08
AN020F	13/05/2016	<0.001	<0.001	3.72	<0.0001	<0.001	0.001	<0.001	<0.001	1.92	<0.001	<0.001	<0.01	11.3	<0.01	<0.005	0.14	14.3	<0.0001	<0.1	<0.01
AN020F	15/11/2016	<0.001	<0.001	3.62		<0.001	<0.001	<0.001	<0.001	1.85	0.001	0.001	<0.01	11	<0.01	<0.005	0.19	8.25		<0.1	<0.05
AN020F	15/11/2017	<0.001	<0.001	3.42		<0.001	<0.001	<0.001	<0.001	1.17	0.005	0.006	<0.01		<0.01	<0.005	0.14	5.01		<0.1	0.11
AN020F	15/11/2018	<0.001	<0.001	3.88		<0.001	<0.001	0.001	<0.001	1.19	0.007	0.001	<0.01		<0.01	<0.005	0.2	5.36		<0.1	<0.01
AN020F	11/11/2019	<0.001	<0.001	3.66		<0.001	<0.001	0.005	<0.001	1.42	0.002	0.002	<0.01		<0.01	<0.005	0.13	1.68		<0.1	<0.01
AN020F	21/11/2020	0	0	5.34				<0.001		2.28	0.002					0.006	0.16	2.99	<0.0001	<0.1	0.01
AN020F	30/10/2021	<0.001	<0.001	3.7		<0.001	<0.001	0.001	<0.001	1.51	0.003	0.003	<0.01		<0.01	0.014	0.09	1.87		0.1	<0.01

DEEP MONITORING BORES

Monitoring Bore ID	Sample Date	Field pH	Electrical Conductivity µS/cm	Total Dissolved Solids (grav) mg/L	Hydroxide Alkalinity (OH-) as CaCO3 mg/L	Carbonate Alkalinity as CaCO3 mg/L	Bicarbonate Alkalinity as CaCO3 mg/L	Total Alkalinity as CaCO3 mg/L	Sulphate, SO4 mg/L	Chloride, Cl mg/L	Calcium - Dissolved mg/L	Magnesium - Dissolved mg/L	Sodium - Dissolved mg/L	Potassium - Dissolved mg/L	Aluminium - Dissolved mg/L	Arsenic-Dissolved mg/L	Beryllium-Dissolved mg/L	Barium-Dissolved mg/L	Cadmium-Dissolved mg/L	Chromium-Dissolved mg/L	Cobalt-Dissolved mg/L	Copper-Dissolved mg/L	Lead-Dissolved mg/L	Manganese-Dissolved mg/L	Molybdenum mg/L	Nickel-Dissolved mg/L	Selenium mg/L	Strontium mg/L	Vanadium-Dissolved mg/L	Zinc-Dissolved mg/L	Boron mg/L	Iron mg/L	Mercury-Dissolved mg/L	Fluoride, F mg/L	Phosphate as P in water mg/L
M313W	25/07/2014	9.42	1710	1160	<1	51	283	334	12	252	7	<1	319	98		0.004	<0.001	0.843		0.018	0.01	2.12	2.19	0.429		0.032			0.02	0.568				0.6	
M313W	13/02/2015	8.12	6940	4110	<1	<1	781	781	4	1810	26	5	1420	126		<0.001	<0.001	4.88		<0.001	<0.001	0.055	<0.001	0.139		0.004			<0.01	<0.005				2.4	
M313W	11/11/2015	8.3	6890	3870	<1	<1	666	667	2	1910	22	4	1250	56	<0.01	<0.001	<0.001	2.8		<0.001	<0.001	0.002	<0.001	0.099		0.002			<0.01	<0.005				2.4	0.87
M313W	30/05/2016	8.48	4570	2420	<1	41	443	484	2	1130	10	1	1000	60		<0.001	<0.001	1.23	<0.001	<0.001	<0.001	<0.001	<0.001	0.04	0.017	<0.001	<0.01	1.39	<0.01	0.008	0.5	0.28			0.6
M313W	15/11/2016	7.8	5620	2950	<1	<1	634	634	<1	1420	20	3	1170	62		0.002	<0.001	2.63	<0.001	<0.001	<0.001	0.002	<0.001	0.077	0.035	0.003	<0.01	3.02	<0.01	0.018	0.95	1.08		2.3	0.89
M313W	19/11/2017	8.59	6020	3320	<1	48	587	636	<1	1720	24	4	1370	60		0.003	<0.001	2.54		<0.001	<0.001	<0.001	<0.001	0.071	0.035	0.002	<0.01		<0.01	<0.005	0.92	0.57		2	
M313W	16/11/2018	8.05	5840	3210	<1	4	621	625	<1	1350	24	4	1200	61		0.003	<0.001	2.25		<0.001	<0.001	0.002	<0.001	0.106	0.039	0.002	<0.01		<0.01	<0.005	0.81	1.07		1.9	0.77
M313W	14/11/2019	7.99	6030	3360	<1	<1	621	621	2	1600	20	4	1260	55		0.003	<0.001	2.42		<0.001	<0.001	<0.001	<0.001	0.088	0.041	0.002	<0.01		<0.01	<0.005	0.88	0.45		2.1	0.68
M313W	23/11/2020	8.23	6020	3390	<1	<1	648	648	1	1700	26	5	1520	67		0.003	<0.001	2.85		<0.001	<0.001	<0.001	<0.001	0.082	0.055	0.003	<0.01		<0.01	<0.005	1.31	1.4		2.2	0.65
M313W	29/10/2021	8.18	5740	3510	<1	19	624	643	<1	1530	21	5	1320	62		0.003	<0.001	2.18		<0.001	<0.001	<0.001	<0.001	0.074	0.044	0.002	<0.01		<0.01	<0.005	0.95	0.76		2	0.69
M314W	24/07/2014	8.57	5090	4790	<1	9	1210	1220	134	198	46	1	212	1450		0.013	<0.001	0.575		0.015	0.005	7.08	0.562	0.446		0.018			<0.01	0.472				0.4	
M314W	13/02/2015	8.04	7150	5470	<1	<1	1180	1180	69	1370	29	6	1040	795		0.004	<0.001	1.37		<0.001	0.002	0.995	<0.001	0.141		0.01			<0.01	<0.005				0.9	
M314W	13/11/2015	8.01	8210	5280	<1	<1	836	836	2	2190	17	5	1420	335		0.003	<0.001	1.31		<0.001	<0.001	0.031	<0.001	0.14		0.013			<0.01	0.011				1.1	17.4
M314W	30/05/2016	8.6	8500	4880	<1	49	767	817	<1	2370	22	6	1640	326		0.003	<0.001	5.21	<0.001		<0.001	0.022	<0.001	0.028	0.053	0.001	<0.01	5.5	<0.01	0.01	0.87	0.1	0.87		9.67
M314W	15/11/2016	8.88	8180	4810	<1	108	827	934	<1	2290	19	6	1500	404		0.004	<0.001	3.88	<0.001	<0.001	<0.001	0.03	<0.001	0.036	0.062	0.002	<0.01	3.67	<0.01	0.009	0.9	0.21		1.3	12.1
M314W	18/11/2017	8.9	8300	4860	<1	169	908	1080	<1	2190	17	5	1880	543		0.004	<0.001	2.91		<0.001	<0.001	0.024	<0.001	0.053	0.068	0.002	<0.01		<0.01	<0.005	0.76	0.18		1.2	
M314W	20/11/2018	8.72	8010	4910	<1	142	892	1030	<1	2010	15	5	1530	459		0.005	<0.001	2.86		<0.001	<0.001	0.024	<0.001	0.057	0.078	0.002	<0.01		<0.01	<0.005	0.81	0.29		1.2	13.1
M314W	16/11/2019	8.59	7910	4900	<1	86	991	1080	2	1860	8	4	1460	465		0.005	<0.001	2.43		<0.001	<0.001	0.024	<0.001	0.068	0.082	0.003	<0.01		<0.01	<0.005	0.77	0.33		1.3	13.8
M314W	24/11/2020	8.64	7880	4510	<1	37	1010	1050	5	2130	10	4	1610	506		0.006	<0.001	2.82		<0.001	<0.001	0.021	<0.001	0.073	0.089	0.003	<0.01		<0.01	<0.005	0.91	0.59		1.3	14.5
M314W	31/10/2021	8.36	7620	5020	<1	73	992	1060	<1	1910	6	4	1500	468		0.006	<0.001	2.44		<0.001	<0.001	0.017	<0.001	0.025	0.078	0.002	<0.01		<0.01	<0.005	0.79	0.7		1.2	15.3
GR067V	30/08/2016	9.05	7020	4000	<1	407	1550	1960	19	1180	7	1	1580	14		0.003	<0.001	1.48	0.001	0.001	<0.001	0.002	<0.001	0.11	0.032	0.006	<0.01	1.18	<0.01	0.011	0.81	1.56			
GR067V	15/11/2016	8.12	7850	4640	<1	<1	2310	2310	3	1260	15	3	1850	13		0.003	<0.001	4.94	0.001	0.001	<0.001	<0.001	<0.001	0.024	0.024	0.001	<0.01	3.72	<0.01	0.018	1.17	0.68		1.8	
GR067V	19/11/2017	8.72	8210	4910	<1	238	2120	2360	4	1440	19	3	2190	12		0.003	<0.001	3.83		<0.001	<0.001	<0.001	<0.001	0.008	0.019	<0.001	<0.01		<0.01	0.008	1.03	0.16		1.7	
GR067V	23/11/2018	8.46	8340	6020	<1	456	1950	2410	7	1460	18	3	2050	12		0.002	<0.001	4.44		<0.001	<0.001	<0.001	<0.001	0.008	0.023	<0.001	<0.01		<0.01	0.008	1.18	0.22		2	
GR067V	16/11/2019	8.19	7950	4950	<1	47	2380	2420	7	1350	7	3	2040	9		0.002	<0.001	3.23		<0.001	<0.001	<0.001	<0.001	0.009	0.019	<0.001	<0.01		<0.01	0.005	1.28	0.29		2	
GR067V	24/11/2020	8.73	7980	5040	<1	111	2240	2350	12	1520	7	3	1860	10		0.003	<0.001	5.28		<0.001	<0.001	<0.001	<0.001	0.014	0.03	<0.001	<0.01		<0.01	<0.005	1.56	0.54		2.2	
GR067V	31/10/2021	8.44	7700	5240	<1	223	2070	2300	22	1410	6	3	1980	10		0.002	<0.001	4.06		<0.001	<0.001	0.001	<0.001	0.012	0.017	<0.001	<0.01		<0.01	<0.005	1.39	0.32		1.9	0.44
M162V	14/11/2015	8.44	11500	6970	<1	38	1060	1090	3	3640	10	6	2370	12		<0.001	<0.001	0.236		<0.001	<0.001	<0.001	<0.001	0.092		<0.001			<0.01	<0.005				1.9	
M162V	30/05/2016	7.91	12700	7250	<1	<1	1050	1050	2	4040	56	19	2590	12		<0.001	<0.001	11	<0.001	<0.001	<0.001	0.01	<0.001	0.063	0.002	0.001	<0.01	10.8	<0.01	0.16	2.4	3			
M162V	15/11/2016	7.7	12300	6660	<1	<1	1060	1060	<1	3870	69	18	2670	12		<0.001	<0.001	9.93	<0.001	<0.001	<0.001	<0.001	<0.001	0.034	0.001	<0.001	<0.01	9.77	<0.01	0.032	2.02	2.19		2.6	
M134W	14/11/2017	8.1	15600	9810	<1	<1	168	168	<1	5770	209	62	3490	12		<0.001	<0.001	23		<0.001	<0.001	<0.001	<0.001	0.064	0.001	<0.001	<0.01		<0.01	0.009	0.46	0.4		0.5	
M134W	215/11/2018	7.3	16000	9710	<1	<1	159	159	<1	5310	182	61	2990	12		<0.001	<0.001	20.3		<0.001	<0.001	0.002	<0.001	0.063	0.001	<0.001	<0.01		<0.01	0.011	0.48	0.3		0.5	
M134W	14/11/2019	7.27	15500	9670	<1	<1	162	162	1	5460	134	58	3200	12		0.002	<0.001	20.2		<0.001	0.005	<0.001	<0.001	0.098	0.007	0.02	<0.01		<0.01	0.02	0.47	1.18		0.5	
M134W	24/11/2020	7.73	15500	9430	<1	<1	166	166	<1	5850	114	55	3100	11	<0.01							<0.001		0.068						0.011	0.49	0.45	<0.0001	0.6	
GM031V	21/12/2021	8.06	10170	5750	<1	<1	694	694	<1	3300	20	11	2240	6		<0.001	<0.001			<0.001	<0.001	0.006	<0.001	0.011	0.002	<0.001	<0.01		<0.01	0.007	1.11	0.07		1.5	
MB1-D	17/11/2019	7.95	8790	5110	<1	<1	817	817	<1	2250	14	12	1900	16		0.002	<0.001	4.29		<0.001	0.001	0.005	0.008	0.049	0.018	0.036	<0.01		<0.01	0.045	1.04	1.53		2.2	
MB1-D	20/11/2020	8.26	9380	5460	<1	<1	1600	1600	<1	2560	14	10	2410	24		0.003	<0.001	4.12		<0.001	<0.001	0.002	0.006	0.015	0.017	0.032	<0.01		<0.01	0.024	1.68	1.14	<0.0001	2	
MB1-D	27/10/2021	8.15	8600	5320	<1	<1	1870	1870	<1	1970	12	6	2010	21		0.002	<0.001	2.72		<0.001	<0.001	<0.001	0.004	0.007	0.014	0.01	<0.01		<0.01	<0.005	1.19	0.56		2	
GW007B	15/11/2019	6.79	15700	9910	<1	<1	1380	1380	<1	4920	276	256	2330	64		0.005	<0.001	12.2		<0.001	0.001	<0.001	<0.001	0.12	0.006	0.02	<0.01		<0.01	2.16	0.24	2.94		0.2	
M324W	26/07/2014	9.17	1170	707	<1	48	177	225	24	188	26	5	199	31		0.005	<0.001	0.31		0.004	0.004	0.582	0.459	0.304		0.008			<0.01	0.427				1	
M324W	13/02/2015	8.83	2660	1540	<1	105	615	720	1	505	7	2	627	29		<0.001	<0.001	0.482		<0.001	<0.001	<0.001	<0.001	0.018		0.002			<0.01	0.093				3.7	
M324W	30/05/2016	8.57	2750	1390	<1	64	624	688	6	522	6	1	599	12		<0.001	<0.001	0.921	<0.001	<0.001	<0.001	<0.001	<0.001	0.025	0.02	<0.001	<0.01	0.889	<0.01	0.006	0.76	0.22			0.46
M324W	15/11/2016	8.58	2650	1540	<1	59	635	694	<1	503	5	1	612	12		0.001	<0.001	0.738	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	0.024	<0.001	<0.01	0.807	<0.01	0.01	0.78	0.13		4.5	0.44
M324W	19/11/2017	8.86	2740	1300	<1	104	568	672	<1	536	4	1	666	13		0.001	<0.001	0.572		<0.001	<0.001	<0.001	<0.001	0.006	0.027	<0.001	<0.01		<0.01	<0.005	0.72	<0.05		3.9	
M324W	16/11/2018	8.66	2740	1520	<1	86	565	651	<1	507	3	1	579	13		0.001	<0.001	0.555		<0.001	<0.001	0.001	<0.001	0.006	0.031	<0.001	<0.01		<0.01	<0.005	0.74	0.12		3.8	0.49
M324W	14/11/2019	8.7	2690	1530	<1	74	571	645	1	524	2	<1	595	12		0.001	<0.001	0.56		<0.001	<0.001	<0.001	0.001	0.005	0.03	<0.001	<0.01		<0.01	<0.005	0.72	0.2		4.3	0.49
M324W	23/11/2020	8.99	2590	1480	<1	92	556	648	<1	566	1	1	748	15		0.001	<0.001	0.584		<0.001	<0.001	0.002	0.002	0.005	0.044	<0.001	<0.01		<0.01	0.005	0.99	0.22		4.3	0.57
M324W	29/10/2021	8.89	2650	1570	<1	87	552	639	<1	529	<1	<1	612	13		0.001	<0.001	0.433		<0.001	<0.001	<0.001	0.002	0.004	0.036	<0.001	<0.01		<0.01	<0.005	0.77	0.18		3.8	0.59
M325W	13/02/2015	8.55	3410	2260	<1	14	252	297	68	906	2	<1	709	73		0.002	<0.001	0.005		<0.001	0.003	0.016	<0.001	0.009		0.009			<0.01	0.024				0.7	
M325W	13/11/2015	8.13	5000	2730	<1	<1	450	450	4	1400	8	1	919	40		0.001	<0.001	0.252		<0.001	0.002	<0.001	<0.001	0.086		<0.001			<0.01	<0.005				1.1	
M325W	30/05/2016	8.74	6150	3310	<1	75	370	446	1	1600	6	<1	1250	39		0.002	<0.001	0.384	<0.001	<0.001	<0.001	0.008	<0.001	0.057	0.114	0.002	<0.01	0.639	<0.01	0.009	1.17	0.24			
AN019F	10/11/2015	11.8	10200	5430	456	82	<1	539	33	2920	154	<1	1620	19		0.002	<0.001	2.79		<0.001	<0.001	0.006	<0.001	<0.001		0.007			<0.01	0.01				0.8	0.04
AN019F	30/05/2016	11.6	10800	5970	410	100	<1	510	38	3180	168	<1	1840	29		0.004	<0.001	3.25	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.056	0.008	<0.01	8.18	<0.01	<0.005	0.42	<0.05	0.42		0.05
AN019F	15/11/2016	11.8	11100	6140	428	125	<1	553	37	3400	162	<1	1970	28		0.004	<0.001	2.65	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.036	0.006	<0.01	5.92	<0.01	0.014	0.46	<0.05		0.7	<0.05
AN019F	15/11/2017	11.1	10700	5890	123	135	<1	258	35	3340	104	<1	2330	27		0.004	<0.001	2.4		<0.001	<0.001	<0.001	<0.001	<0.001	0.027	0.003	<0.01		<0.01	0.006	0.45	<0.05		0.7	
AN019F	11/11/2019	11.41	10700	6550	195	125	<1	319	32	3540	82	<1	2280	23		0.004	<0.001	2.34		<0.001	<0.001	<0.001	<0.001	<0.001	0.024	0.002	<0.01		<0.01	<0.005	0.57	<0.05		0.8	<0.01
AN019F	21/11/2020	11.37	10800	5750	230	61	<1	291	29	3670	63	<1	2590	24		0.004	<0.001	2.86		<0.001	<0.001	<0.001	<0.001	<0.001	0.03	0.002	<0.01		<0.01	<0.005	0.75	<0.05		0.8	<0.01
AN019F	30/11/2021	11.43	10000	6040	66	157	<1	223	26	3410	41	<1	2120	20		0.004	<0.001	2.41		<0.001	<0.001	<0.001	<0.001	<0.001	0.019	0.002	<0.01		<0.01	<0.005	0.47	<0.05		0.7	0.08

arrow energy go further

APPENDIX C – Australian Groundwater and Environmental Consultants Pty Ltd (AGE) - Arrow Project – Bowen Sector & Regional model results

Australasian Groundwater
and Environmental Consultants Pty Ltd
Level 2 / 15 Mallon Street
Bowen Hills, QLD 4006 Australia

ABN 64 080 238 642
T. +61 7 3257 2055
F. +61 7 3257 2088
brisbane@ageconsultants.com.au
www.ageconsultants.com.au

Memorandum

Project number	G1885G
To	St.John Herbert
From	Neil Manewell
Date	5 March 2021
RE	**Bowen Sector & Regional model results**

1 Introduction

This document provides a summary of a local sector model and a revised regional model developed to simulate additional production from the Red Hill field to the north of the Moranbah Gas Project (MGP) CSG production area. The Red Hill Development is a relatively small (~5.5 km^2) addition to Arrow development in the area, consisting of 14 multi-lateral production wells extracting gas from the Goonyella coal measures.

The impact of the additional development has been assessed using both the local sector model and the revised regional model. Predictions made using the latter regional model therefore relate to the cumulative impacts of all proposed Arrow developments in the area.

2 Background

The original Northern Bowen Basin numerical groundwater model was developed by Ausenco Norwest for Arrow Energy in 2012 to predict and delineate areas where predicted groundwater level drawdowns exceed the Queensland Department of Environmental and Heritage Protection (DEHP) threshold criteria. The model was built in MODFLOW-SURFACT™ using the Groundwater Vistas 6 software package. A uniform mesh of 1500 m x 1500 m cells was simulated over 18 model layers (Norwest, 2012).

AGE updated the Ausenco Norwest model in 2017 by remeshing the model to increase the resolution of the mesh around the MGP area, to better delineate groundwater structures, and to increase the layer resolution within the Moranbah Coal Measures (MCM), increasing the total count to 22 layers. Pilot point multipliers were added to the aquifer/aquitard hydraulic and storage parameter fields and the model was calibrated to groundwater head data from January 2014 to November 2017. Updated measured and predicted production data from Arrow Energy was provided on a monthly basis, per production bore and used to revise the MODFLOW well input package (AGE, 2017).

3 Scope of Works

Production from the Red Hill field is scheduled to commence in February 2021. Gas will be extracted from the Goonyella Middle Seam and Lower Seams (Layers 15 and 17). This production was not simulated in the 2017 AGE model; hence the model mesh incorporates relatively large cell sizes in the Red Hill part of the model domain.

Arrow wishes to modify the current model to provide revised groundwater impact predictions for a new field development plan including development of the Red Hill area.

The objectives of the modelling work were to:

- develop a local sector model of the Red Hill development
- update the field development plan in the 2017 AGE regional model;
- change the regional model stress period setup;
- review and where necessary revise modelled specific storages values based on recent literature (Rau et al, 2018); and
- produce updated impact predictions.

4 Numerical model development

4.1 Regional and local model set up

Analysis of the groundwater impacts predicted using the 2017 AGE model suggest drawdowns of more than 5 m extending to approximately 2 km from the northern boundary of the MGP production field; approximately 2 km from the Red Hill field (AGE, 2017). GW001 is the closest monitoring bore to the MGP production field, situated approximately 5.6 km from the most northerly MGP extraction well (see Figure 4.1). Hence, it was considered unlikely that cumulative drawdown induced by the MGP would have a significant impact on GW001. Accordingly, a localised sector model (or sub-model) centred around the Red Hill development area was constructed initially to rapidly analyse future impacts due to Goonyella depressurisation. Subsequently the grid of the 2017 AGE regional model was also refined.

The original 22-layer setup from the 2017 model remained unchanged outside the Red Hill production area. The following cell dimensions were adopted for the Red Hill production areas for both the sector and regional models:

- 150 m cells within the Red Hill Production area, and
- 150 m cells centred at the location of each monitoring well.

Figure 4.1 and Figure 4.2 presents the adopted model cells over the entire sector and regional model domains and in the vicinity of the Red Hill production area, respectively.

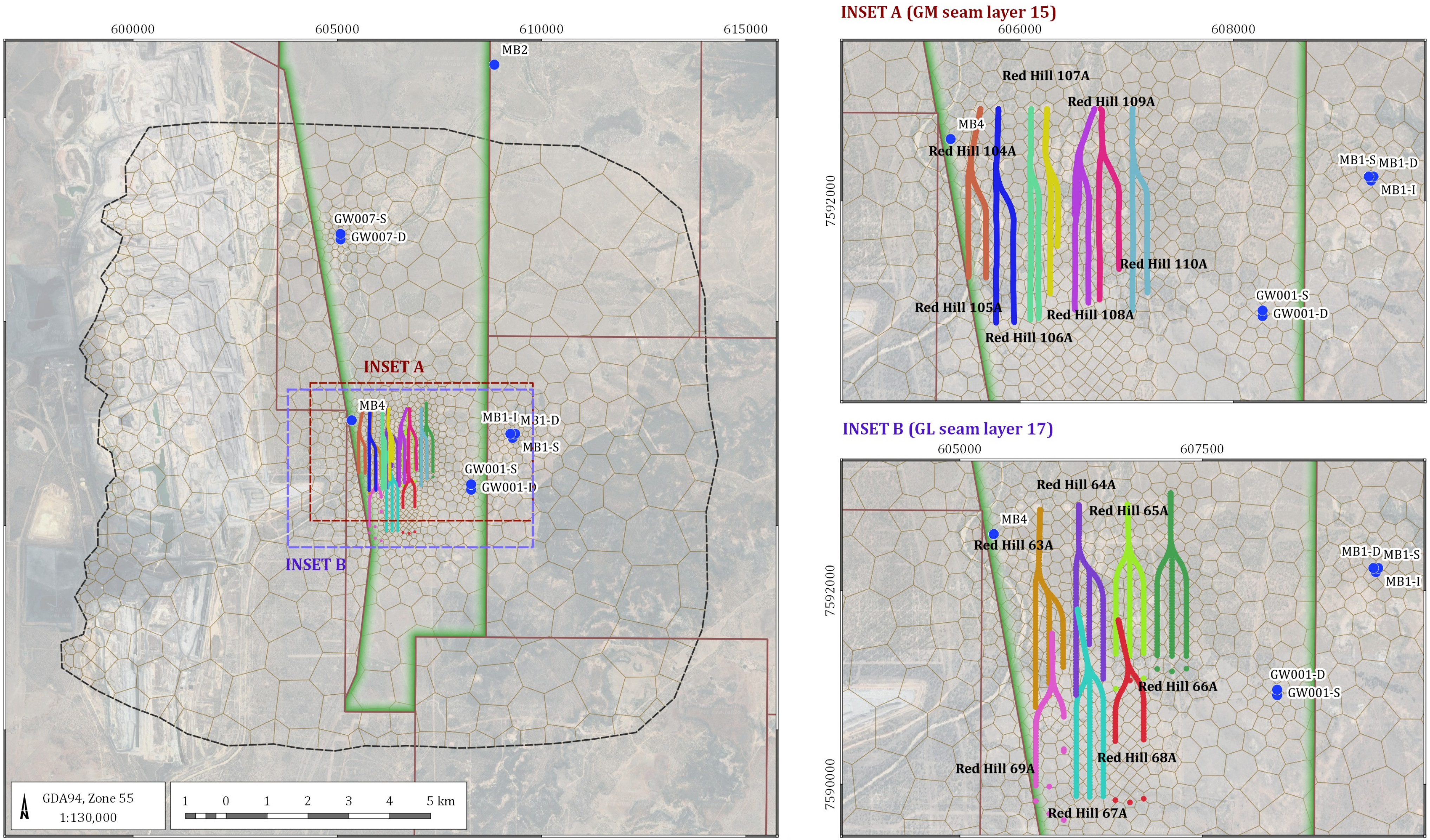
Overall, the sector model comprised of 18,450 cells across the 22 layers with significantly reduced model run times compared to the regional version. The refined regional model increased its cell count by 24,151 cells to a total of 212,667 cells across 22 layers.

The stress period setup for the sector model was as follows:

- 31 December 2003- steady state stress period, pre-mining initial conditions.
- January 2004 to May 2030 – 318 monthly stress periods.

A similar stress period setup was adopted for the regional model although longer model runs incorporating additional stress periods to year 2180 as follows:

- June to December 2099 – 1 seven-month and 69 yearly stress periods.
- January 2100 to 2180 – 1 six-year and 15 five-year stress periods.



LEGEND

- Bowen GMMP monitoring
- Petroleum lease
- Arrow Petroleum lease
- Model boundary
- Sector model grid

Arrow.BOWEN.Sector (G1885G)

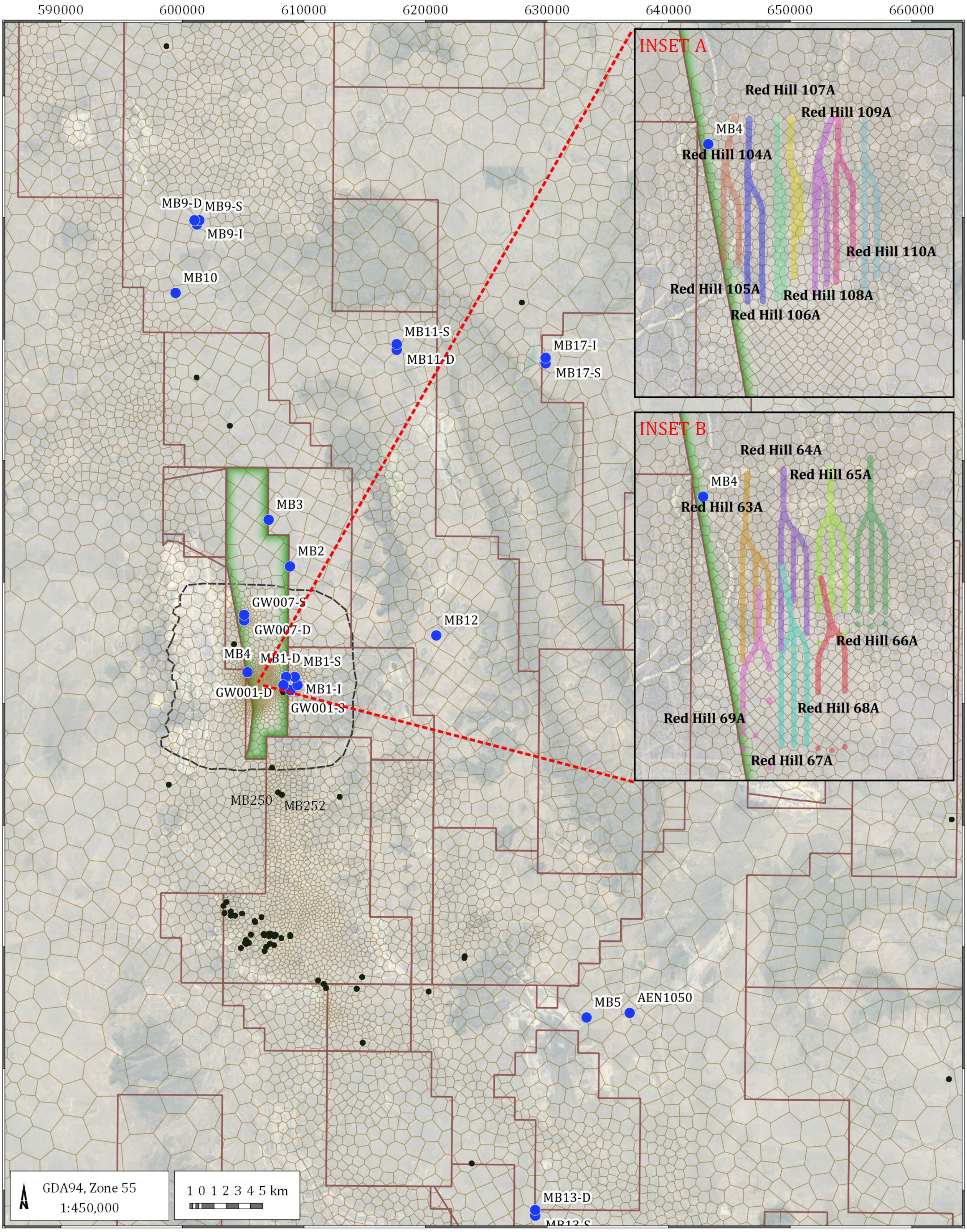
AGE

Sector model grid

DATE
05/03/2021

FIGURE No:
4.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1885G.Bowen Groundwater Model Update\3_GIS\Workspaces\001_Deliverable1\04.01_G1885G_Sector model grid.qgs



LEGEND

- Bowen GMMP monitoring
- Petroleum lease
- Arrow Petroleum lease
- Sector model boundary
- Regional model grid
- Regional monitoring bores

Red Hill GL seam (Layer - 17)

- Red Hill 63A
- Red Hill 64A
- Red Hill 65A
- Red Hill 66A
- Red Hill 67A
- Red Hill 68A
- Red Hill 69A

Arrow.BOWEN.Sector model (G1885G)

Regional model grid

DATE 05/03/2021

FIGURE No: **4.2**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1885B.GHD.Arrow.BOWEN.UWIR\3_GIS\Workspaces\003_Deliverable3\04.02_G1885G_Regional model grid.qgs

4.2 Well package (WEL) construction

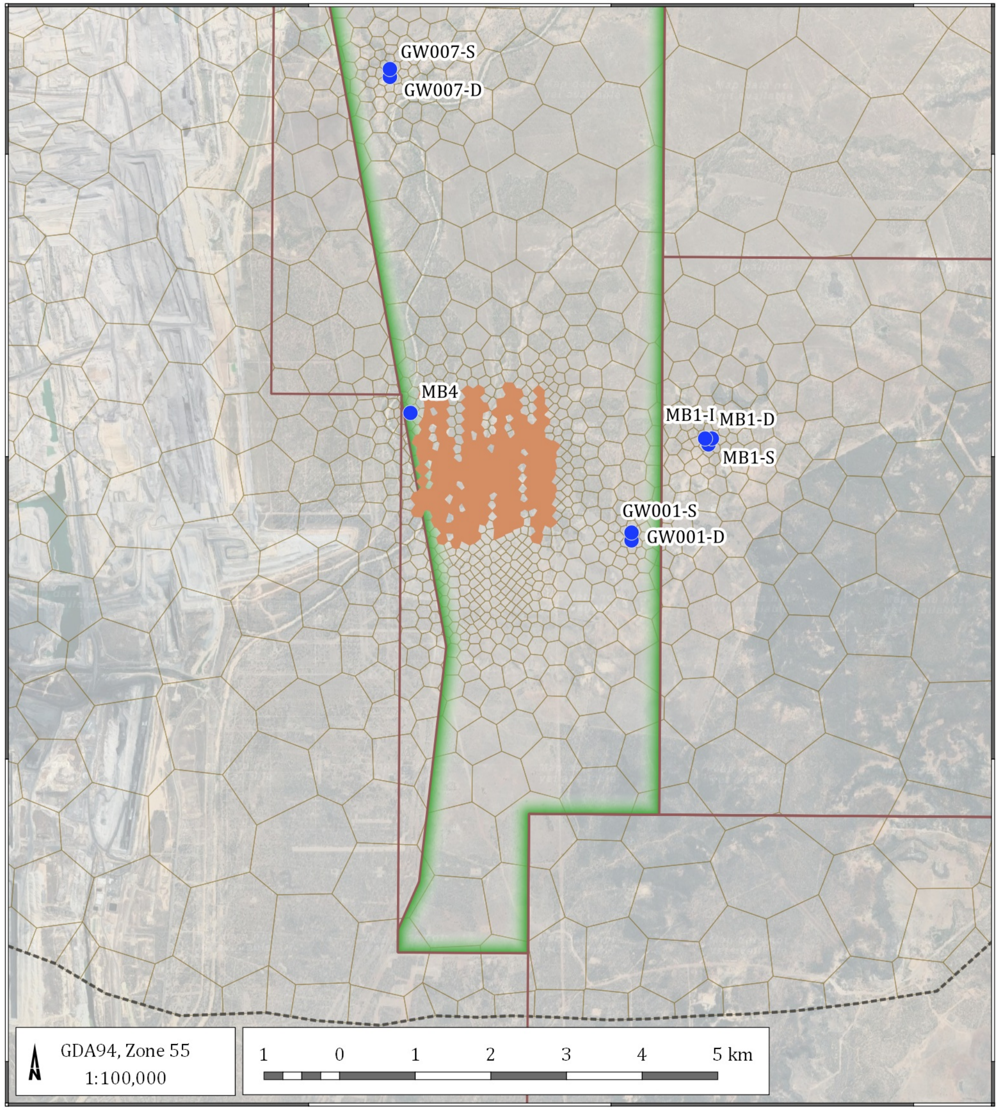
Monthly CSG well production data for all 14 Red Hill wells was provided by Arrow Energy. To best represent pumping in the model, a Fortran script was written to efficiently replicate future production in the sector model. Where a particular in-seam well intercepts a series of model cells, the WEL package was applied and the total flux rate was divided by the number of intercepted model cells.

Figure 4.3 show the model cells on the updated mesh, showing the start year for the Red Hill production simulated in the sector and regional models.

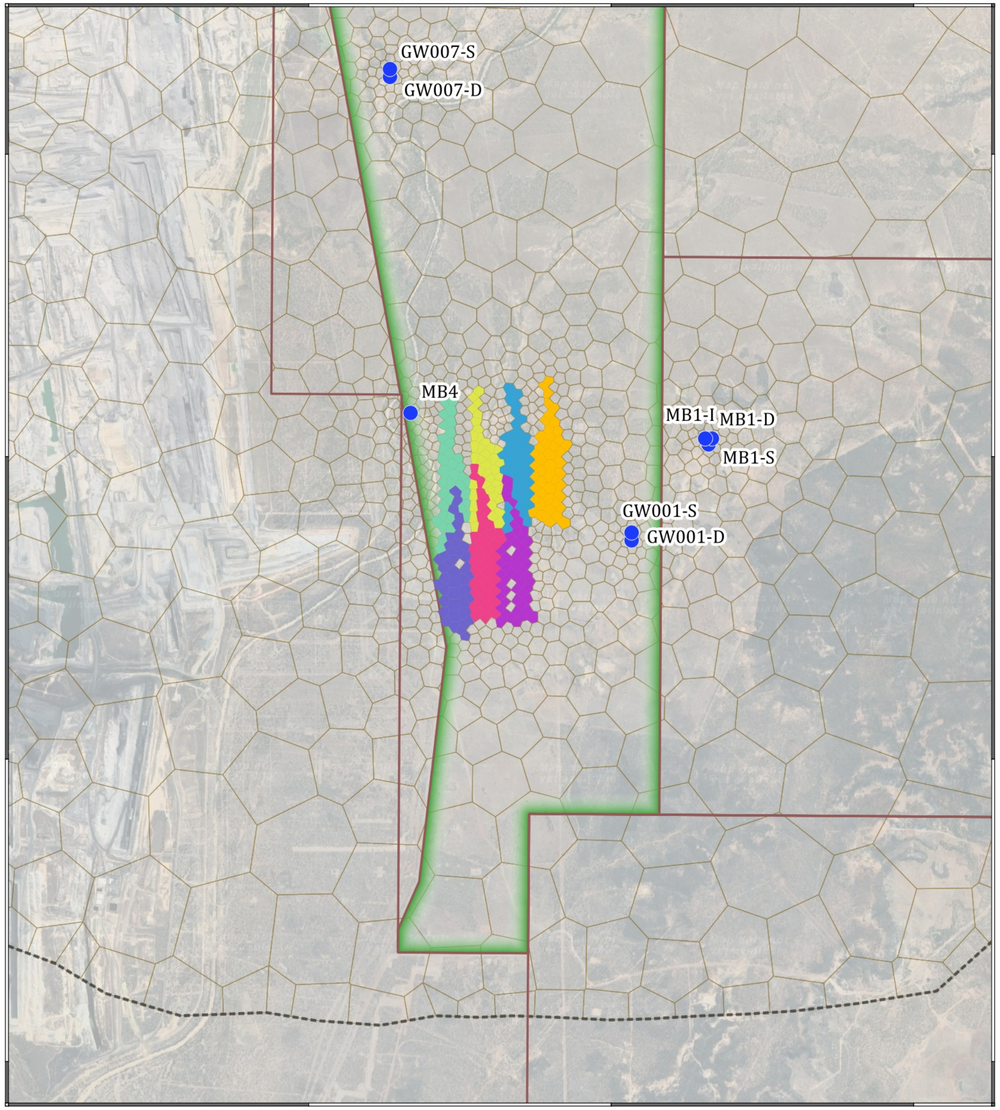
Figure 4.4 presents well production simulated in the sector and regional models.

Regional MGP and Mavis Downs production, as detailed in the AGE 2017 report, was unchanged. Bowen Gas Project (BGP) production was offset by three years to align with Arrows most recent field development plans.

Well production strat year - Layer 15 GM Seam



Well production strat year - Layer 17 GL Seam



LEGEND

- Bowen GMMP monitoring
- Petroleum lease
- Arrow Petroleum lease
- Model boundary
- Sector model grid

Start Year

1/02/2021	1/05/2024
1/02/2024	1/06/2024
1/03/2024	1/07/2024
1/04/2024	1/08/2024

Arrow.BOWEN.Sector (G1885G)

WEL production start year

DATE
05/03/2021

FIGURE No:
4.3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1885G.Bowen Groundwater Model Update\3_GIS\Workspaces\001_Deliverable1\04.03_G1885G_WEL production start year.qgs

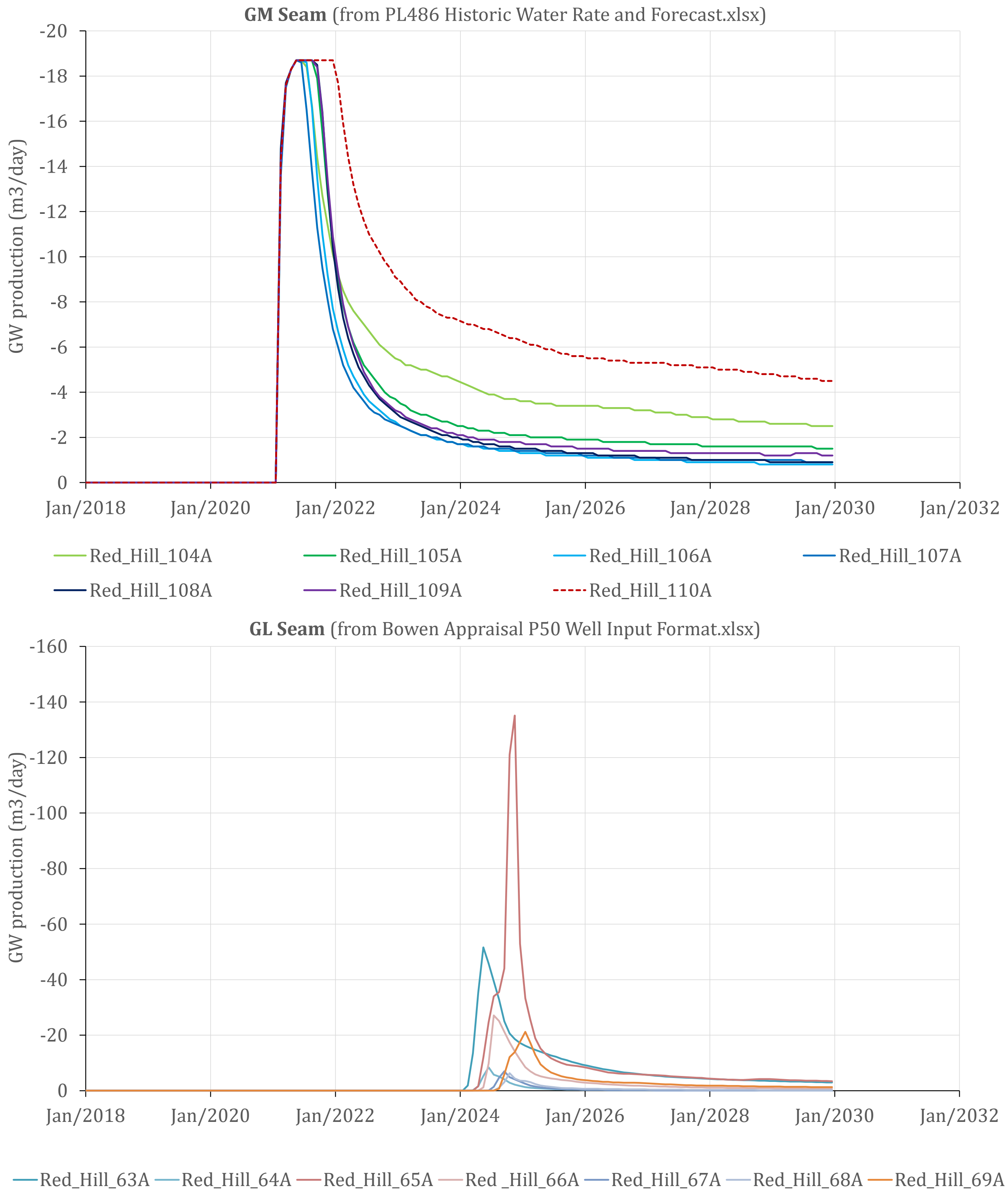


Figure 4.4 Red Hill production

4.3 Specific storage update

As discussed below since the development of the 2017 model, several papers have been released highlighting likely physical upper and lower bounds relating to specific storage. Specific storage represents the volume of water a portion of an aquifer (or aquitard) releases from storage, per unit change in hydraulic head, under fully saturated conditions. It is also known as 'elastic storage' as water can only be released from the decompression of the water, or compression of the aquifer.

To determine the magnitude and range for elastic storage, it is necessary to first understand the compressibility water, the compressibility of the aquifer matrix which contains the groundwater and the compressibility of the individual aquifer grains themselves.

Pells (2017) presented the following equation for specific storage based on poroelastic theory as part of a review of a proposed underground coal mine in NSW:

$$S_s = \rho_w g \left[\frac{(1+v)(1-2v)}{K(1-v)} + \theta\beta_w\right]$$

Where ρ_w is the density of water, g is the gravitational constant, β_w is water compressibility, v is Poisson's ratio, K is the bulk modulus, β_w is water compressibility, and θ is total porosity.

Rau et al (2018) described their work calculating uniaxial specific storage from undrained poroelastic properties, namely bulk modus, loading efficiency and the *Biot-Willis* coefficient. Specific storage was then derived using Loading efficiency (LE), derived from Barometric efficiency, the confined bulk modulus (K_v^u) and the Biot-Willis coefficient (α), as:

$$S_s = \rho_w g \frac{\alpha}{K_v^u LE(1-\alpha LE)}$$

Rau tested the methodology using field datasets collected at two sites with sand and clay dominated lithologies. Rau undertook a theoretical analysis using the equation outlined above to derive the physical limits of 2.3 x 10^{-7} m^{-1} and 1.3 x 10^{-5} m^{-1}.

Although the theoretically derived bounds presented in Rau (2018) use different combinations of elastic moduli to the Pells (2017) equation, and the relationships between the parameters possess inherent uncertainty at their upper and lower bounds, the results are consistent with the Pells (2017) relationship.

In light of these studies, it likely that the range of specific storage of the coal measures is between 1.0 x 10^{-6} m^{-1} and 4.0 x 10^{-6} $m^{-1.}$ The calibrated 2017 model simulated specific storage of approximately 8.5 x 10^{-5} m^{-1} in the coal measures, and the uncertainty analysis explored values as low as 1.0 x 10^{-7} m^{-1}, although these parameter values were considered 'unlikely'. Hence, the specific storage values in the sector model were updated by 'recentering' the average value in three different sensitivity scenarios which span the likely range.

Table 4.1 presents the range of specific storage parameters tested in this assessment.

Table 4.1 Range of specific storage tested in sector model

Scenario	Coal Measures average Ss (m^{-1})	Interburden average Ss (m^{-1})	Tertiary average Ss (m^{-1})
Lower Pells bound	1.0 x 10^{-6}	1.0 x 10^{-6}	1.0 x 10^{-6} - 2.0 x 10^{-5}
Pells bound	4.0 x 10^{-6}	4.0 x 10^{-6}	1.0 x 10^{-6} - 2.0 x 10^{-5}
Upper Rau bound	2.0 x 10^{-5}	1.0 x 10^{-6}	1.0 x 10^{-6} - 2.0 x 10^{-5}

5 Drawdown predictions

5.1 Sector model

Table 5.1 presents the drawdown at the four Arrow groundwater monitoring bores within the sector model domain from 2020 to 2030. There is uncertainty regarding the construction details of the monitoring bores, therefore all major aquifer units present in the model at each location were extracted. The numbers at the end of the bore name indicate the layer the head was extracted from. The bold lines indicate the most likely screened section.

Table 5.1 Predicted maximum drawdown (sector model)

Bore	Unit	Upper Rau bound (2E-05)		Pells bound (4E-06)		Lower Pells bound (1E-06)	
		Date when >5 m drawdown occurs	Max drawdown (m)	Date when >5 m drawdown occurs	Maximum drawdown (m)	Date when >5 m drawdown	Max drawdown (m)
GW001-S_01	**Alluvium/ Regolith**	**NA**	**0.00**	**NA**	**0.00**	**NA**	**0.00**
GW001-D_08	FCCM	NA	0.00	NA	0.00	NA	0.00
GW001-D_09	FCCM	NA	0.00	NA	0.00	NA	0.00
GW001-D_10	**FCCM**	**NA**	**0.00**	**NA**	**0.00**	**NA**	**0.00**
GW001-D_11	MCM	NA	0.00	NA	0.00	NA	0.01
GW001-D_13	MCM	NA	0.01	NA	0.06	NA	0.95
GW001-D_15	MCM	NA	4.50	1/09/2022	50.75	1/07/2021	88.82
GW001-D_17	MCM	NA	0.18	1/04/2027	15.63	1/12/2024	49.66
GW007-S_01	**Alluvium/ Regolith**	**NA**	**0.01**	**NA**	**0.01**	**NA**	**0.01**
GW007-D_09	FCCM	NA	0.00	NA	0.00	NA	0.01
GW007-D_10	**FCCM**	**NA**	**0.00**	**NA**	**0.00**	**NA**	**0.00**
GW007-D_11	MCM	NA	0.01	NA	0.01	NA	0.01
GW007-D_13	MCM	NA	0.00	NA	0.02	NA	0.46
GW007-D_15	MCM	NA	0.09	NA	1.27	NA	2.35
GW007-D_17	MCM	NA	0.00	NA	0.23	NA	1.32
MB1-S_01	Alluvium/Regolith	NA	0.00	NA	0.00	NA	0.00
MB1-I_08	FCCM	NA	0.00	NA	0.00	NA	0.00
MB1-I_09	FCCM	NA	0.00	NA	0.00	NA	0.00
MB1-I_10	FCCM	NA	0.00	NA	0.00	NA	0.00
MB1-D_11	MCM	NA	0.00	NA	0.00	NA	0.01
MB1-D_13	MCM	NA	0.00	NA	0.01	NA	0.64
MB1-D_15	MCM	NA	0.00	NA	4.25	1/05/2023	19.14
MB1-D_17	MCM	NA	0.00	NA	0.06	1/04/2029	6.12
MB4_01	Alluvium/Regolith	NA	0.01	NA	0.01	NA	0.01
MB4_08	FCM	NA	0.01	NA	0.01	NA	0.01

Bore	Unit	Upper Rau bound (2E-05)		Pells bound (4E-06)		Lower Pells bound (1E-06)	
		Date when >5 m drawdown occurs	Max drawdown (m)	Date when >5 m drawdown occurs	Maximum drawdown (m)	Date when >5 m drawdown	Max drawdown (m)
MB4_09	FCM	NA	0.01	NA	0.01	NA	0.01
MB4_10	FCM	NA	0.00	NA	0.00	NA	0.00
MB4_11	MCM	NA	0.01	NA	0.01	NA	0.01
MB4_13	MCM	NA	0.03	NA	0.07	NA	0.77
MB4_15	MCM	1/06/2021	37.56	1/03/2021	104.47	1/03/2021	168.45
MB4_17	MCM	1/05/2025	16.48	1/06/2024	51.41	1/04/2024	97.06

The results indicate that GW001 and GW007 are unlikely to experience groundwater drawdown, given that the depth of these bores indicates they are constructed in the Fort Cooper Coal measures (FCCM) and above. MB4 is situated within the production field, so is predicted to experience groundwater drawdown exceeding 5 m in 2021. Results also suggest that MB1 will experience groundwater drawdown exceeding 5 m in May 2023.

Figure 5.1 presents a cross-section of modelled groundwater levels in the Goonyella Middle seam in April 2024 (upper panel). As shown groundwater levels remain well above the GM seam where the Upper Rau bound (SS of 2E-05 m^{-1}) is applied to the calibrated model. Conversely, scenarios simulating lower specific storage result in groundwater levels at or close to the top of the GM seam. Groundwater levels recovers faster in the scenarios with higher specific storage as less water is displaced, whereas the lower Pells bound scenario maintains some depressurisation down the GM seam until September 2027 (lower panel).

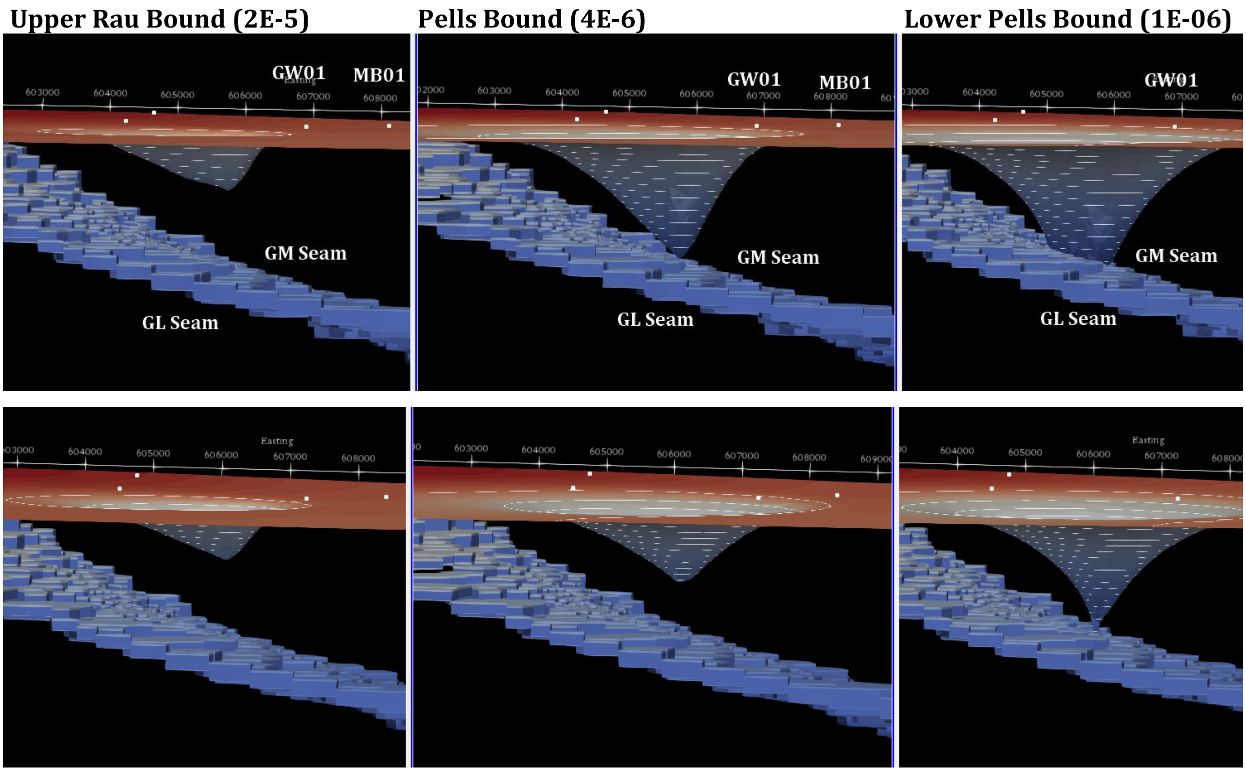
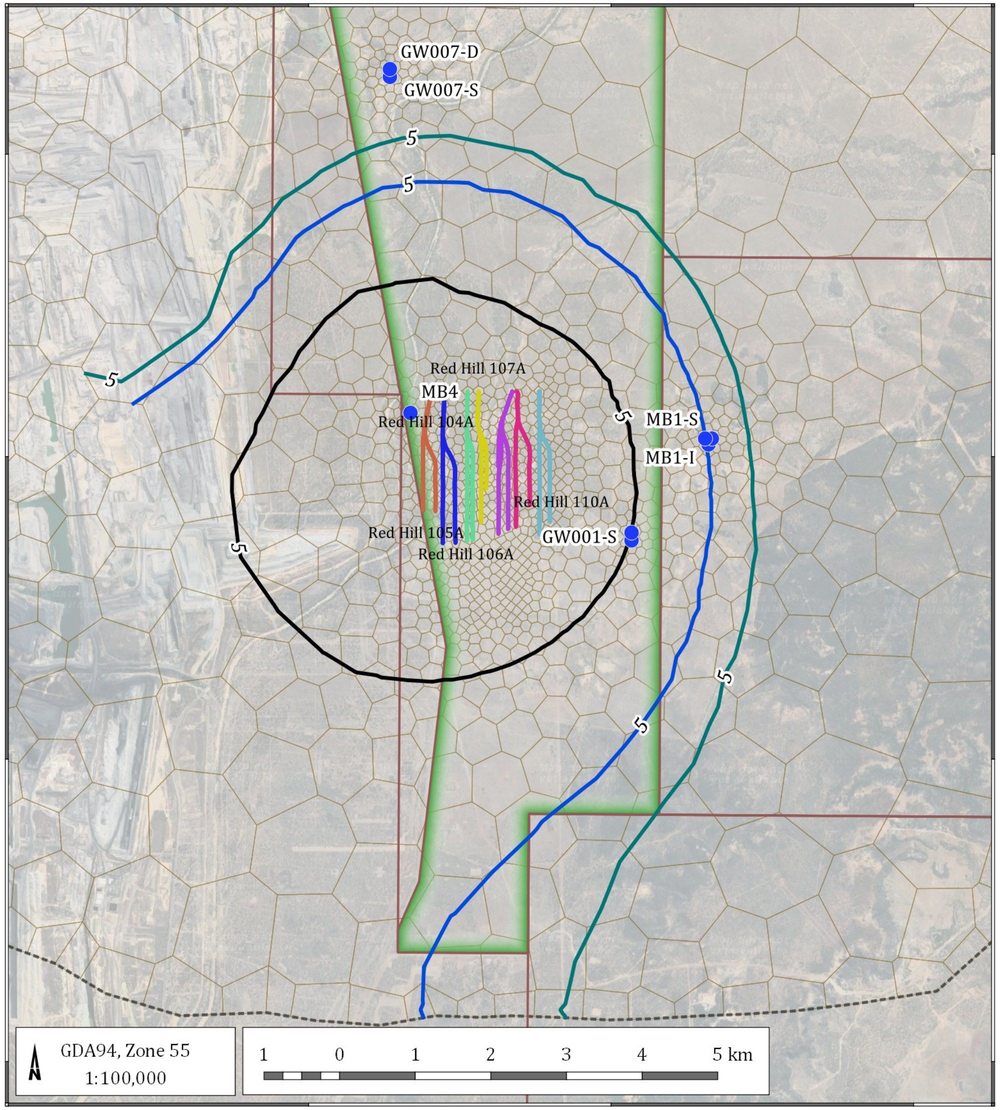
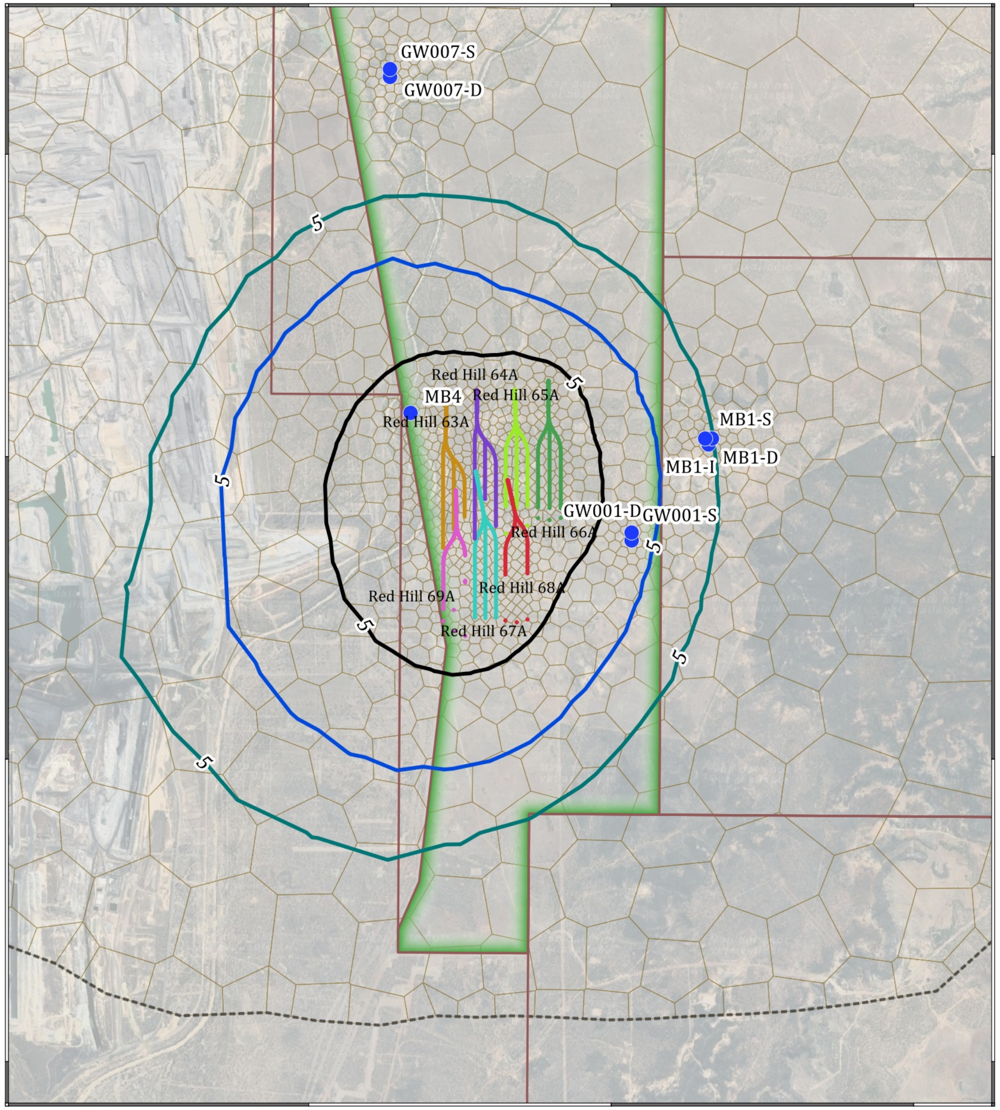


Figure 5.1 Cross section of GM head pressure (April 2024 and September 2027)

Drawdown contour (5 m) - Layer 15 GM Seam



Drawdown contour (5 m) - Layer 17 GL Seam



LEGEND

- Bowen GMMP monitoring
- Petroleum lease
- Arrow Petroleum lease
- Model boundary
- Sector model grid
- 5m drawdown contour - Upper Rau bound (2E-05)
- 5m drawdown contour - Pells bound (4E-06)
- 5m drawdown contour -Lower Pells bound (1E-06)

CSG production well

GM seam (Layer - 15)	**GL seam (Layer - 17)**
Red Hill 104A	Red Hill 63A
Red Hill 105A	Red Hill 64A
Red Hill 106A	Red Hill 65A
Red Hill 107A	Red Hill 66A
Red Hill 108A	Red Hill 67A
Red Hill 109A	Red Hill 68A
Red Hill 110A	Red Hill 69A

Arrow.BOWEN.Sector (G1885G)

AGE

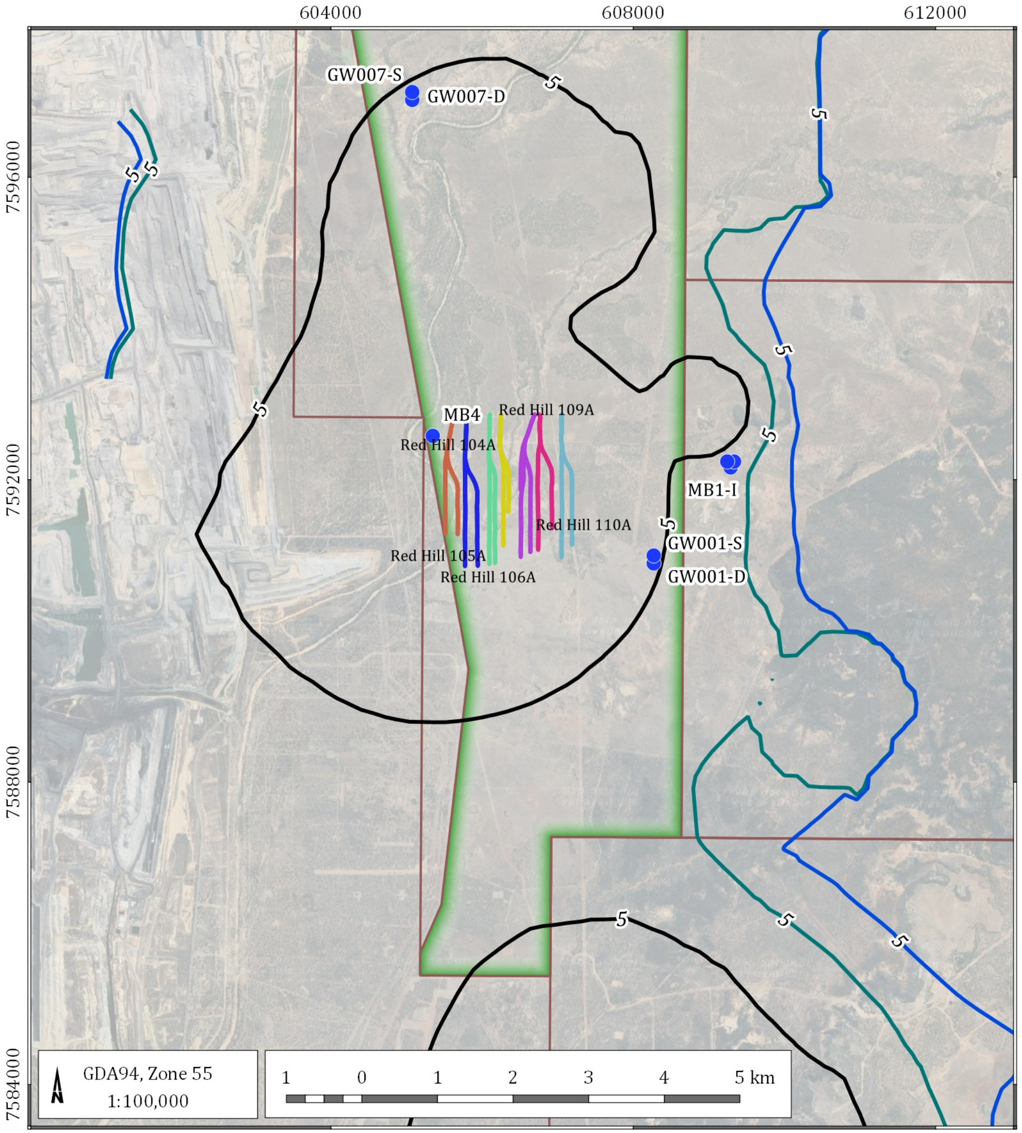
Sensitivity of maximum Red Hill drawdown (2020 to 2030)

DATE
05/03/2021

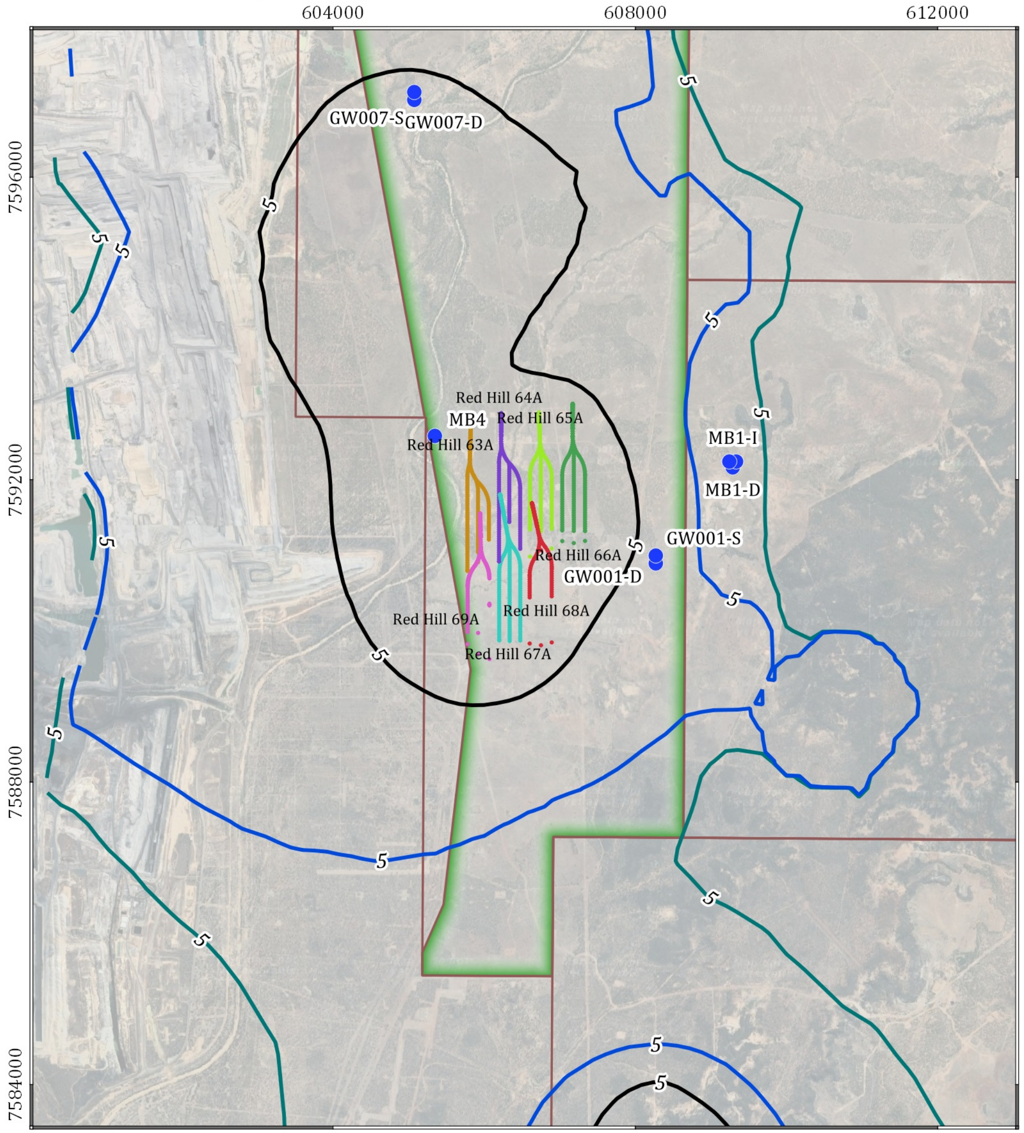
FIGURE No:
5.2

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1885G.Bowen Groundwater Model Update\3_GIS\Workspaces\001_Deliverable1\05.02_G1885G_Sensitivity of maximum Red Hill drawdown (2020 to 2030).qgs

Drawdown contour (5 m) - Layer 15 GM Seam



Drawdown contour (5 m) - Layer 17 GL Seam



LEGEND

- Bowen GMMP monitoring
- Petroleum lease
- Arrow Petroleum lease
- Model boundary
- Sector model grid
- 5m drawdown contour - Upper Rau bound (2E-05)
- 5m drawdown contour - Pells bound (4E-06)
- 5m drawdown contour -Lower Pells bound (1E-06)

CSG production well

GM seam (Layer - 15)	GL seam (Layer - 17)
Red Hill 104A	Red Hill 63A
Red Hill 105A	Red Hill 64A
Red Hill 106A	Red Hill 65A
Red Hill 107A	Red Hill 66A
Red Hill 108A	Red Hill 67A
Red Hill 109A	Red Hill 68A
Red Hill 110A	Red Hill 69A

Arrow.BOWEN.Sector (G1885G)

Sensitivity of maximum Red Hill drawdown (2020 to 2030) - Regional model

DATE
05/03/2021

FIGURE No:
5.3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1885G.Bowen Groundwater Model Update\3_GIS\Workspaces\001_Deliverable1\05.03_G1885G_Sensitivity of maximum Red Hill drawdown (2020 to 2030).qgs

Figure 5.2 presents the sensitivity of maximum groundwater drawdown within the Goonyella Middle Seam (layer 15) and the Goonyella Lower Seam (layer 17) from 2020 to 2030 due to Red Hill Production to specific storage changes.

The results show that maximum drawdowns extends 2.5 km east and 3.3 km north of the Red Hill Production area are possible by 2030 if specific storage within the coal seams is 1×10^{-6} m^{-1}. Drawdown in the Goonyella Lower seam does not extend as far as the Goonyella Middle seam due to lower permeability and shorter CSG production.

Figure 5.3 presents maximum drawdown encountered in the regional model over the same period. The results show the effects of cumulative depressurisation of MGP and BGP production.

5.2 Regional model

Table 5.2 presents the drawdown at the four Arrow groundwater monitoring bores within the sector model domain from 2020 to 2180.

Table 5.2 Predicted maximum drawdown (regional model)

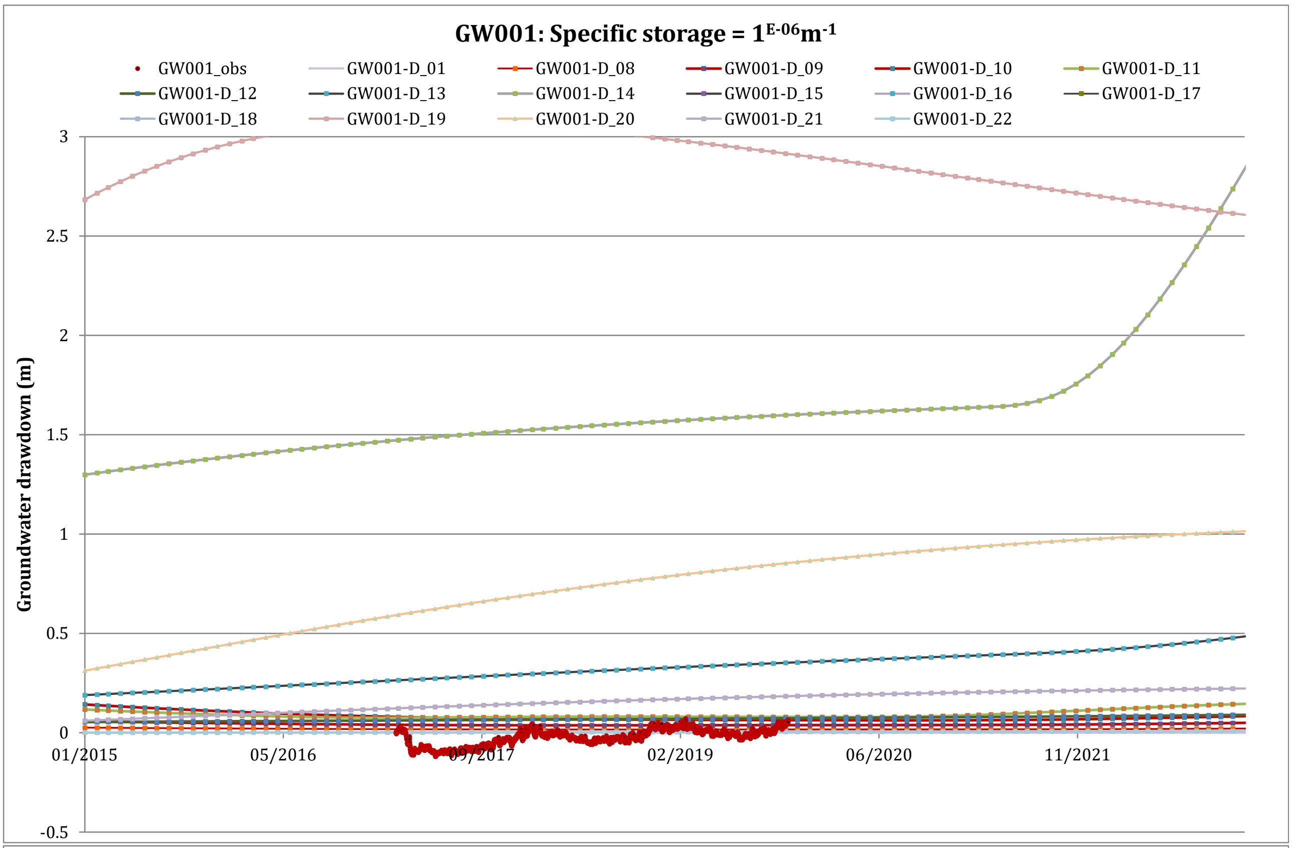
Bore	Unit	Upper Rau bound (2E-05)		Pells bound (4E-06)		Lower Pells bound (1E-06)	
		Date when >5 m drawdown occurs	Max drawdown (m)	Date when >5 m drawdown	Max drawdown (m)	Date when >5 m drawdown occurs	Max drawdown (m)
GW001-S_01	**Alluvium/ Regolith**	NA	0.01	NA	0.02	NA	0.04
GW001-D_08	FCCM	NA	0.41	NA	1.51	NA	3.40
GW001-D_09	FCCM	NA	0.95	NA	3.47	1/01/2035	7.82
GW001-D_10	**FCCM**	**NA**	**4.10**	**1/01/2035**	**14.22**	**1/01/2034**	**33.24**
GW001-D_11	MCM	1/01/2034	17.24	1/01/2034	50.66	1/01/2034	100.03
GW001-D_13	MCM	1/01/2034	20.48	1/01/2034	66.29	1/01/2034	141.74
GW001-D_15	MCM	1/04/2028	146.17	1/12/2011	173.59	1/09/2009	219.68
GW001-D_17	MCM	1/01/2036	107.46	1/09/2026	132.61	1/11/2010	195.77
GW007-S_01	**Alluvium/ Regolith**	**NA**	**0.03**	**NA**	**0.05**	**NA**	**0.07**
GW007-D_09	FCCM	NA	0.37	NA	1.26	NA	2.87
GW007-D_10	**FCCM**	**NA**	**1.38**	**NA**	**4.33**	**1/01/2034**	**8.23**
GW007-D_11	MCM	NA	3.63	1/01/2034	8.13	1/01/2034	16.40
GW007-D_13	MCM	1/01/2116	7.23	1/01/2043	8.22	1/01/2041	11.54
GW007-D_15	MCM	1/12/2028	64.79	1/02/2024	67.25	1/01/2035	21.75
GW007-D_17	MCM	1/04/2027	49.02	1/03/2024	61.82	1/04/2023	85.04
MB1-S_01	Alluvium/R egolith	NA	0.01	NA	0.03	NA	0.04
MB1-I_08	FCCM	NA	0.48	NA	1.83	NA	4.64
MB1-I_09	FCCM	NA	1.04	NA	4.02	1/01/2038	10.11
MB1-I_10	FCCM	NA	2.38	1/01/2043	9.57	1/01/2035	22.73
MB1-D_11	MCM	1/01/2054	5.61	1/01/2036	18.11	1/01/2034	32.46

Bore	Unit	Upper Rau bound (2E-05)		Pells bound (4E-06)		Lower Pells bound (1E-06)	
		Date when >5 m drawdown occurs	Max drawdown (m)	Date when >5 m drawdown	Max drawdown (m)	Date when >5 m drawdown occurs	Max drawdown (m)
MB1-D_13	MCM	1/01/2058	20.42	1/01/2038	52.50	1/01/2034	100.53
MB1-D_15	MCM	1/01/2052	81.50	1/02/2015	69.92	1/07/2012	147.76
MB1-D_17	MCM	1/01/2061	67.77	1/01/2049	72.93	1/01/2027	145.89
MB4_01	Alluvium/Regolith	NA	0.01	NA	0.02	NA	0.04
MB4_08	FCM	NA	0.03	NA	0.09	NA	0.19
MB4_09	FCM	NA	0.12	NA	0.39	NA	0.89
MB4_10	FCM	NA	0.61	NA	2.01	NA	4.19
MB4_11	MCM	NA	1.38	NA	4.07	1/01/2034	7.59
MB4_13	MCM	NA	4.55	1/01/2036	12.28	1/01/2034	26.26
MB4_15	MCM	1/05/2021	36.75	1/06/2011	100.08	1/08/2009	165.93
MB4_17	MCM	1/03/2025	21.17	1/07/2023	60.57	1/11/2010	111.41

The results indicate both abstraction from the pilot bores proximal to the Red Hill area and the effects of cumulative drawdown from the MGP + BGP exacerbates groundwater impacts at the monitoring bores. To validate the predictions above, observed groundwater drawdown at these locations was compared to the groundwater model predictions.

Figure 5.4 compares groundwater drawdown at bore GW001, located approximately 700 m east of BGP production. Observed drawdown (red points) is relative to the first reading in early 2017, whereas modelled drawdown (lines for each model layer) is relative to the no CSG production scenario. GW001 likely screens the alluvium (S - layer 1), and the Fort Cooper Coal Measures (D – layer 8 to 10). Observed groundwater level trends suggests drawdown of approximately 0.1 m are anticipated between 2017 and 2019. It is unknown if this rate of observed drawdown is associated with climate variation or CSG/coal mining depressurisation. Nevertheless, if the observation data is representative of the Fort Cooper coal measures, the model with the lowest specific storage values best replicates observed drawdown.

Figure 5.5 and Figure 5.6 present observed drawdown compared to total modelled drawdown at bores MB250 and MB252, located proximal to the MGP production area (see Figure 4.2). Detailed construction detail for these bores were not available and therefore significant uncertainty remains regarding which strata are monitored in of these bores. Regardless, simulated data suggests the model with lower specific storage best replicates observed drawdown.



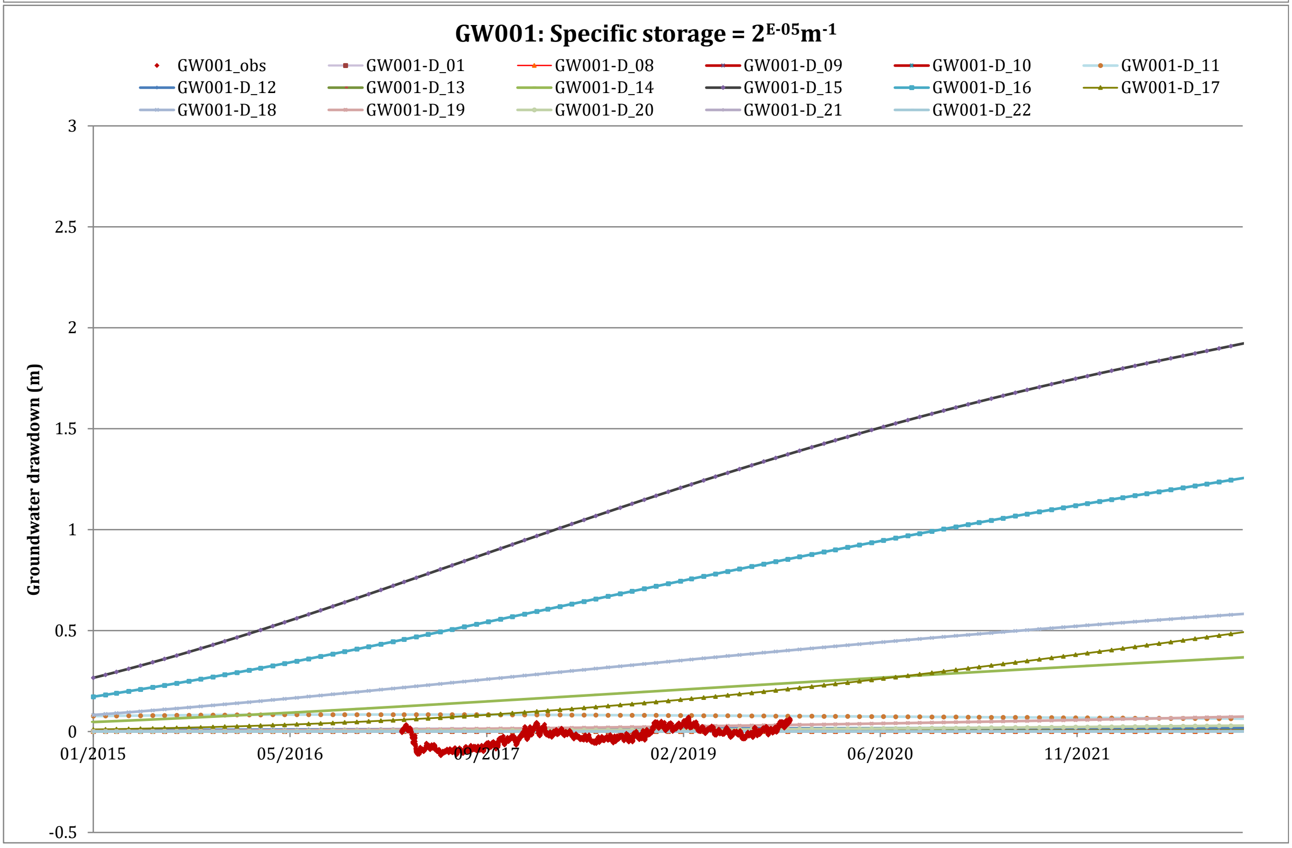
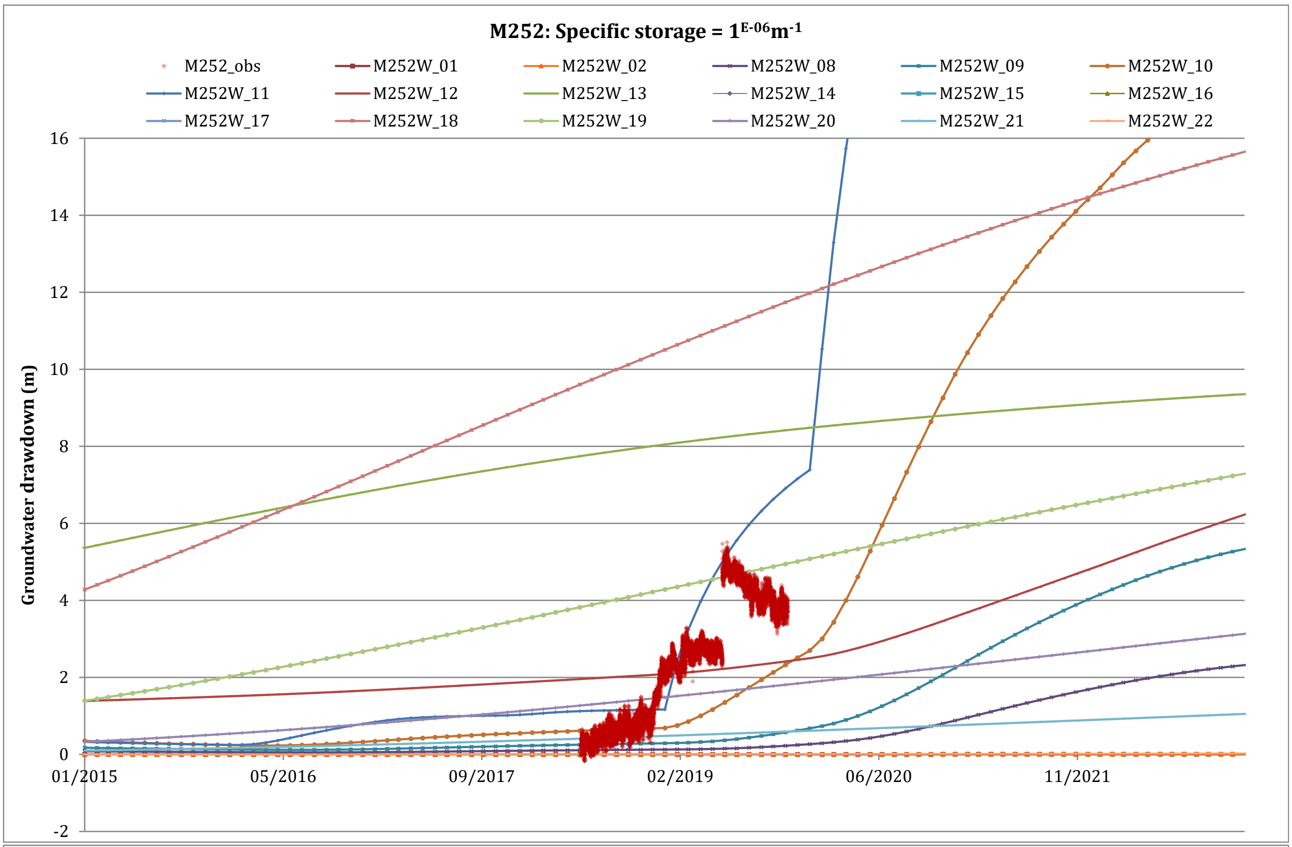


Figure 5.4 GW001 drawdown comparison



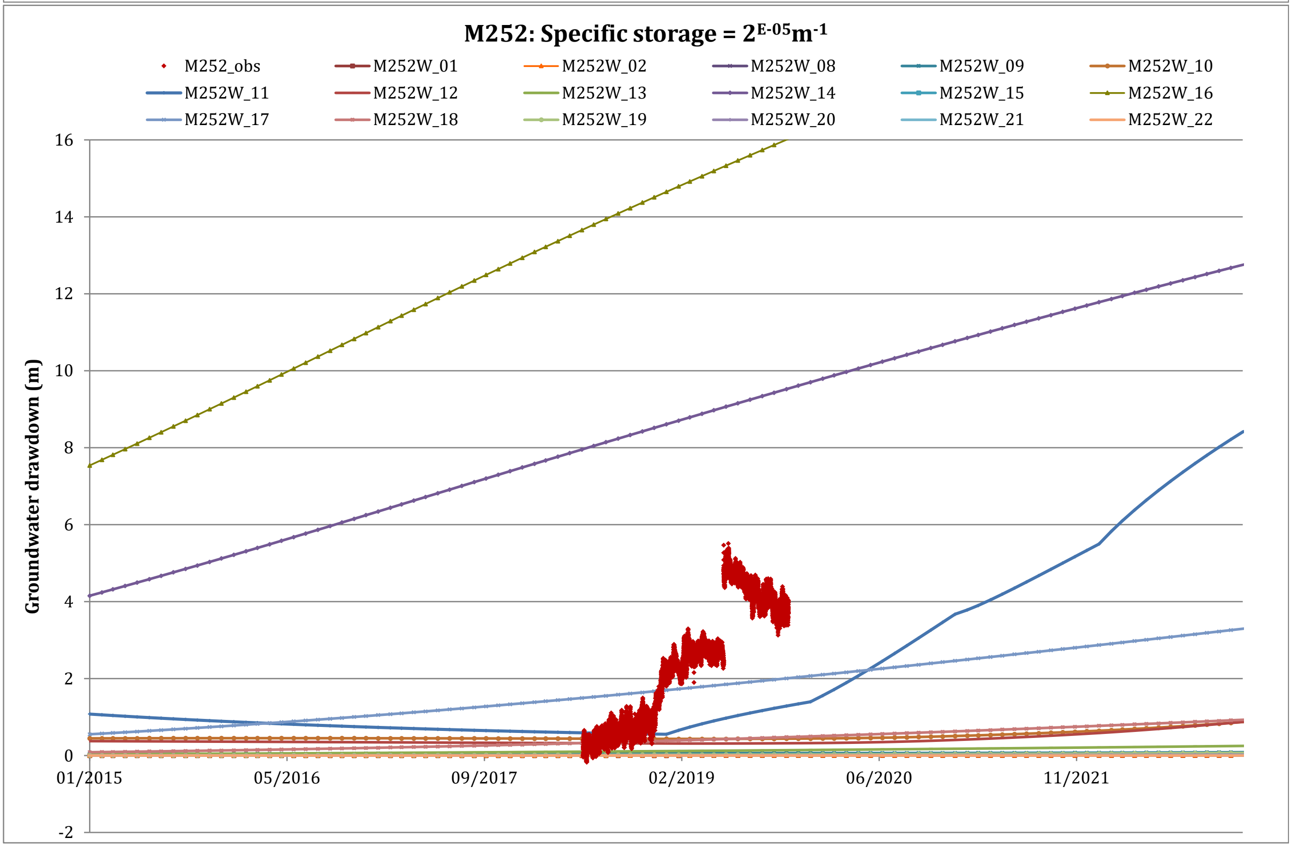


Figure 5.5 M252 drawdown comparison

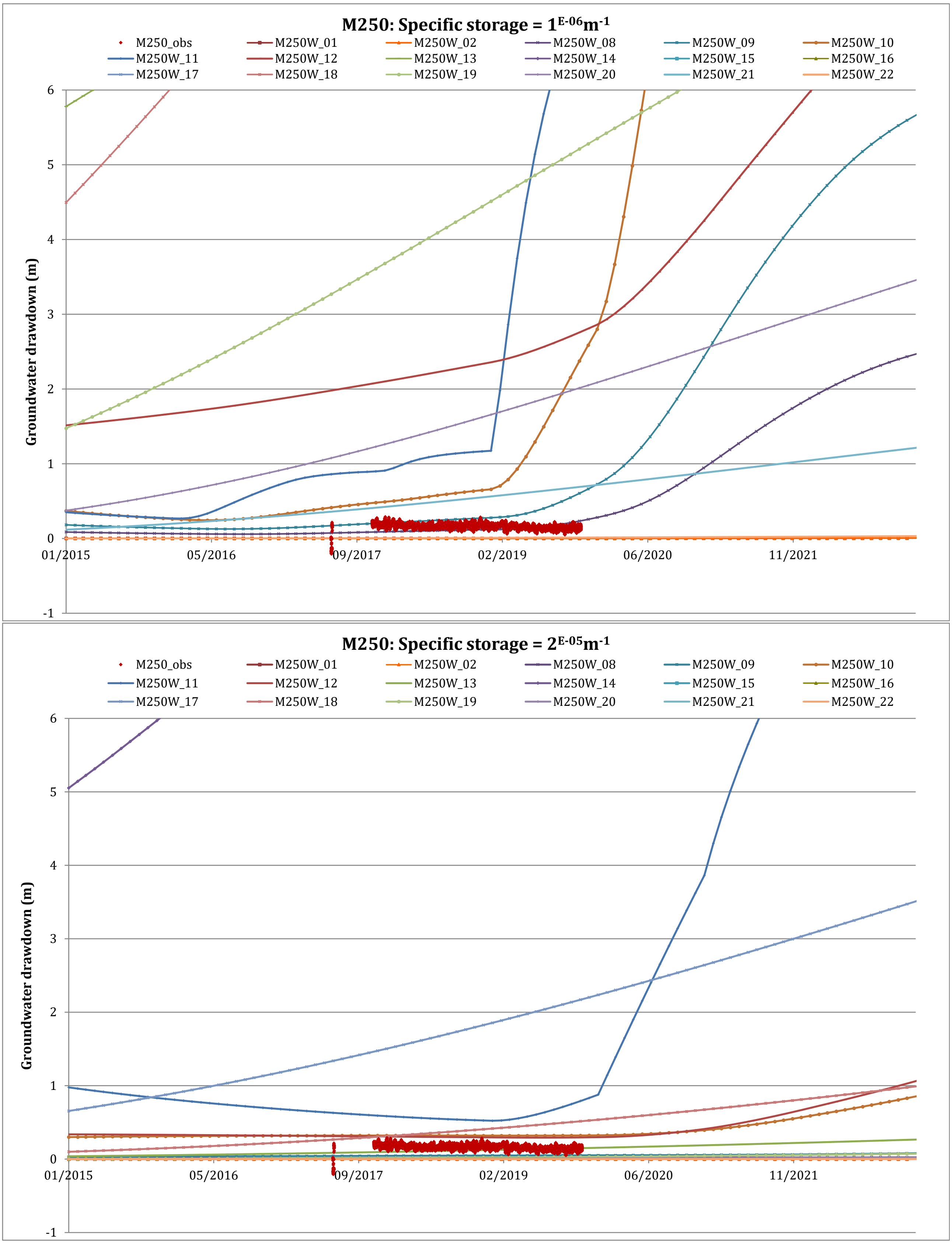


Figure 5.6 M250 drawdown comparison

6 Summary and conclusions

A sector model was developed initially to simulate additional extraction from the Red Hill area from 2021 to 2030. The model adopted the same structure and boundary conditions simulated in the regional 2017 AGE EIS model, however the sensitivity of predictions of a range of different specific storage values was also explored.

Predictions made using this sector model suggest that monitoring bore MB04 will experience groundwater drawdown exceeding 5m in early 2021 if it is screened in the Goonyella Middle seam. Similarly, more than 5 m of drawdown could occur in 2023 at monitoring bore MB01 if this bore is screened into the same coal seam. Conversely sector model predictions suggest it is unlikely that GW001 and GW007 will experience significant groundwater drawdown since none of the specific storage scenarios explored predicted significant drawdown in the Fort Cooper Coal Measures or alluvial sediments.

Since the regional model also includes the cumulative impacts of other Arrow Energy operations the predicted drawdowns are consistently higher than those predicted by the sector model. Accordingly, regional model predictions suggest that drawdowns of more than 5 m may already have occurred in the Goonyella Middle Seam at the location of monitoring bores MB01, MB04, and GW001. Conversely, all scenarios predict it is unlikely that Fort Cooper coal measures and shallow aquifer system will experience significant drawdown at any time in the next 160 years.

Exploring specific storage was undertaken around the 2017 calibrated parameter set. It is possible that the combination of lower specific storage and calibrated horizontal hydraulic conductivity/recharge assessed in this study may produce a poorly calibrated model. Validation of such parameter combinations should be tested using the regional model to ensure adequate history matching proximate to the Red Hill field.

It recommended that groundwater bore construction details regarding screened intervals are collated for the existing Arrow groundwater monitoring network. The potential effects from climate and pumping activities should be explored and separated for the purpose of future calibration exercises and trigger exceedance tests. The regional model could be improved by calibrating the model to the drawdowns apparent in the dataset.

7 References

Australasian Groundwater and Environmental Consultants Pty Ltd (2017), *Arrow Project - Report on Bowen GMMP Uncertainty Analysis.*

Norwest (2012), *Groundwater Model, North West Bowen Basin Regional Model Impact Predictions, Queensland, Australia*, October 10, 2012.

Pells, S. (2017), Groundwater Modelling of the Hume Coal Project, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-7172%2120190319T233221.791%20GMT .

Rau, G. C., Acworth, R. I., Halloran, L. J. S., Timms, W. A., & Cuthbert, M. O. (2018). *"Quantifying compressible groundwater storage by combining cross-hole seismic surveys and head response to atmospheric tides".* Journal of Geophysical Research: Earth Surface, 123, 1910–1930. https://doi.org/10.1029/2018JF004660 .