Underground Water Impact Report

For Petroleum Lease 486 and Authority to Prospect 1103, 742 and 1031

arrow energy

February 2025

REVISION HISTORY

Revision	Revision Date	Revision Summary
0	February 2025	Initial release for community consultation

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EXECUTIVE SUMMARY

This Underground Water Impact Report (UWIR) provides information on the potential decline in water levels in aquifers within the Project Area as a result of the taking of water during production of coal seam gas (CSG) and production testing. The Project Area comprises Petroleum Lease (PL) 486 and Authorities to Prospect (ATPs) 1103, 1031, and 742, and is known as the Bowen Gas Project (BGP).

Since the previous UWIR (Arrow Energy, 2022), the Moranbah Gas Project (MGP) tenures (PL191, 196, 223 and 224) have been divested to QPM Energy (MGP Upstream) Pty Ltd on 20 September 2023. Although the groundwater model developed considers activities on these tenures to assess cumulative impacts, these tenures do not form part this UWIR.

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 2025 groundwater model.

This 2025 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.

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 2025 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 2025 groundwater model, developed as part of this UWIR, simulated historical and forecast production as well as historical production testing. The 2025 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 for the BGP Project Area are:

- within PL486 an IAA exists for the Moranbah Coal Measures (MCM) associated with production of CSG. There are no useable landholder bores in the aquifers of this IAA, and therefore there are no make good obligations in this UWIR.
- within ATPs 742, 1103 and 1031 there are small areas of IAA for the MCM and Rangal Coal Measures (RCM) associated with proposed production testing in these tenures. There are no existing or useable bores located within the aquifers of these IAAs, and therefore there are no make good obligations in this UWIR.
- there are no IAAs in any of the other aquifers (including Alluvial and Tertiary aquifers) modelled within the Project Area.
- there is no LAA (predicted drawdown greater than 2 m trigger threshold) for unconsolidated aquifers in the Project Area;
- the larger LAA (predicted drawdown greater than 5 m trigger threshold) for the consolidated aquifers develop predominantly as a result of production within the ATPs planned to commence from 2046;
    - the LAA for the MCM covers most of the ATP742 and PL486, as well as the western part of the ATPs 1103 and 1031 in the north-south direction within the BGP;
    - similar to the LAA for the MCM, the LAA for the RCM stretches north-south within the BGP but covers a smaller area and does not extend as much over PL486. The RCM footprint is generally positioned further east of the MCM footprint as the RCM is located above the MCM and dips to the east;

- there is a LAA for the Fort Cooper Coal Measures (FCCM), which is much smaller than for the MCM and RCM and is limited to a small area within ATP1103, mainly overlapping with the MCM and RCM LAA footprints in the south;
- there are localised areas of LAA's within the immediate vicinity of some production testing wells for the MCM and RCM; and
- there is no predicted LAA in any other consolidated aquifers;

A water monitoring strategy has been prepared. The monitoring network is comprised of 35 monitoring points at 22 separate locations (comprising 12 single sites and 10 nested sites of 23 monitoring points) from the approved groundwater monitoring network for the BGP area. At present, 13 monitoring points have been installed at 9 locations, and additional bores will be added as the project increases in area.

This report will be reviewed annually, considering:

- 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 2025 Bowen Gas Project Underground Water Impact Report (2025 Bowen UWIR) and provides information on the potential decline in water levels in aquifers due to the taking of water during Coal Seam Gas (CSG) production and CSG production testing activities in Arrow Energy Pty Ltd's (Arrow Energy) Bowen Basin tenure (detailed below), as required by the *Water Act (Qld) 2000*.

The previous 2022 Bowen UWIR (Arrow Energy, 2022) included tenures for Arrow Energy's then domestic gas project in the Bowen Basin, known as the Moranbah Gas Project (MGP), as well as an expansion project referred to as the Bowen Gas Project (BGP). The MGP (tenures PL191, 196, 223 and 224) has been entirely acquired by QPM Energy (MPG Upstream) Pty Ltd (QPM) from Arrow CSG (ATP364) Pty Ltd, CH4 Pty Ltd and AGL Energy Limited effective 20 September 2023, becoming the holder of the resource tenure and the responsible tenure holder for the *Water Act (Qld) 2000* make good and report obligations, including developing a UWIR, for these tenures.

Arrow Energy continues to operate the BGP project (tenures PL486 and ATPs 1103, 1031, 742) and is the responsible tenure holder for make good and report obligations considered in this 2025 Bowen UWIR for the BGP.

Arrow Energy and QPM jointly commissioned groundwater modelling included in this 2025 Bowen UWIR to assess cumulative impacts of both operators CSG operations. Therefore, when presenting the cumulative impact of operations and the effect of MGP operations on the BGP, this report may refer to both the MGP and BGP projects as required.

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

Table 1: Tenements and Registered Holder Details

Tenure	Registered Holder
PL486	CH4 Pty Ltd ACN 092 501 016 Arrow CSG (ATP364) Pty Ltd Pty Ltd ACN 092 970 557
ATP742	CH4 Pty Ltd ACN 092 501 016
ATP1031	Bow CSG Pty Ltd ACN 117 156 742
ATP1103	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 tenures host both production wells (in PLs) and production testing activities (in ATPs) for CSG. The spatial distribution of these tenures in the Bowen Basin, as shown in Figure 1, spans the area from north to south around the towns of Glenden, Moranbah, Dysart and Middlemount. The BGP Area, referred to as the Project Area, is also depicted in Figure 1. The Project Area, within which exploration and production testing have been undertaken, includes PL 486 and ATPs 1103, 1031, and 742 and encompasses the following:

- exploration and testing within:
  - ATP1103 - including 98 wells used for production testing between 2008 and 2021.
  - ATP742 - including 3 wells used for production testing between 2015 and 2018;
  - ATP1031 - including 6 wells used for production testing between 2012 and 2015;
- Development and future proposed development including:
  - Red Hill Central (PL486) - includes 31 wells to be used for production between 2022 and 2026. In the area of PL486, production testing commenced in the then part of ATP1103 prior to PL486 being granted.
  - The remainder of the field development plan (FDP) within ATP1103, ATP742 and ATP1031 to include 1408 production wells between 2045 and 2063.

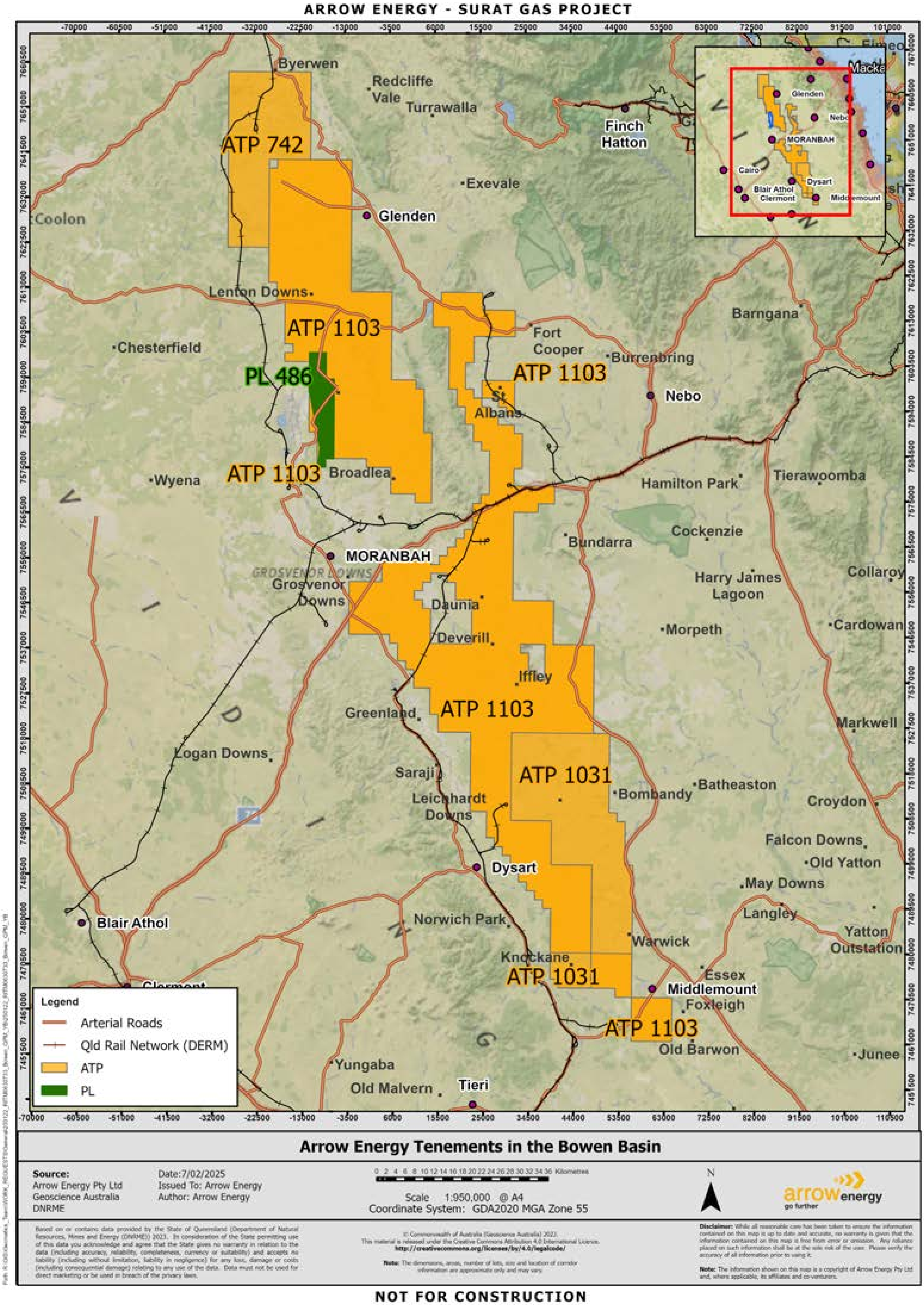


Figure 1: Arrow Energy's Tenements in the Bowen Basin Relevant to This UWIR

1.3 Legislation

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

1.3.1 *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. There is no volumetric limit to the amount of water that may be taken, however these rights are subject to the tenure holder complying with the holder's underground water obligations (defined in the *Water Act (Qld) 2000*).

1.3.2 *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.

The chief executive of the Queensland Department of Environment, Tourism, Science and Innovation (DETSI) 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. The Queensland Government's Office of Groundwater Impact Assessment (OGIA) is responsible for managing these requirements in a declared CMA. Outside of the CMAs, individual tenure holders are responsible for the preparation of the UWIR. The requirements of a UWIR are specifically identified in the *Water Act (Qld) 2000*, with additional description of the requirements provided in the UWIR guideline (DETSI, 2024).

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

- the reasons for the bore's impaired capacity;
- the measures the tenure 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; and
- 0.2 m for a spring.

UWIRs are published for consultation to enable comments from bore owners within the area. Submissions made by bore owners ware summarised, addressed as appropriate and provided to the DETSI. UWIRs are then submitted for approval by DETSI. The OGIA may also advise DETSI about the adequacy of these reports.

The DETSI 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.

1.4 UWIR Requirements

Arrow Energy's operations/project in the Bowen Basin fall outside of the Surat CMA. Under the *Water Act (Qld) 2000*, Arrow Energy as the tenure holder is required to prepare an UWIR, which is addressed in this report.

This report forms the UWIR for Arrow Energy's CSG activities in the Bowen Basin, including production and production testing wells, contained within the bounds of tenures PL486 and ATPs 1103, 1031 and 742.

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.

1.5 Summary of Methods

This UWIR builds on information presented in the:

- UWIR for ATP1103 (Arrow Energy, 2012a);
- Bowen Gas Project Environmental Impact Statement (EIS) (Arrow Energy, 2012b);
- UWIR for ATP1031 (Arrow Energy, 2014a);
- Bowen Gas Project Supplementary Report to the EIS (Arrow Energy, 2014b);
- UWIR for PL 191, 196, 223, 224 and ATP 831, 742, 1031 and 1103 (Arrow Energy 2016);
- UWIR for PL 191, 196, 223, 224 and ATP 742, 1031 and 1103 (Arrow Energy 2019);
- UWIR for PL 191, 196, 223, 224, 486 and ATP 742, 1031 and 1103 (Arrow Energy 2022); and
- 2017, 2018, 2020, 2021, 2023, and 2024 Annual Reviews of the above UWIR's.

Since the development of the previous UWIRs for PL 486 and ATPs 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 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 5
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
ii. Giving the chief executive a summary of the outcome of each review, including a statement	Section 6

UWIR reporting requirement	Report Section
of whether there has been a material change in the information or predictions used to prepare the maps;	
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
s378 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 through tubing to the surface. 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 or through pipelines to the production facility 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 – BGP Area

Historical water production data for the production and production testing wells on PL 486 and ATP 742, 1031 and 1103 is summarised below. The production testing cumulative volume of water approximately 66.07 ML of water since the 2022 Bowen UWIR.

2.1.1 *PL486*

PL 486, which incorporates the Red Hill Central (RHC) development, is located approximately 30 km north of the township of Moranbah and borders the MGP area to the South.

Prior to the grant of PL486, the area of this production tenure was included in the exploration tenure ATP1103. Water volumes for the production testing (from wells RH098A, RH099A and RH100A) during the time this area was under ATP1103 are therefore included in ATP1103 water volumes.

Following grant of PL486, production from PL486 commenced in June 2022. Table 3 below presents the actual water production versus forecast water production from the 2022 Bowen UWIR (Arrow Energy, 2022). By the end of 2024, a total of 42.5 ML water was produced which is 47.9% less than was forecast in the previous UWIR.

Table 3: Actual and Forecast Water Production PL486

Year	2022 Bowen UWIR Forecast Water Production (ML)	Actual Water Production (ML)	Difference
2022	63.8	18.4	45.4 ML less than forecast (71.2% less)
2023	11.8	16.8	5.0 ML more than forecast (42.4% more)
2024	6	7.3	1.3 ML more than current forecast (21.7% more)
Total	**81.6**	**42.5**	**39.1 ML less than the 2022 Bowen UWIR (47.9% less)**

2.1.2 *ATP1103*

ATP1103 is a large exploration tenure located in the North, East and South of the BGP.

As per the previous UWIR (Arrow Energy, 2022), a total of 287.208 ML of water was produced as part of production testing on ATP1103 between 2008 and the time of the UWIR. As per the annual review of the UWIR (Arrow Energy, 2023), a further 18.27 ML of water has been produced from production testing pilots from ATP1103 to the end of 2022. No further production testing on ATP1103 has occurred since that time. Also, as per the annual review of the UWIR (Arrow Energy, 2023), 5.3 ML of water was produced as part of production testing on the area of ATP1103 through to August 2022 before it was converted to PL486. This water volume is from production testing wells (RH098A, RH099A and RH100A) on what was ATP1103, which has now been converted to PL486 (Red Hill Central). Production from these wells occurred through to August 2022, with no further production test since that time.

2.1.3 *ATP1031*

ATP1031 lies approximately 100 km to the south of Moranbah. A total of 15.894 ML of water has been produced as part of production testing on ATP1031 between 2012 and 2021 (Arrow Energy, 2022). No further production testing has been undertaken since 2021.

2.1.4 *ATP742*

ATP742 is located approximately 50 kilometres north of Moranbah. As per the previous UWR (Arrow Energy, 2022), a total of 2.892 ML of water has been produced as part of production testing on ATP742 between 2015 and 2017. No further production testing has been undertaken since 2017.

2.2 Forecast Appraisal Program in BGP Area

New production testing has been planned, the Wards Well pilot approximately 5km north of PL486 in ATP1103, and the Ellensfield pilot in ATP1103 approximately 13km east of the production wells in PL486. The Wards Well pilot is forecast to operate from 2025 to 2027 and produce approximately 52.7 ML of water. The Ellensfield pilot is forecast to operate from 2025 to 2026 and produce approximately 8.3 ML of water.

2.3 Forecast Water Production - BGP

Arrow Energy's proposed BGP involves a phased expansion of Arrow Energy'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 2025 Bowen UWIR is based on an updated FDP as follows:

- Red Hill Central (PL486) commenced 2022 and continuing to 2027.
- the remainder of the field development plan (FDP) area, as presented in the 2022 Bowen UWIR (ATP1103, ATP742 and ATP1031), but commencing 2045 and continuing to 2063.

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 2027, with a total of 54.8 ML of water to be produced (based on actual production of 42.5 ML and forecast water production of 12.3 ML); and
- production from the remainder of the FDP area, tentatively planned from 2045 to 2063, will comprise 1,377 wells and total water production of 39.93 GL.

3 EXISTING CONCEPTUAL MODEL

The conceptual hydrogeological model was described in the previous UWIRs for PL486 (Arrow Energy, 2022), ATPs 1103 (Arrow Energy, 2012a), 1031 (Arrow Energy, 2014a) and the 2016, 2019, and 2022 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 DETSI and DNRME.

Additionally, an EIS (Arrow Energy, 2012b), 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 7), including geology and aquifers is provided in the following sections.

3.1 Geological Summary

The Bowen Basin covers an area of approximately 200,000 km2, 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 2). 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 mainly confined 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 4Table 4. 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 4: Regional Stratigraphy Bowen Basin

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

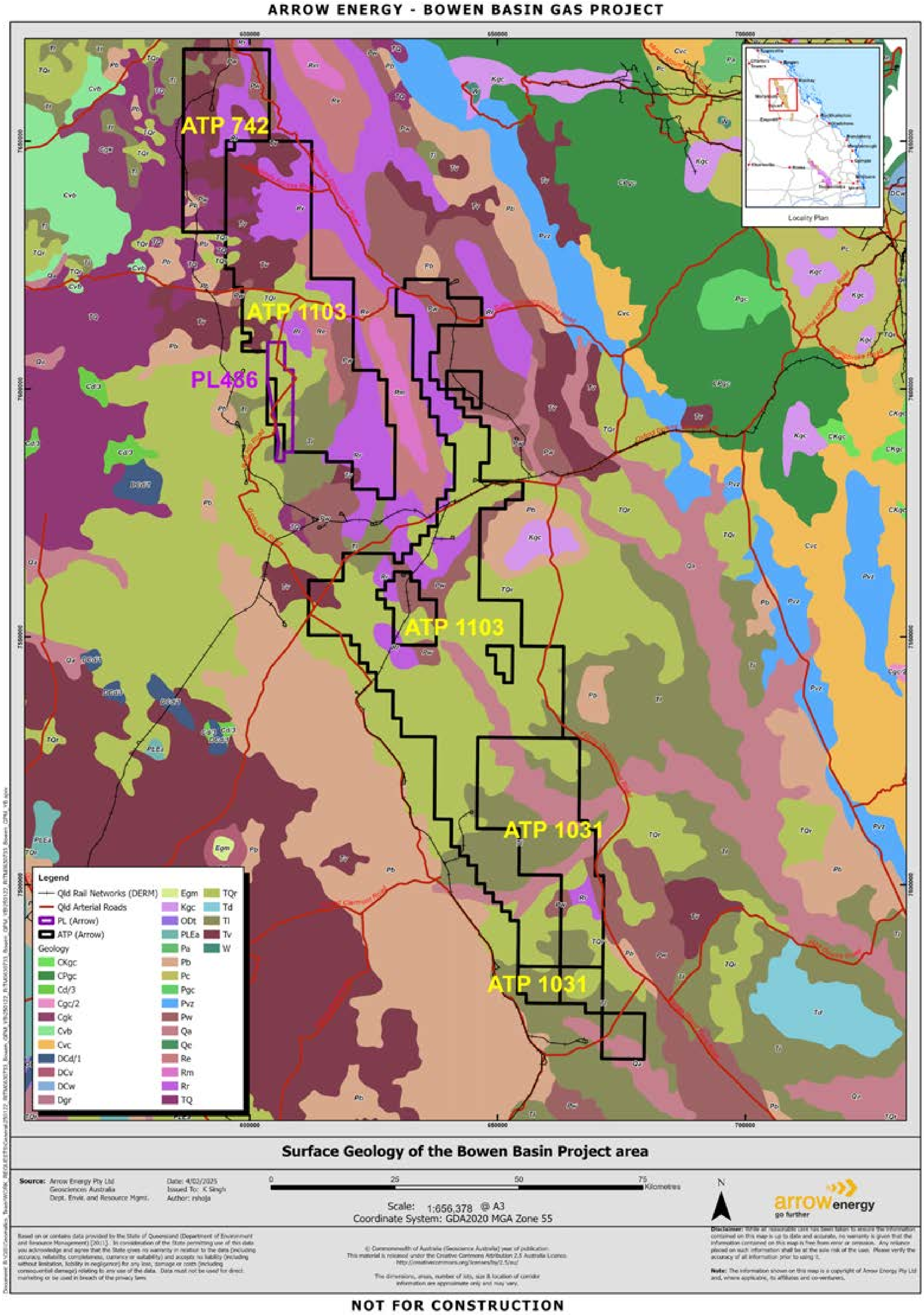


Figure 2: Surface Geology of the Bowen Basin

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 3 to Figure 6 provide schematic cross-sections through each of the Arrow Energy tenure (Petroleum Lease 486 and, ATP 742, 1031 and 1103), presented as four southwest to northeast orientated sections from the northern-most tenure to the southernmost. Each cross section was generated from the Arrow Energy geological model using PetrelTM. 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).

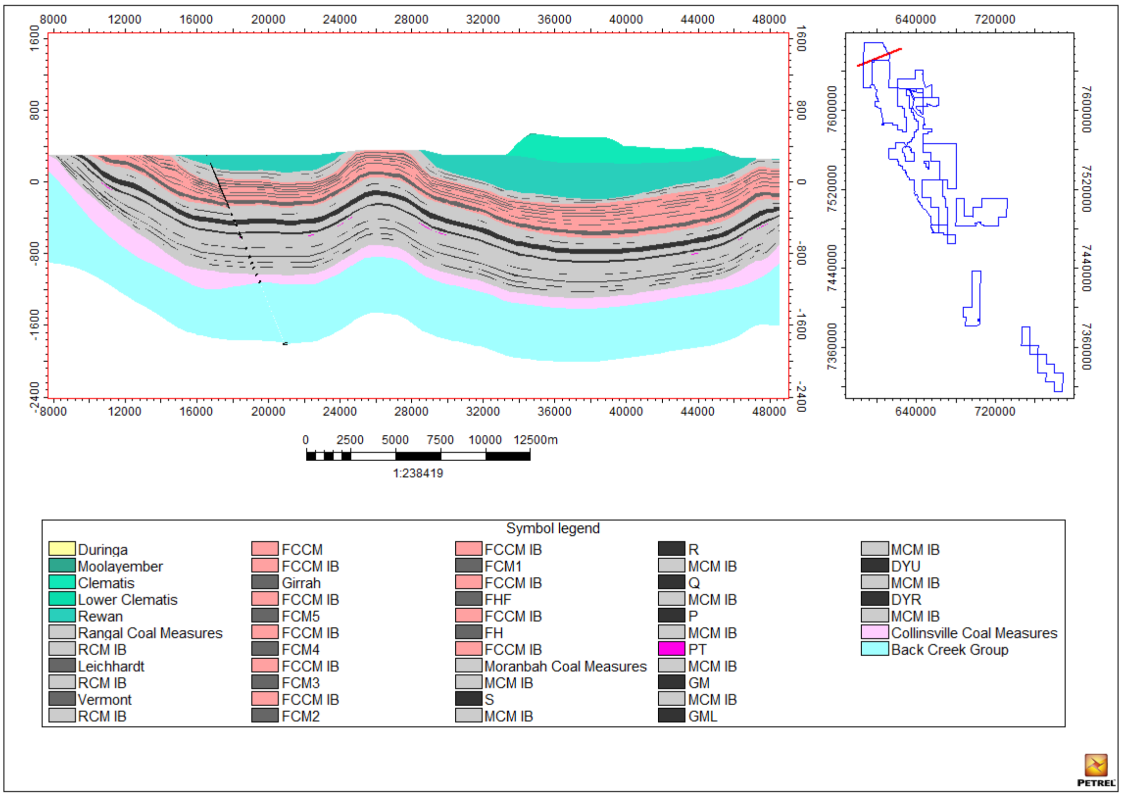


Figure 3 : Stratigraphy Underlying ATP742

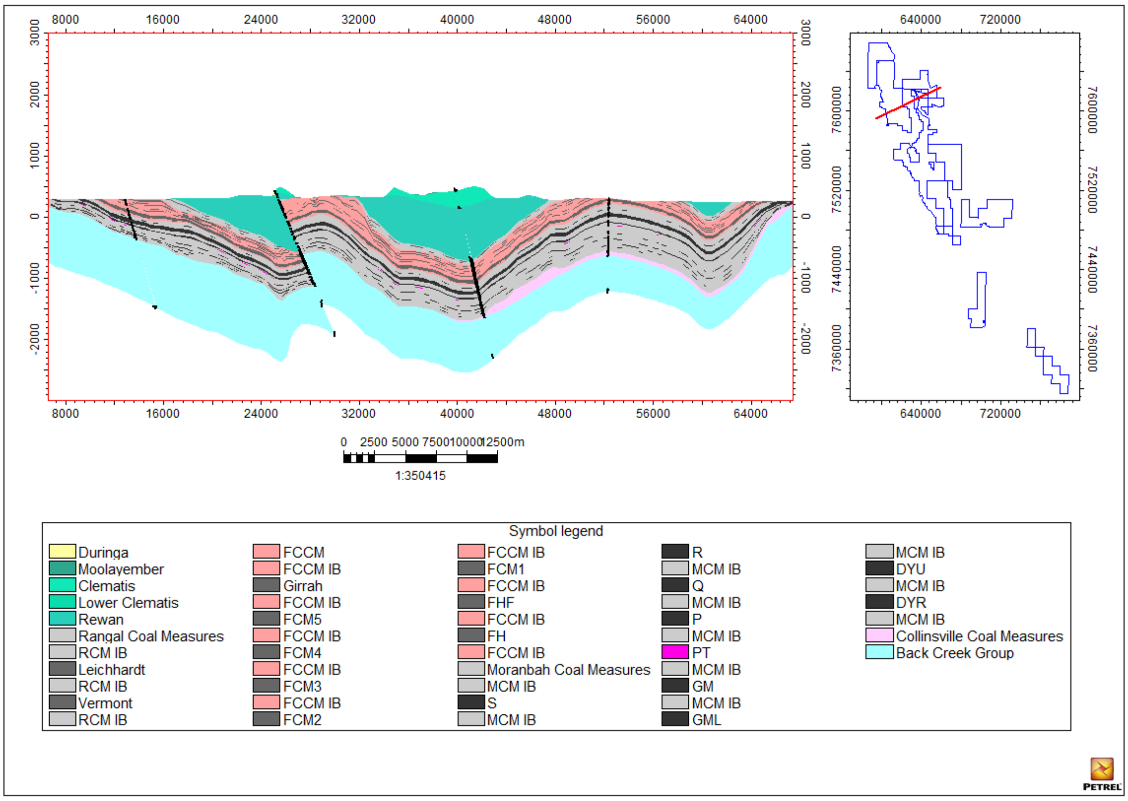


Figure 4 : Stratigraphy Underlying Northern ATP1103

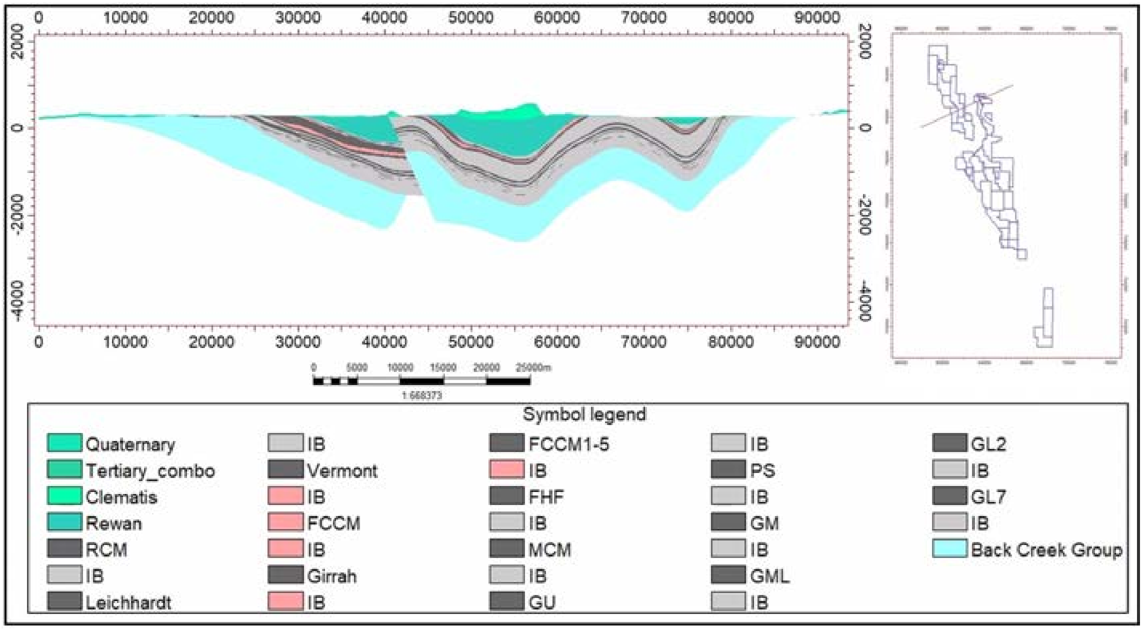


Figure 5 : Stratigraphy Underlying PL486 Area

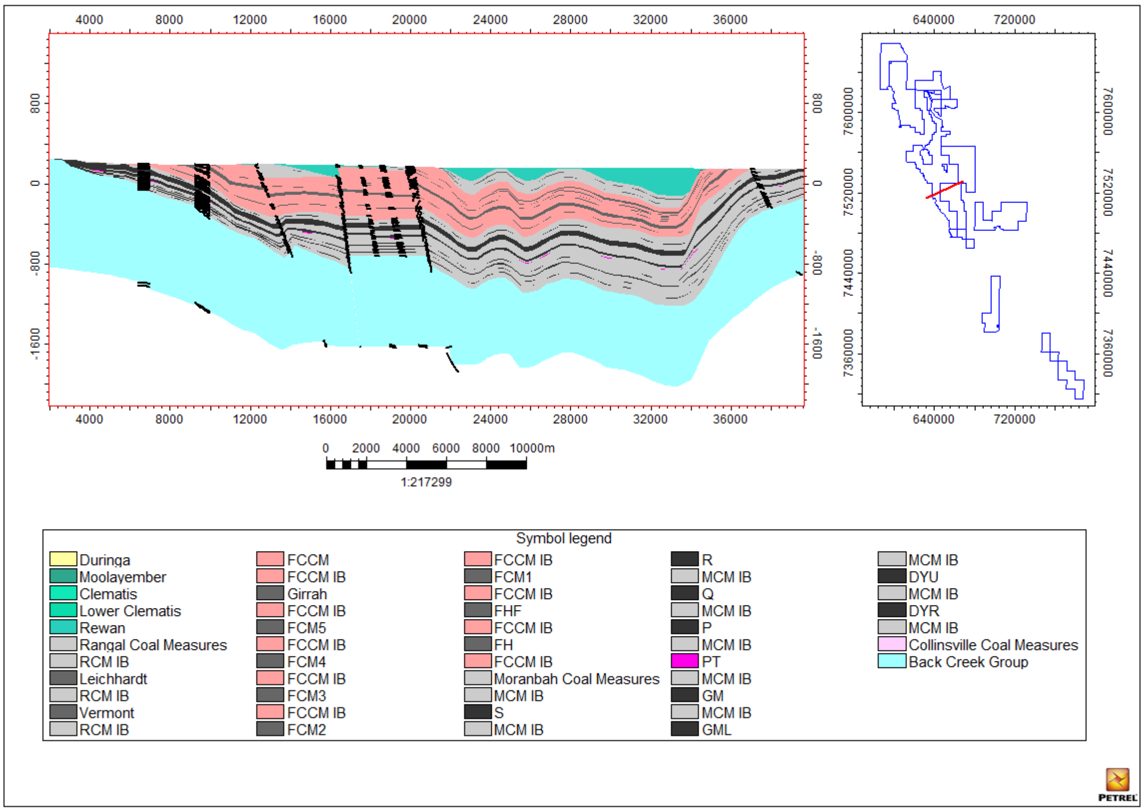


Figure 6 : Stratigraphy Underlying ATP1031

3.2 Conceptual Hydrogeological Model

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

Table 5: 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 3 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 7.

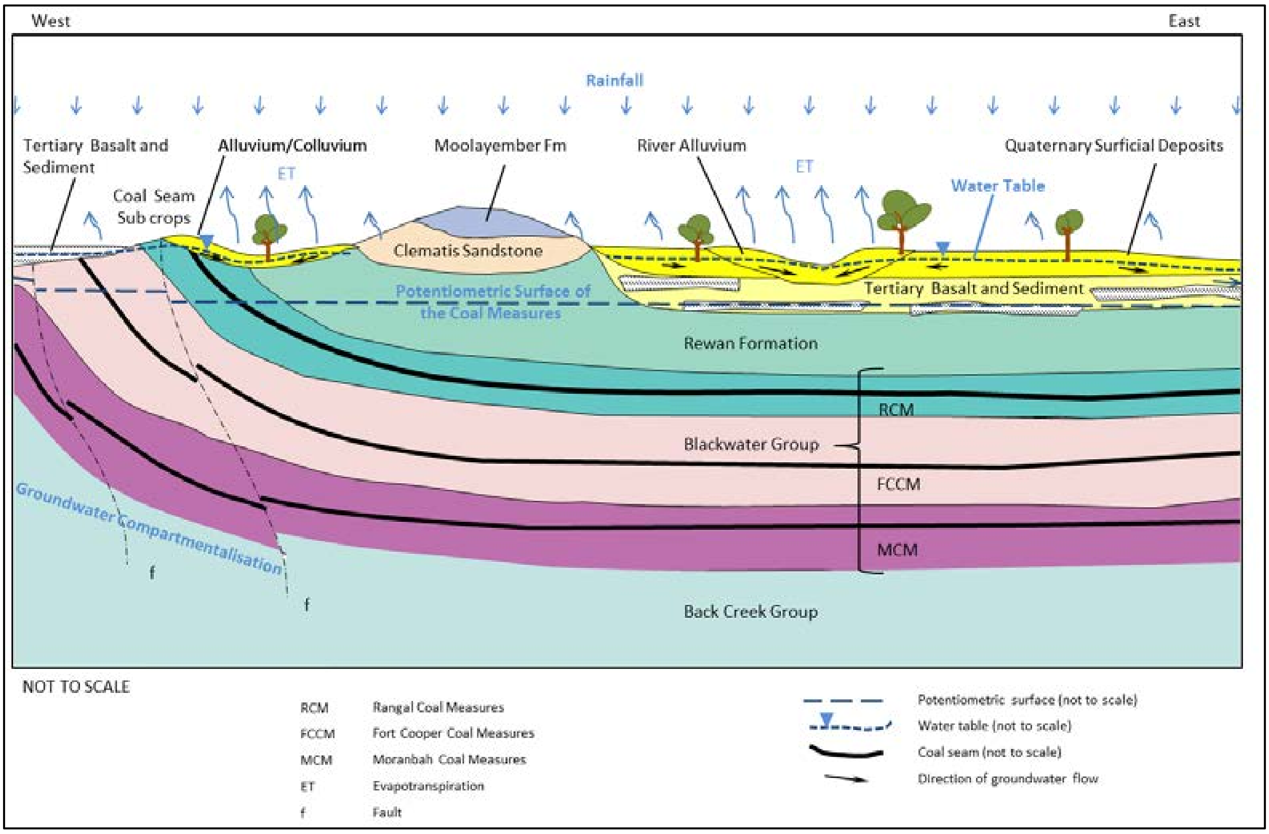


Figure 7: Conceptual Hydrogeological Model (Arrow Energy, 2012c)

A summary of the existing understanding of the hydrogeological setting, as conceptualised in Figure 7, 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 riverbed sands and relatively low permeability riverbank sediments;
- recharge mainly occurs through direct infiltration of rainfall, overland flow and surface water flow;
- discharge generally occurs 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, 2006). 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 are highly variable depending on degree of weathering and interconnectedness of jointing and/or fracturing;
- recharge occurs 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 generally occurs 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, 2006). 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 occurs through direct infiltration of rainfall, overland flow and surface water flow in outcrop areas;
  - discharge is localised and generally occurs 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 occurs through direct infiltration of rainfall, overland flow and surface water flow in outcrop areas;

- discharge is localised and generally occurs 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 major 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 occurs 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 generally occurs 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 occurs 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 generally occurs 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 required for the UWIR is shown in Figure 8. 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 deep 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.

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.

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 8 provides an overview of the spatial distribution of the groundwater monitoring network. Table 6 presents the monitoring requirements of the BGP, along with the status of each location. Note that Table 6 provides 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. Arrow Energy is the responsible entity for monitoring these bores.

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, thirteen monitoring points have been installed at nine locations as a part of the monitoring network; MB1-S/I/D, MB2, MB3, MB12, GW004A/B, GW007A/B, AEN1214, AEN1234, and AEN1063 as detailed below.

The design and layout of the groundwater monitoring network are based on the 2021 numerical groundwater modelling (Arrow Energy, 2022), and reviewed considering Arrow's most recent groundwater modelling efforts (AGE, 2025) which simulated the impacts of BGP as well as the effects of MGP operations on BGP. The model simulates groundwater abstraction and predicts the degree and extent of aquifer depressurisation, both spatially and temporally. 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 and timing for commencement of monitoring.

In summary, in designing the monitoring network, consideration has been given 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 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 6.

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 6) are met.

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

It should be noted that the ultimate location of the monitoring wells will be subjected to site and access constraints that may lead to re-positioning.

Table 6: 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	ATP1103 (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.
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	Rewan Formation	ATP1103	Current	Suitable replacement for proposed AEN1050. Manual measurements recorded every 6-months.
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.

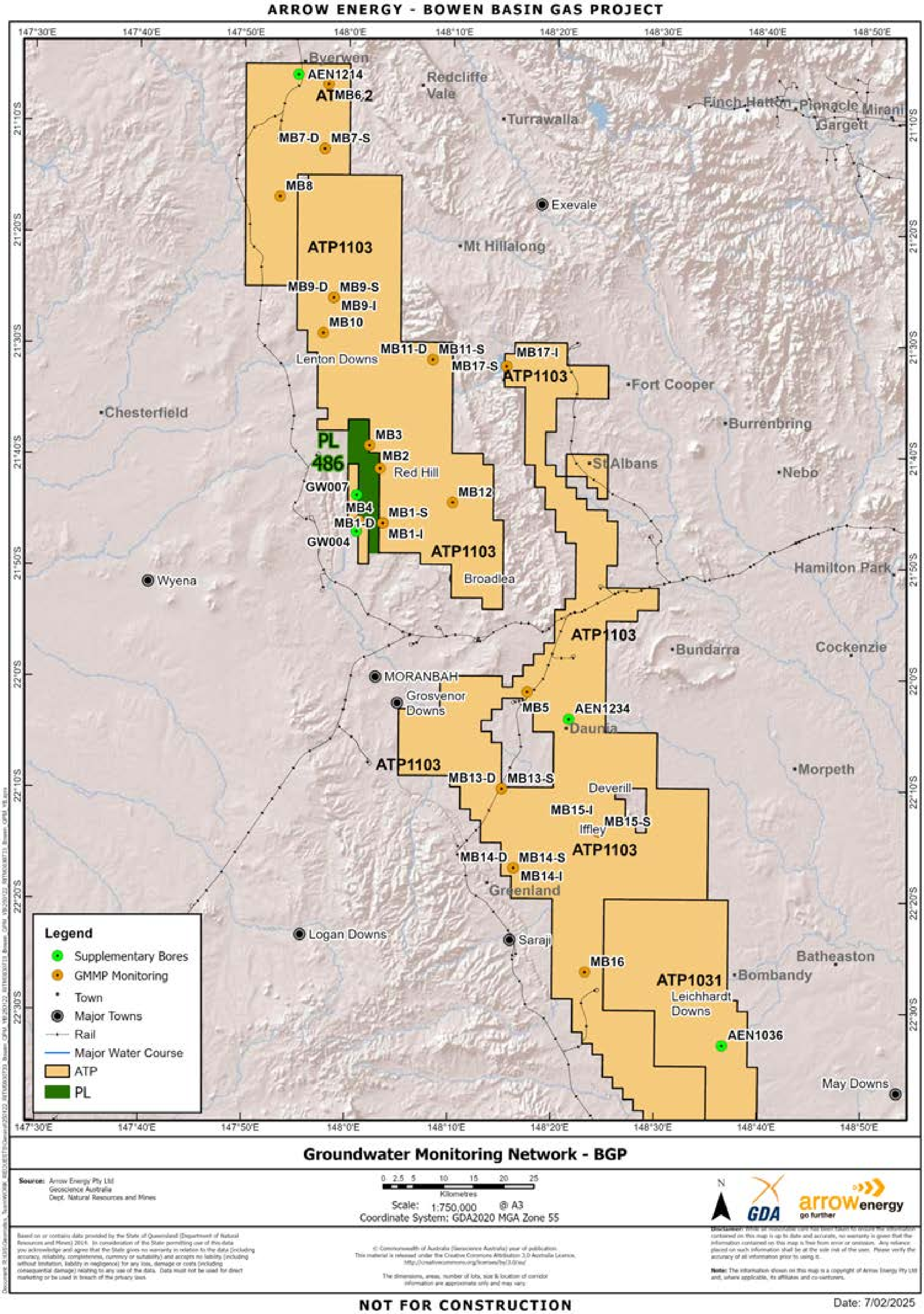


Figure 8: Groundwater Monitoring Network – BGP

4.1.2 *Groundwater Monitoring Frequency*

The groundwater monitoring frequency for the WMS bores are shown in Table 7.

Table 7: 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-D[1]	Deep	November 2019 to November 2020		November 2019 onwards	November 2019 onwards
MB1-I	Deep	November 2019 to November 2020		November 2019 onwards	N/A
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
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		November 2020 onwards	N/A
AEN1234	Shallow	N/A		November 2020 onwards	N/A
AEN1063	Shallow	N/A		November 2020 onwards	N/A

For any future WMS bores in the BGP area, 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)

[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.

- data will be reviewed on an annual basis and presented in the annual review report to DETSI 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 procedures developed with reference to the Monitoring and Sampling Manual (DETSI, 2018), AS/NZS 5667.1:1998 Water quality (Australian/New Zealand Standard, 1998), 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 8 and Table 9 below respectively.

Table 8: Field Parameters Monitoring Suite

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

Table 9: 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^-), Ammonium (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), Cobalt (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 for water bores predicted to be impacted on land outside the tenures is also required as part of the WMS. 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 the 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 for water bores outside of tenure, consistent with the approach adopted for the Surat Cumulative Management Area UWIR.

Figure 9 shows the area within which drawdown of more than 1 m for MCM is expected within three years. The 1 m drawdown contours have been simulated using 2025 Bowen groundwater model (AGE 2025) and presented for both cumulative (the scenario in which both MGP and BGP are in operation) and BGP only scenarios. It can be observed that the predicted impact of 1 m for BGP only scenario is mainly limited within PL486 and ATP 1103 (and a small area in ATP 1031) and does not extend to ATP742. Where the predicted impact of 1 m for BGP only extends outside of tenure west of PL486, two baseline assessments for water supply bores, AEN1011 (registered number 182313) and AEN1154 (registered number 141787, which could not be found and is assumed abandoned and destroyed), have been completed. No other registered or unregistered bores have been identified in the predicted 1 m impact area.

Based on this, there are no remaining water bores that require a baseline assessment under this UWIR.

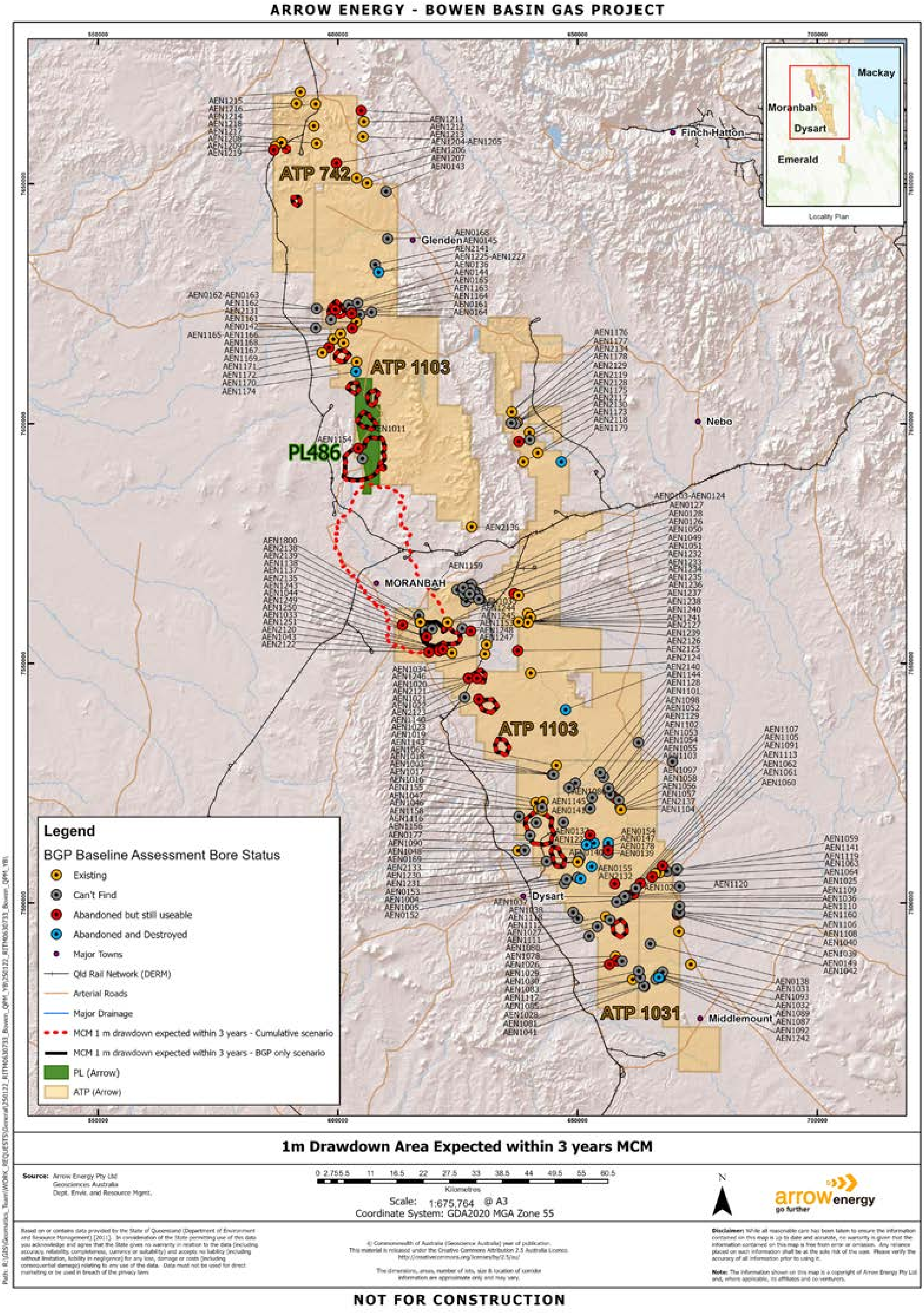


Figure 9: 1 m Drawdown Area Expected with 3 Years for MCM

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 MONITORING RESULTS

Groundwater monitoring has been undertaken by Arrow Energy in accordance with the UWIR WMS groundwater monitoring network located in the BGP Area. The locations of these bores are shown in Figure 8. This site-specific data is presented in more detail in the following sections. Additionally, new data on groundwater levels and water quality provide an updated understanding of the conceptual hydrogeological model.

5.1 Groundwater Levels

5.1.1 *Shallow UWIR Monitoring Data Summary*

Groundwater level monitoring has been conducted in the following shallow groundwater monitoring bores, which form 2025 Bowen UWIR groundwater monitoring network for the BGP Area. A summary of these bores is provided in Table 10.

- monitoring since January 2018 for bore MB12;
- monitoring since November 2019 for bores MB1-S and GW007A; and
- monitoring since November 2020 for bores GW004A, GW004B, AEN1214, AEN1234 and AEN1063.

Table 10: Shallow Groundwater Monitoring Bores

Bore ID	Network	Total Constructed Depth (m)	Screen Interval (mbgl)	Screened Formation
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	– *	Rangal Coal Measures
AEN1234	BGP	102	48.2 – 102.0	Rewan Formation
AEN1063	BGP	52.6	39.6 – 45.7	Blackwater Group

* Screened interval could not be determined due to pumping infrastructure

The groundwater level monitoring results are provided in Appendix A. As shown in Figure 10, groundwater levels in BGP area range from:

- 234.03 to 235.16 m Australian Height Datum (AHD) in the Tertiary Sediment aquifer;
- 230.95 to 263.51 m AHD in the weathered Fort Cooper Coal Measures aquifer;
- 286.31 to 299.00 m AHD in the Rewan Formation;
- 210.89 to 217.69 m AHD in the Rangal Coal Measures; and
- 142.53 to 185.64 m AHD in the Blackwater Group.

Based on the monitoring data presented in Figure 10, there is no apparent influence of CSG production to the Tertiary Sediment, Fort Cooper Coal Measures, Rewan, and Blackwater Group aquifers in which these bores are installed. This is expected given no water production has commenced in the BGP.

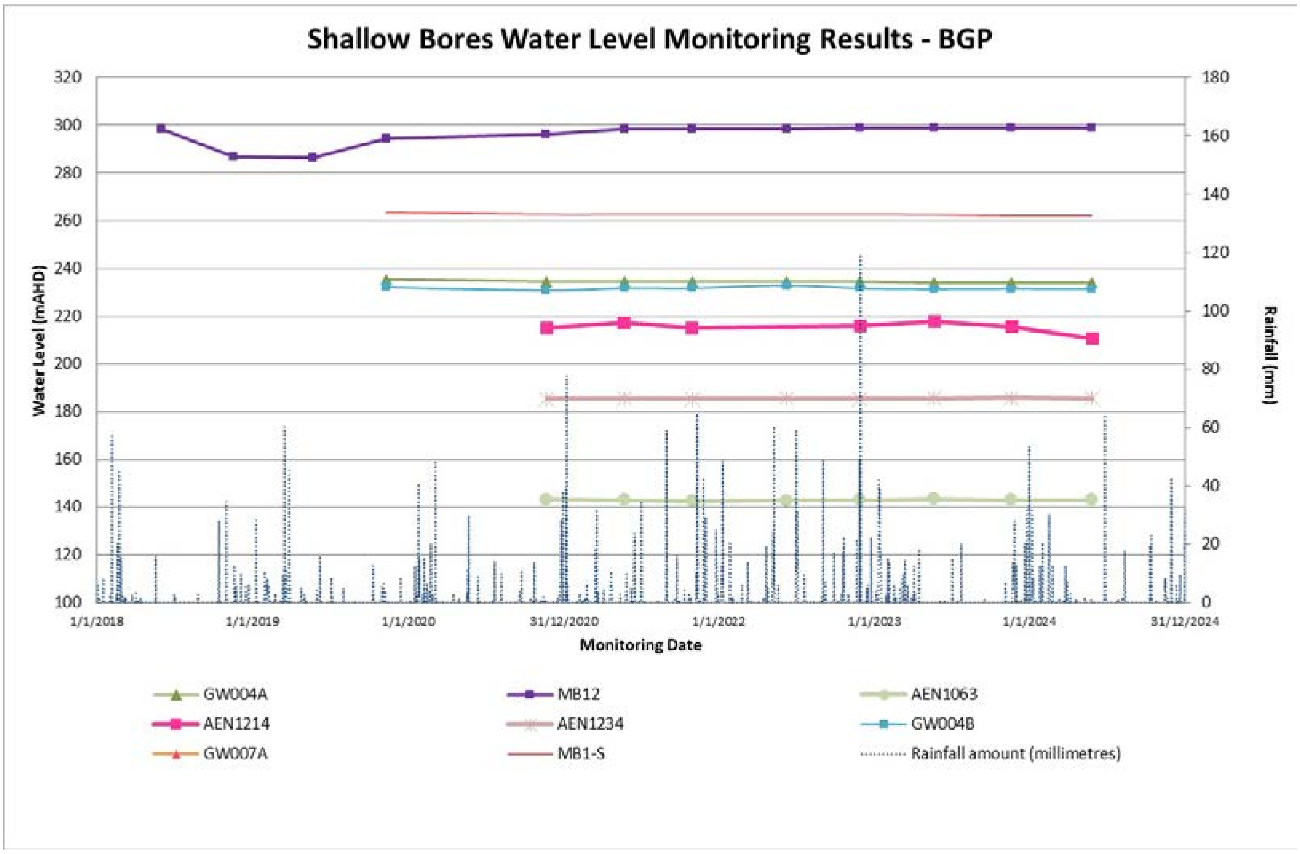


Figure 10: Shallow Bores Water Level Monitoring Results – BGP

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 2025 Bowen UWIR groundwater monitoring network. Table 11 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; and
- monitoring since November 2019 for bore GW007B.

Table 11: Deep Groundwater Monitoring Bores

Bore ID	Network	Total Constructed Depth (m)	Screen Interval (mbgl)	Screened Formation
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

The groundwater level monitoring results are shown in Figure 11. Observed groundwater levels or calculated potentiometric water levels ranged from:

- 238.96 to 264.98 m AHD in the FCCM; and
- -356.33 to 212.05 m AHD in the MCM.

While the MCM's water levels are undergoing long-term recovery following CSG development, as observed from the water levels in the appraisal (pilot) production wells MB1, MB2, and MB3 (Figure 12), FFCM's water levels are experiencing a long-term decline, as depicted in MB1 and GW007B water levels (Figure 13).

This initial decline in water levels in the FCCM at MB1 (10.45 m) 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 to a lesser extent the MCM, a decline in water level was observed. For the FCCM at MB1 water levels having remained relatively stable since the 2022 Bowen UWIR and the commencement of CSG production in PL486, with a decline of 0.78 m. Similar to MB1, GW007B's water levels have experienced a long-term decline, but they have remained below the trigger threshold. Decline in water levels noted for the FCCM are observed to correlate to the water abstraction 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.

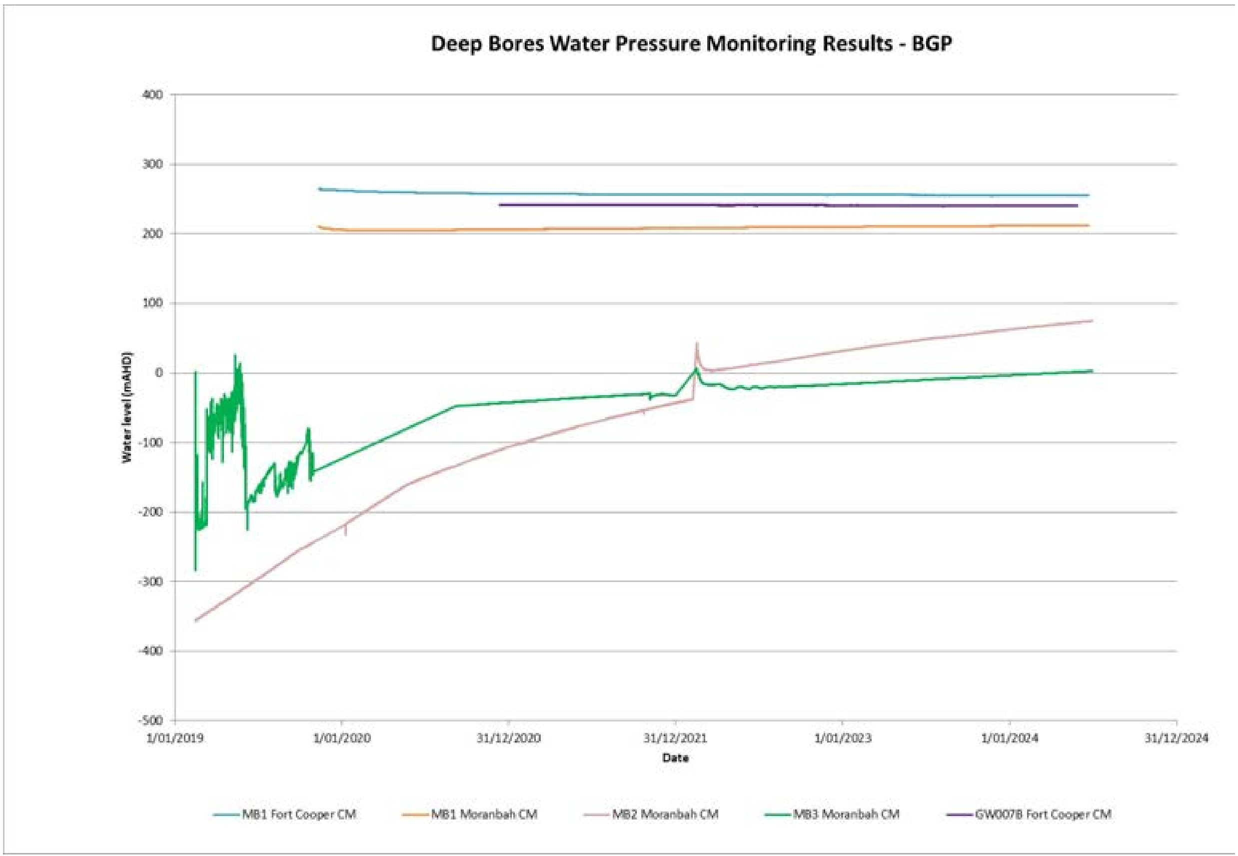


Figure 11: Deep Bores Water Pressure Monitoring Results – BGP

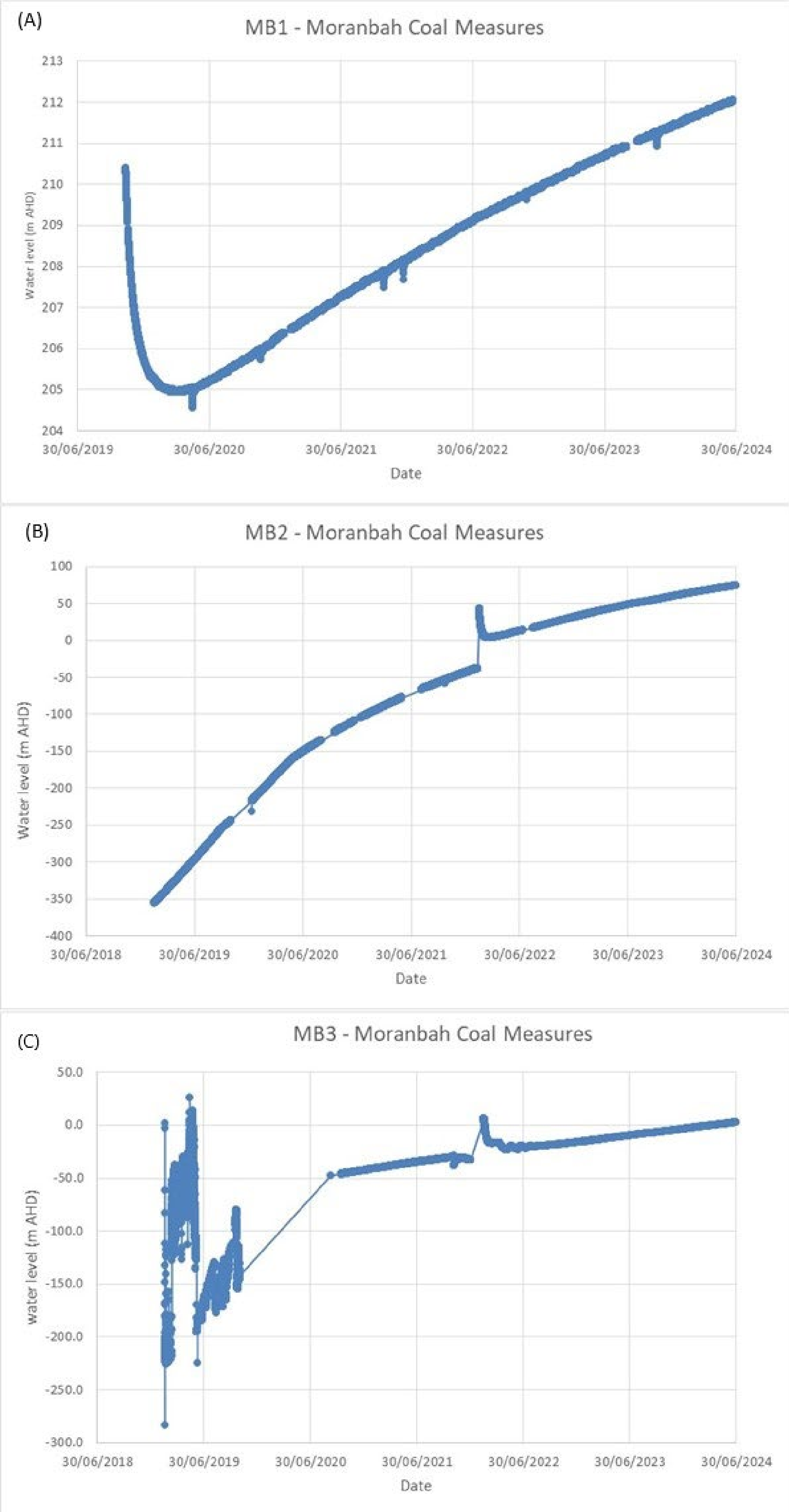
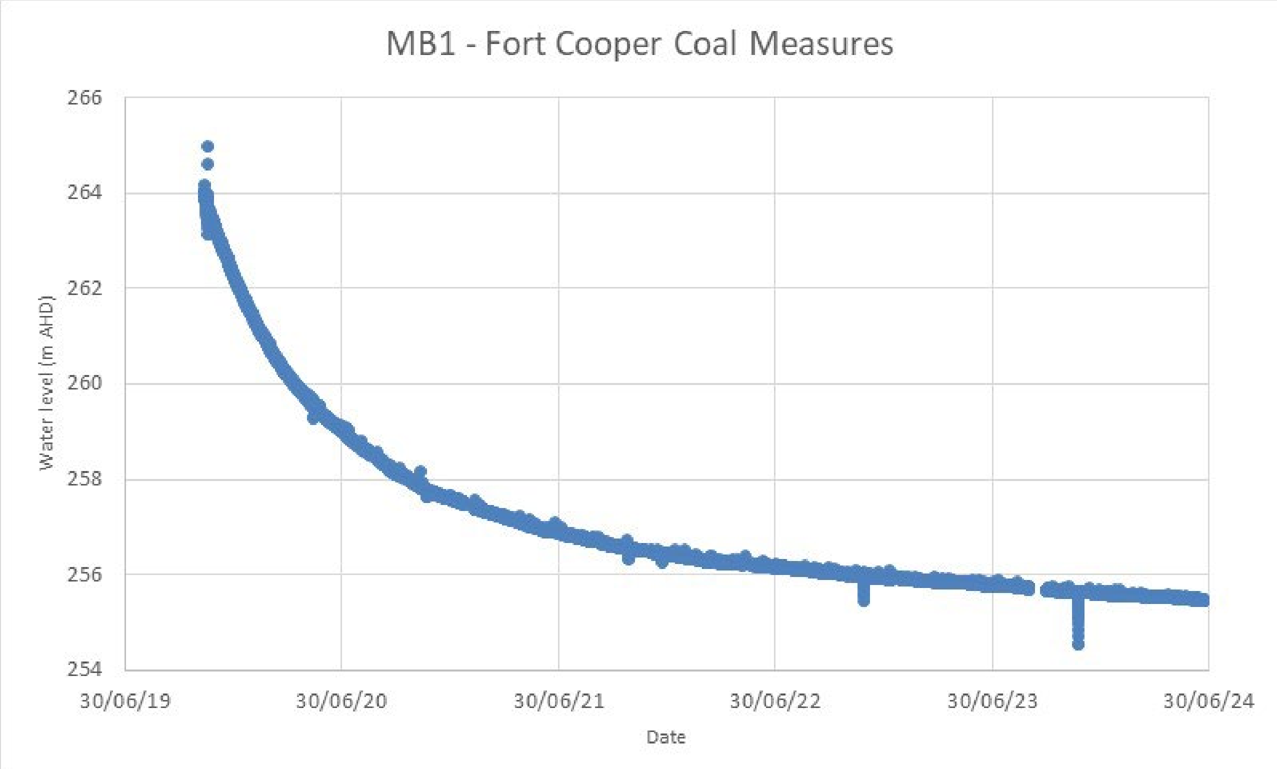


Figure 12: Deep Bores with a Long-term Recovery of Water Level



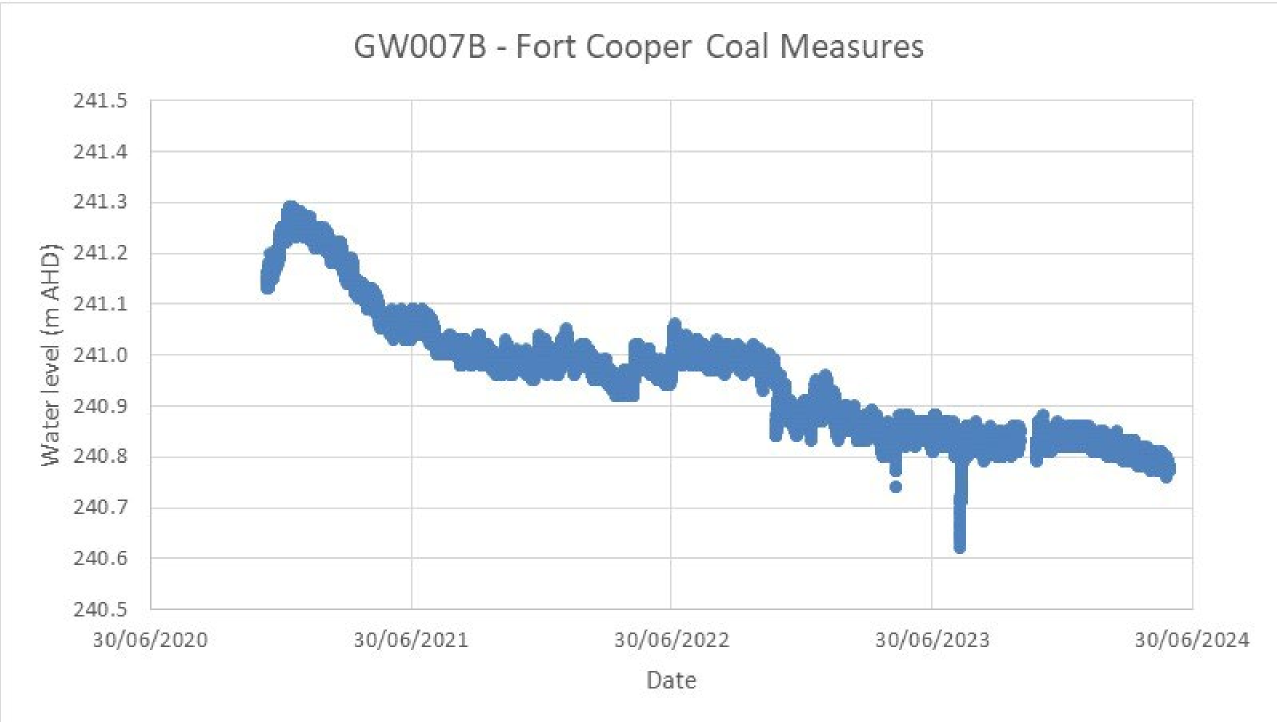


Figure 13: Deep Bores with a Long-term Declining Water Level

5.2 Groundwater Flow

A review of vertical gradients was undertaken for one monitoring location (MB1) with three monitoring points, which includes three monitoring points: MCM, FCCM, and FCCM (Girrah seam), in the BGP area.

Figure 14 shows the vertical gradients for MB1 and based on the presented data, an initial decrease in water levels in the MCM is visible, 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 observed. As of the end of 2024, the water levels in all three zones were stabilised, 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 gas 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.

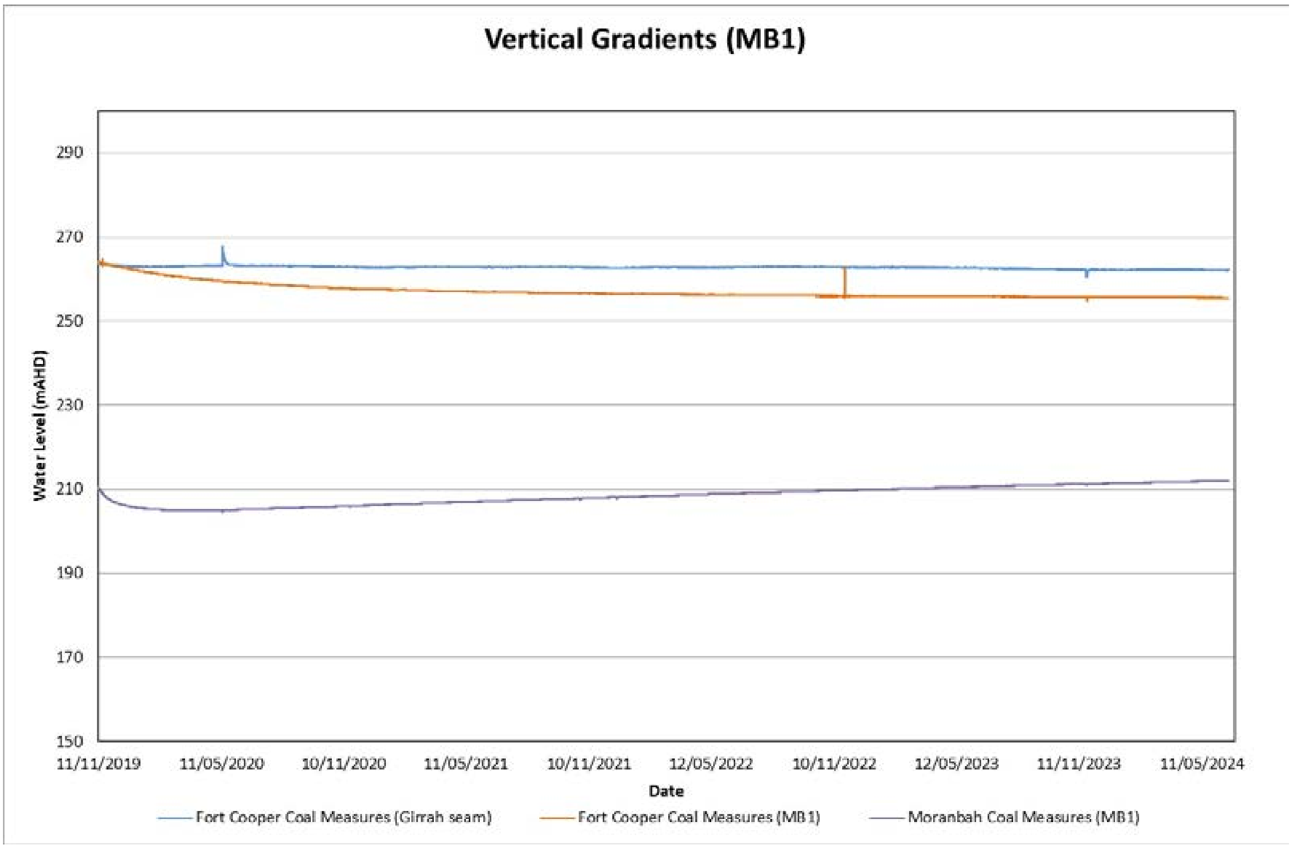


Figure 14: Review of Vertical Gradients for MB1

5.3 Groundwater Quality

5.3.1 *Shallow aquifer water quality*

There is no requirement for monitoring the water quality of the shallow bores in the BGP (Table 7), and as such, no water quality data pertaining to the shallow aquifer is presented here.

5.3.2 *Deep aquifer water quality*

Table 7 outlines the water quality monitoring requirements for the deep bores in the BGP. As previously mentioned, for any future WMS bores in the BGP area, groundwater quality monitoring is proposed to be conducted every six months for the first 12 months. Following this period, monitoring will occur annually for the remainder of the CSG operations.

Biannual sampling for MB1-D, installed in Moranbah Coal Measures (Table 7), was completed in the first year, with annual monitoring required thereafter.

Table 12 presents a summary of water quality results obtained from MB1-D targeting the deep aquifer (Moranbah Coal Measures). This provides an indication of water quality ranges for each parameter analysed based on the water quality samples collected from this bore (Appendix B). A review of this data indicates that there are no notable trends. Based on the data presented in Table 12, it can be concluded that the groundwater quality of the Moranbah Coal Measures at the location of MB1-D is saline (EC > 4800 µS/cm) (Government of South Australia, Department for Environment and Water, 2021).

Table 12: Background Water Quality – Deep Monitoring Bore (MB1-D)

Parameters	Units	Moranbah Coal Measures	
		Min	Max
Field pH		7.78	8.26
Electrical Conductivity (EC)	µS/cm	8600	9370
Total Dissolved Solids (TDS)	mg/L	5040	5320
Hydroxide Alkalinity (OH-) as CaCO3	mg/L	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	<1	48
Bicarbonate Alkalinity as CaCO3	mg/L	817	1870
Total Alkalinity as CaCO3	mg/L	817	1870
Sulphate, SO4	mg/L	<1	<1
Chloride, Cl	mg/L	1790	2560
Calcium - Dissolved	mg/L	4	14
Magnesium - Dissolved	mg/L	5	12
Sodium - Dissolved	mg/L	1900	2410
Potassium - Dissolved	mg/L	16	24
Arsenic-Dissolved	mg/L	0.001	0.003
Beryllium-Dissolved	mg/L	<0.001	<0.001
Barium-Dissolved	mg/L	2.41	4.29
Chromium-Dissolved	mg/L	<0.001	0.002
Cobalt-Dissolved	mg/L	<0.001	0.001
Copper-Dissolved	mg/L	<0.001	0.005
Lead-Dissolved	mg/L	0.001	0.008
Manganese-Dissolved	mg/L	0.007	0.049
Molybdenum	mg/L	0.011	0.018
Nickel-Dissolved	mg/L	0.01	0.05
Selenium	mg/L	<0.01	<0.01
Vanadium-Dissolved	mg/L	<0.01	<0.01
Zinc-Dissolved	mg/L	<0.005	0.045
Boron	mg/L	1.04	1.80
Iron	mg/L	0.48	1.53
Fluoride, F	mg/L	2.0	2.2
Phosphate as P in water	mg/L	0.45	1.31

5.4 Groundwater Use

The results from baseline assessments completed by Arrow Energy 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 DETSI. 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 OGIA.

5.4.1 *ATP1103*

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 166 assessments, including registered (115) and unregistered bores (51), have been undertaken on ATP1103. The results concluded that:

- 72 bores could not be found (43%)
- 8 bores are abandoned and destroyed (5%)
- 34 bores are abandoned but still useable (21%)
- 52 bores have been verified to exist (31%)

The locations of these bores are shown in Figure 15.

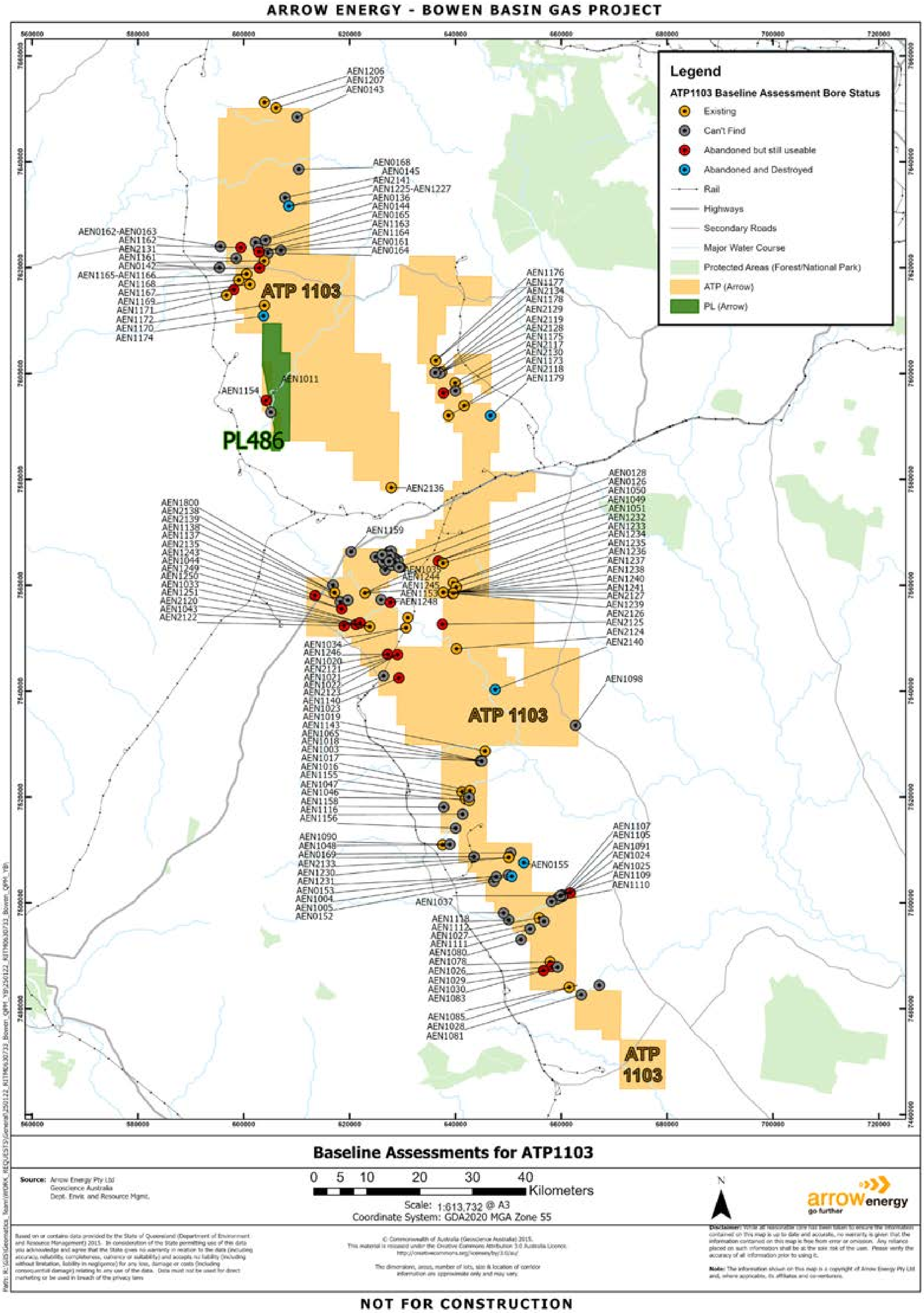


Figure 15: Completed Baseline Assessments for ATP1103 (and PL486)

5.4.2 *ATP1031*

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 ATP1031. To date, 58 assessments, including registered (44) and unregistered bores (14), have been undertaken on ATP1031. The results concluded that:

- 29 bores could not be found (50%)
- 5 bores are abandoned and destroyed (9%)
- 15 bores are abandoned but still useable (26%)
- 9 bores have been verified to exist (15%)

The locations of these bores are shown in Figure 16.

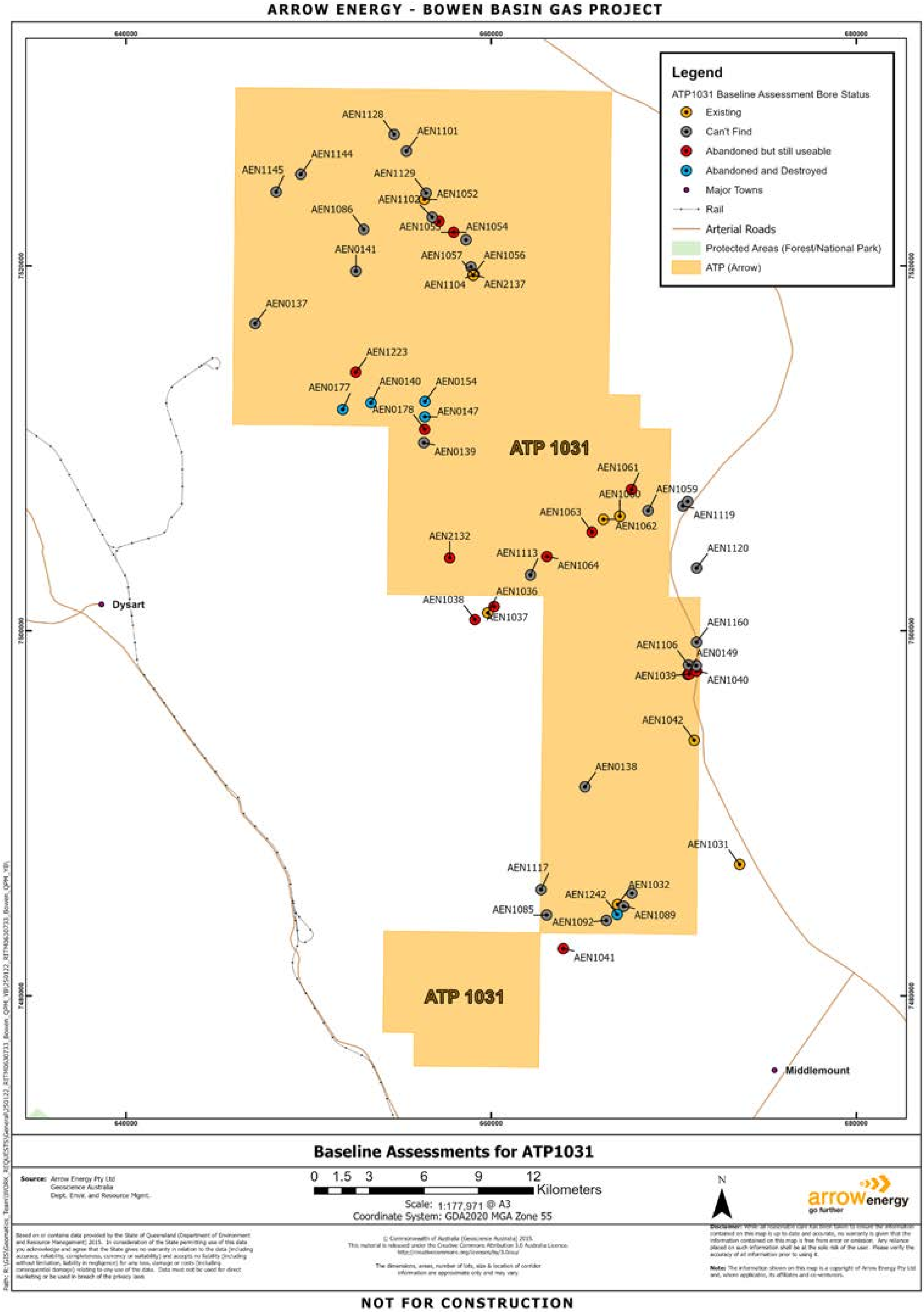


Figure 16: Completed Baseline Assessments for ATP1031

5.4.3 *ATP742*

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 ATP742. To date, a total of 13 assessments, including registered (6) and unregistered bores (7), have been undertaken on ATP742. The results concluded that:

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

The locations of these bores are shown in Figure 17.

5.4.4 *Future Baseline Assessments*

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

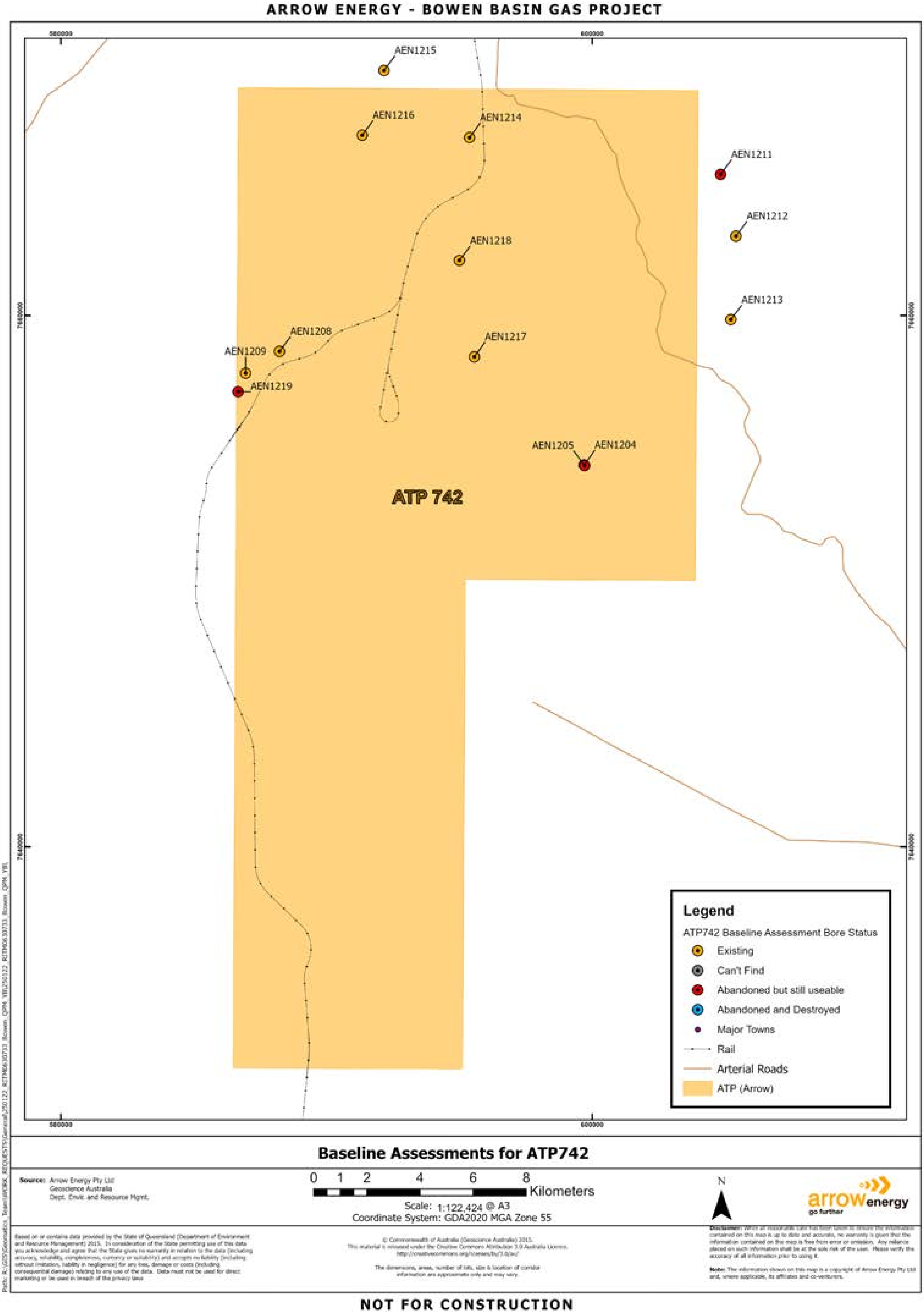


Figure 17: Completed Baseline Assessments for ATP742

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, 2019 and 2022UWIR 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 BGP Area has been implemented. Data obtained from groundwater monitoring bores making up the WMS provide site specific observations on groundwater levels/pressures and interconnectivity. Table 13 provides a comparison of this data. Overall, the existing conceptual model as presented in Section 3 remains valid.

Table 13: 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
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 saline.	No change

6.2 Groundwater Users

Baseline assessments have been undertaken by Arrow Energy 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 BGP area.

6.3 Conclusion

Prior to QPM Energy's acquisition of MGP on 20 September 2023, groundwater monitoring data focused on the MGP area. After this date, Arrow shifted its attention to collecting data exclusively from the BGP monitoring network. The previously collected monitoring data around the MGP area has contributed to the understanding of the Bowen Basin's hydrogeology, and it is concluded that the groundwater monitoring data collected to date for the BGP supports the conceptual hydrogeological model presented in Section 3 of this report.

The 2019 and 2022 Bowen UWIR groundwater models (AGE 2019 and AGE 2021) assessed the regional-scale groundwater impacts of Arrow Energy's BGP area at that time. In the most recent 2025 Bowen UWIR groundwater model, the 2022 model has been updated and recalibrated to incorporate the new available 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

Numerical groundwater modelling has been undertaken for Arrow Energy (AGE, 2025) to update the existing groundwater model (AGE, 2021) developed for MGP and BGP for use with the Bowen Underground Water Impact Report (UWIR) and the Bowen Groundwater Management and Monitoring Plan (GMMP). Details of the Bowen UWIR 2025 groundwater model can be found in Appendix C.

The overarching goal of the updated groundwater model is to outline the potential immediate and long-term groundwater impacts to groundwater levels due to CSG production. Although the updated model simulated both cumulative MGP and BGP impacts, as well as BGP impacts alone, the focus of the 2025 Bowen UWIR report will be solely on BGP impacts.

7.1 Model Development

The original Northern Bowen Basin numerical groundwater model was developed by Ausenco and Norwest (2012) for Arrow Energy to predict and delineate areas where predicted groundwater level drawdowns exceed the then 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 with 1500 m x 1500 m cells was used across 18 model layers (Ausenco and Norwest, 2012).

AGE (2019) updated the Ausenco and Norwest model in 2017 by refining the mesh to enhance the resolution around the MGP area to better delineate groundwater structures and increase the layer resolution within the Moranbah Coal Measures (MCM), raising the total number of layers to 22. Pilot point multipliers were added to the aquifer/aquitard hydraulic and storage parameter fields, and the model was calibrated using 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, 2019). A further refinement (AGE, 2021) was conducted in 2020 to refine the mesh in the Red Hill area and update the stress periods.

In 2025, Arrow Energy appointed AGE to update the above groundwater model for use with the Bowen UWIR and the Bowen GMMP. The updated groundwater model simulated both cumulative MGP and BGP impacts, as well as BGP impacts alone, using updated field development plan for the MGP and BGP.

Relative to the previous version of the model (AGE, 2021) which was used to assess groundwater impacts in the previous UWIR (Arrow, 2022) the following changes have been made:

- extension of the model calibration period from January 2018 to January 2024 (see Section 2.4, Section 2.7 and Section 3.1 of Appendix C);
- update the MODFLOW well (WEL) package based on actual historic CSG related water extraction data (Section 2.7 of Appendix C);
- refinement of model mesh around monitoring bores and within PL486 around the production area;
- update the MODFLOW recharge (RCH) package based on updated historic actual climate records from Bureau of Meteorology (BoM) SILO website; and
- generate revised predictions based on revised calibrated model parameters (Section 2.6 of Appendix C) and revised MGP and BGP field development plans provided by Arrow Energy and QPME (Chapter 4 of Appendix C).

No changes have been made to the model domain, mesh or layering relative to the previous Bowen Basin model (AGE, 2021). The sections below therefore provided a brief description of these features of the model for completeness.

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 18.

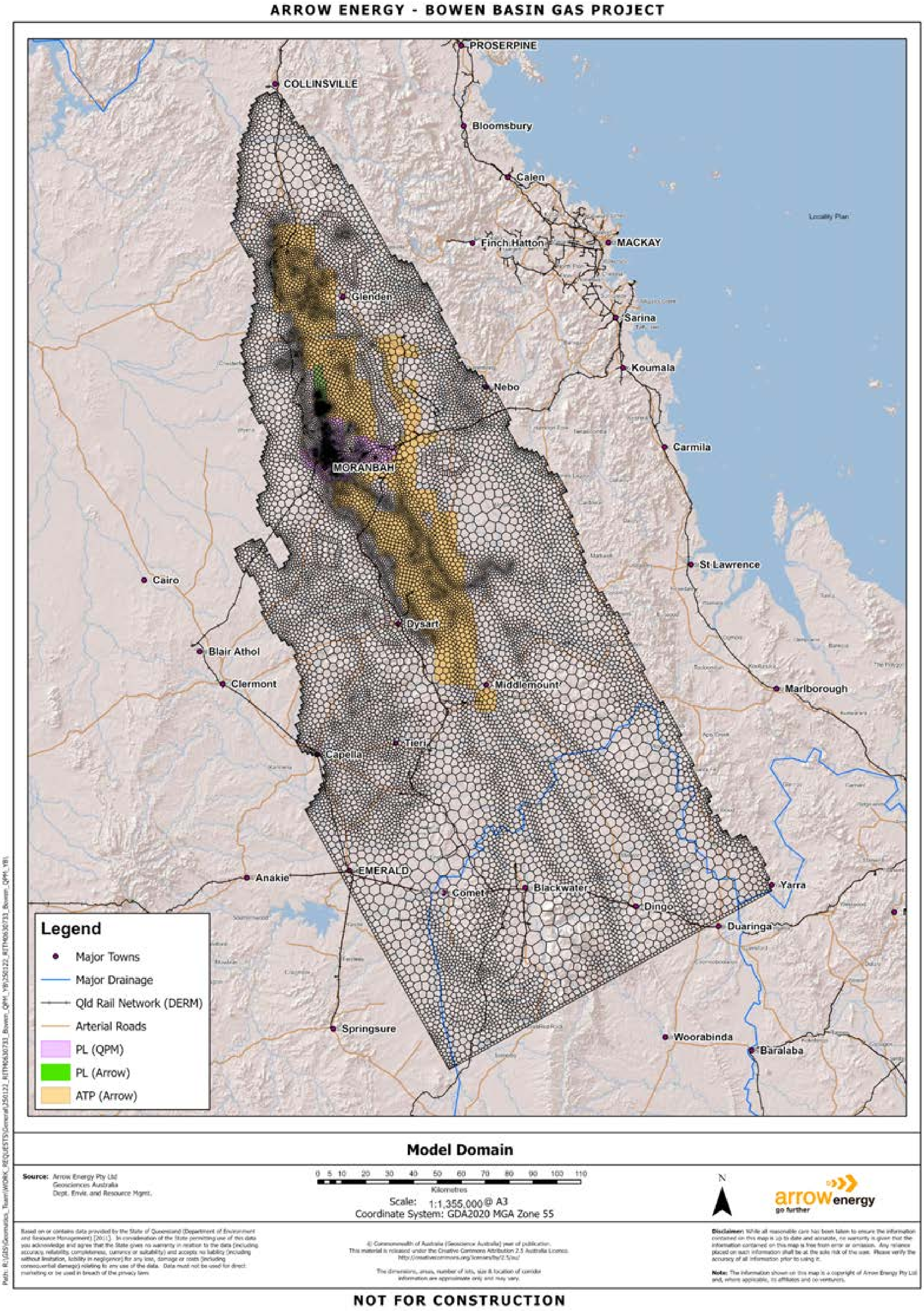


Figure 18: Model Domain

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 modelled faults;
- surficial aquifer systems (e.g. basalt): ~1000 x 1000m centred either side of aquifer extents;
- major drainage systems: ~500 x 500m centred along river lines proximal to the MGP;
- 150 m cells within the Red Hill Production area in PL486 which forms part of the BGP; and
- 150 m cells centred at the location of each monitoring well.

Overall, the model comprised 212,667 cells across 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 Bowen basin geological model. A summary of the model layers is presented in the Table 14.

Table 14: Model Layers

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

7.1.2 *Stress Period Setup*

No changes have been made to the stress period setup relative to the previous Bowen Basin model (AGE, 2021). Model simulations comprise the following 405 stress-periods:

- December 2003, a single steady state stress period to simulate pre-CSG initial conditions.
- December 2003 to May 2030, 318 monthly stress periods to simulate historical and anticipated near-future CSG developments in the model domain which include all historical and future MGP developments.
- June 2030 to December 2099, one seven-month and 68 annual stress periods to simulate long-term future CSG developments that form part of the BGP and initial post-CSG recovery.
- January 2100 to 2180, one six-year and 15 five-year stress periods for long-term post-CSG recovery simulations.

7.1.3 *Boundary Conditions*

The boundary conditions of the 2025 Bowen model are based on the 2022 Bowen model developed by AGE (2021). No changes were made to the following input packages:

- The MODFLOW River package (RIV) was used to represent the perennial reaches of the Bowen and Isaac Connors River system with river elevations, stage heights, incisions depths and vertical conductivity rates based on the Isaac Connors Groundwater Project (SKM, 2009).
- A general head boundary (GHB) package was used at all model boundaries to replicate regional groundwater gradients.
- Potential and actual evapotranspiration dataset was applied to the model using the MODFLOW evapotranspiration (EVT) package using a constant maximum evapotranspiration rate of 0.00274 m/day and an extinction depth of 15 m (i.e. when groundwater levels fall below this extinction depth no evapotranspiration losses occur).

As part of extending the calibration period of the previous Bowen basin model to January 2024, changes were made to recharge (RCH) package to represent rainfall recharge (see Section 2.5 of Appendix C) and the MODFLOW WEL package to simulate CSG water extraction (see Section 2.7 of Appendix C).

7.1.4 *Rainfall Recharge*

Rainfall recharge rates were derived based on soil-moisture bucket (SMB) model calculations, which computes a daily balance of water entering the soil zone via rainfall and exiting via evapotranspiration. On any days where soil moisture storage capacity is exceeded i.e., the soil moisture deficit reaches zero, then any rainfall in excess of evapotranspiration forms recharge to the underlying groundwater. Inputs to the SMB calculations are daily rainfall and evapotranspiration using climate data downloaded from the Bureau of Meteorology (BOM) for grid point coordinates -21.05 and 147.95. Calculated SMB recharge seepage rates were aggregated for each stress-period of the Bowen groundwater model and applied to the MODFLOW recharge package.

7.1.5 *Initial Hydraulic Properties*

As the Bowen Basin model was not re-calibrated for the 2022 UWIR (Arrow, 2022) initial (pre-calibration) hydraulic properties were assigned based the previous calibration (AGE, 2019), except for specific storage. For specific storage, a number of papers, in particular Rau et al. (2018), have been released since completion of the previous calibration (AGE, 2019) suggesting that the calibrated specific storage values may be unrealistically high. Rau et al. (2018) suggested an upper bound of 2.0×10^{-5} m^{-1} for specific storage and hence the previously calibrated values were adjusted downwards where necessary to prevent initial values exceeding this bound.

As per the previous model iterations (AGE, 2019, 2021) initial hydraulic properties of different formations in Moranbah and Rangal Coal Measures also feature a depth-dependency. These depth relationships, presented in AGE (2018), are based on aquifer parameters reported by Ausenco and Norwest (2012) for different subregions in these hydrogeological units. A summary of initial hydraulic properties per model layer is provided in Table 15, which also indicates whether the hydraulic conductivity is depth-dependent for each model layer. Upper and lower bounds used for model calibration can be found in Appendix C (Section 3.3 and listed in Table 3.3).

Similar to AGE (2018, 2021), two-phase flow relative permeability effects encountered in the vicinity of CSG production wells are not considered in the model. These effects comprise a reduction of effective permeability due to the presence of gas and as reported in AGE (2018) lead to a potential misrepresentation of drawdowns in the immediate vicinity of the CSG production wells. In addition, there is a considerable amount of upscaling for regional scale models representing the interburden units surrounding the in-seam wells. This further contributes to the uncertainty of the groundwater pressures proximal to CSG production wells. As reported in AGE (2018), these effects are considered local with minimal implications to regional groundwater drawdown predictions.

Table 15: Summary of Initial Hydraulic Parameters

Layer	Primary formation	Unit	Horizontal (Kh) (m/day)	Vertical (Kv) (m/day)	Depth Dependency	Specific storage average and max-min range (m^{-1})	Specific yield average and max-min range (%)
1	Quaternary Alluvium, weathered materials	Surficial coverage	8.44E+00 (8.50E-03 - 1.40E+02)	1.61E+00 (8.50E-05 - 1.00E+01)	No	2.0E-05 (2.0E-05 - 2.0E-05)	19.1% (18.0% - 20.0%)
2	Tertiary sediments (Duringa), Basalts (Anakie) & Moolayember	Tertiary, Triassic	4.76E+00 (1.40E-05 - 6.20E+01)	2.53E+00 (2.60E-09 - 1.40E+02)	No	1.6E-05 (9.9E-07 - 2.0E-05)	14.7% (5.0% - 50.0%)
3	Clematis Sandstone	Triassic	2.06E-02 (6.30E-03 - 5.50E-02)	2.07E-03 (3.60E-04 - 7.50E-03)	No	2.0E-05 (2.0E-05 - 2.0E-05)	17.0% (17.0% - 17.0%)
4	Rewan	Triassic	1.08E-03 (7.50E-04 - 1.00E-02)	1.54E-07 (9.70E-08 - 5.50E-06)	No	1.0E-06 (9.9E-07 - 1.0E-06)	6.0% (6.0% - 6.0%)
5	Rangal Coal Measures	Leichardt seam	2.56E-02 (8.60E-06 - 1.00E-01)	6.90E-03 (8.60E-06 - 5.40E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
6		Interburden	1.00E-04 (1.00E-04 - 1.00E-04)	1.00E-08 (1.00E-08 - 1.00E-08)	No	1.0E-06 (9.9E-07 - 1.0E-06)	6.0% (6.0% - 6.0%)
7		Vermont seam	2.08E-02 (8.60E-06 - 1.00E-01)	5.25E-03 (8.60E-06 - 5.40E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
8	Fort Cooper Coal	Girrah	1.00E-04 (1.00E-04 - 1.00E-04)	8.60E-06 (8.60E-06 - 8.60E-06)	No	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
9		FCCM	4.40E-03 (4.40E-03 - 4.40E-03)	8.00E-05 (8.00E-05 - 8.00E-05)	No	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
10		FHF	1.00E-04 (1.00E-04 - 1.00E-04)	8.60E-06 (8.60E-06 - 8.60E-06)	No	2.0E-05 (1.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
11	Moranbah Coal	Q seam	1.62E-02 (8.60E-06 - 1.00E-01)	5.31E-03 (8.60E-06 - 1.00E-01)	Yes	1.9E-05 (9.0E-07 - 2.1E-05)	5.0% (5.0% - 5.0%)
12		Interburden	9.98E-05 (8.80E-05 - 1.00E-04)	2.08E-08 (2.00E-08 - 9.20E-08)	No	9.6E-07 (7.0E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)
13		P seam	1.16E-02 (8.60E-06 - 1.00E-01)	4.28E-03 (8.60E-06 - 1.00E-01)	Yes	1.9E-05 (9.0E-07 - 2.0E-05)	5.0% (5.0% - 5.0%)
14		Interburden	9.69E-05 (1.30E-05 - 1.00E-04)	6.69E-08 (1.00E-08 - 7.10E-08)	No	9.7E-07 (7.0E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)

Layer	Primary formation	Unit	Horizontal (Kh) (m/day)	Vertical (Kv) (m/day)	Depth Dependency	Specific storage average and max-min range (m^{-1})	Specific yield average and max-min range (%)
15		GM seam	7.72E-03 (8.60E-06 - 1.00E-01)	1.61E-03 (8.60E-06 - 3.20E-02)	Yes	1.8E-05 (9.0E-07 - 2.0E-05)	5.0% (5.0% - 5.0%)
16		Interburden	1.03E-04 (9.90E-05 - 3.40E-04)	8.29E-08 (6.90E-08 - 3.00E-06)	No	1.2E-06 (9.7E-07 - 6.5E-05)	5.0% (5.0% - 5.0%)
17		GML seam	6.90E-03 (8.60E-06 - 1.00E-01)	1.59E-03 (8.60E-06 - 3.20E-02)	Yes	2.0E-05 (1.9E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
18		Interburden	1.00E-04 (1.00E-04 - 1.00E-04)	7.00E-08 (7.00E-08 - 7.00E-08)	No	1.0E-06 (9.8E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)
19		DYU seam	6.47E-03 (8.60E-06 - 1.00E-01)	1.50E-03 (8.60E-06 - 3.20E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
20		Interburden	1.00E-04 (1.00E-04 - 1.00E-04)	7.00E-08 (7.00E-08 - 7.00E-08)	No	1.0E-06 (9.9E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)
21		DYR seam	6.40E-03 (8.60E-06 - 1.00E-01)	1.50E-03 (8.60E-06 - 3.20E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
22		Permian basement	4.40E-04 (4.40E-04 - 4.40E-04)	8.80E-06 (8.80E-06 - 8.80E-06)	No	1.0E-06 (9.9E-07 - 1.0E-06)	6.0% (6.0% - 6.0%)

7.1.6 *Field Development Plan and CSG Extraction*

Field Development Plans (FDP) and well locations for the MGP and BGP are presented in Figure 19. These FDPs have not materially changed with the acquisition of the MGP by QPM. The total daily water production for the MGP and BGP development scenarios is summarised in Figure 20. The MGP has reducing water production rates whilst the large volume of water production is predicted for post 2045 after start of the larger Bowen field development.

Both historical and future CSG FDP data were used in developing the groundwater model. Historical FDP data included monthly historical water extraction rates for each individual existing CSG well which form part of the MGP and BGP. This data was used to extend the historical CSG extraction period in the model to the end of the calibration period (i.e. January 2025) using the MODFLOW WEL package. Many of these existing CSG wells are non-vertical, penetrating multiple model layers. Hence, prior to using the supplied well extraction volumes it was first necessary to distribute these volumes across several model nodes. This was carried out using inhouse AGE software which distributes the reported volumes based on the nodes intersected by each well and the modelled hydraulic conductivity of these nodes.

Information on expected future CSG well locations and forecast water extraction relating to both existing and proposed wells based on current FDPs for the MGP and BGP were also provided. Relative to the previous Bowen UWIR (Arrow, 2022) the following changes have been made to the MGP and BGP FDPs:

- revised FDP data provided for the BGP for the period 2025 to 2045 includes an additional 15 CSG wells on ATP 1103 and seven additional wells on PL486;
- no changes have been made to the BGP FDP, apart from a delay in production, for the period 2045 to 2063; and
- no changes have been made to MGP FDP and hence the predicted water extraction related to this project are the same as reported in the previous UWIR (Arrow, 2022).

Modelled CSG extraction start and end dates based on updated information, provided by Arrow Energy and QPME, are presented in Figure 21 and Figure 22. During the model calibration period (i.e. to January 2025) only CSG production wells related to the MGP are active, although several pilot CSG wells associated with the BGP are also operating over this period.

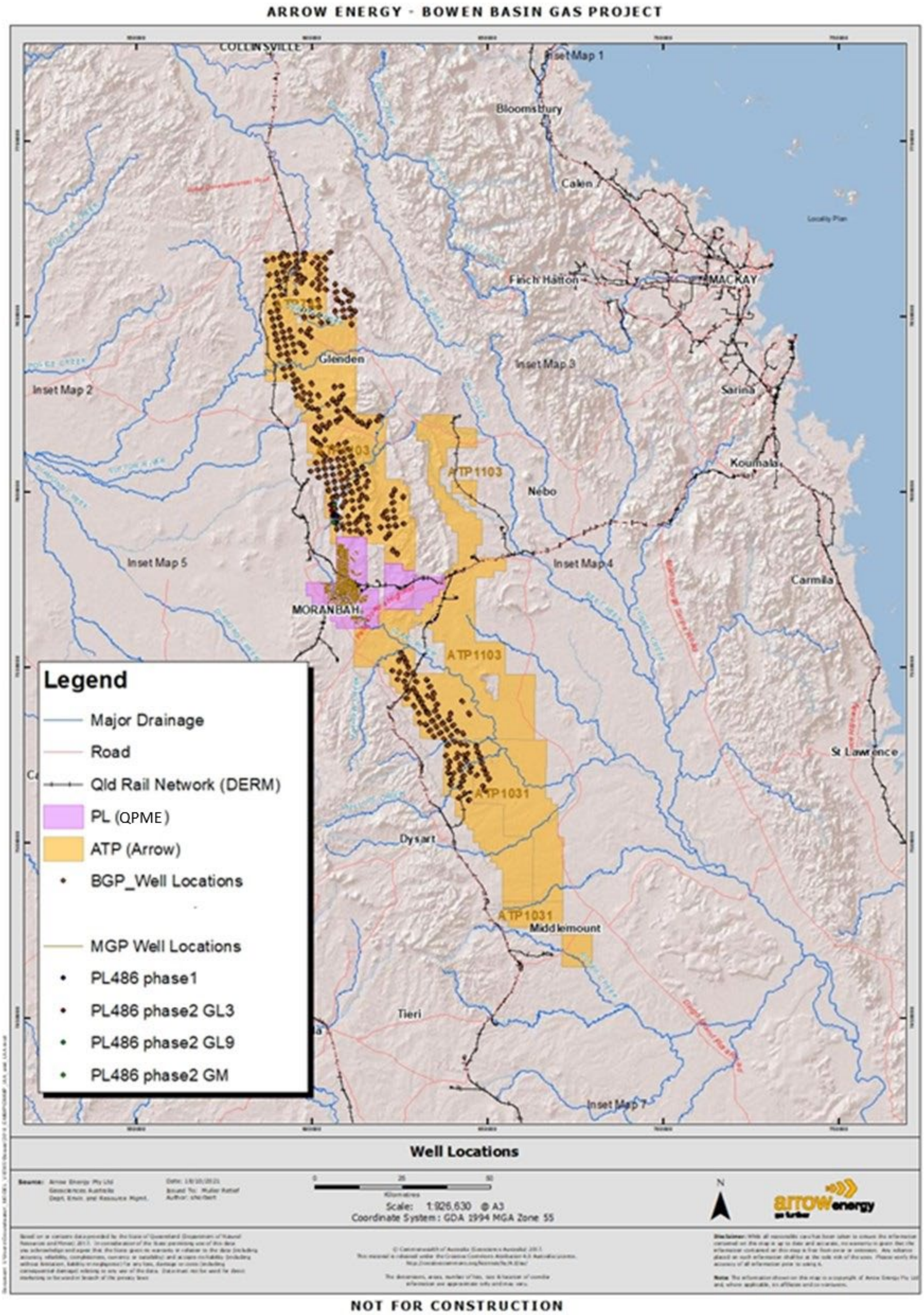


Figure 19: Field Development Well Locations

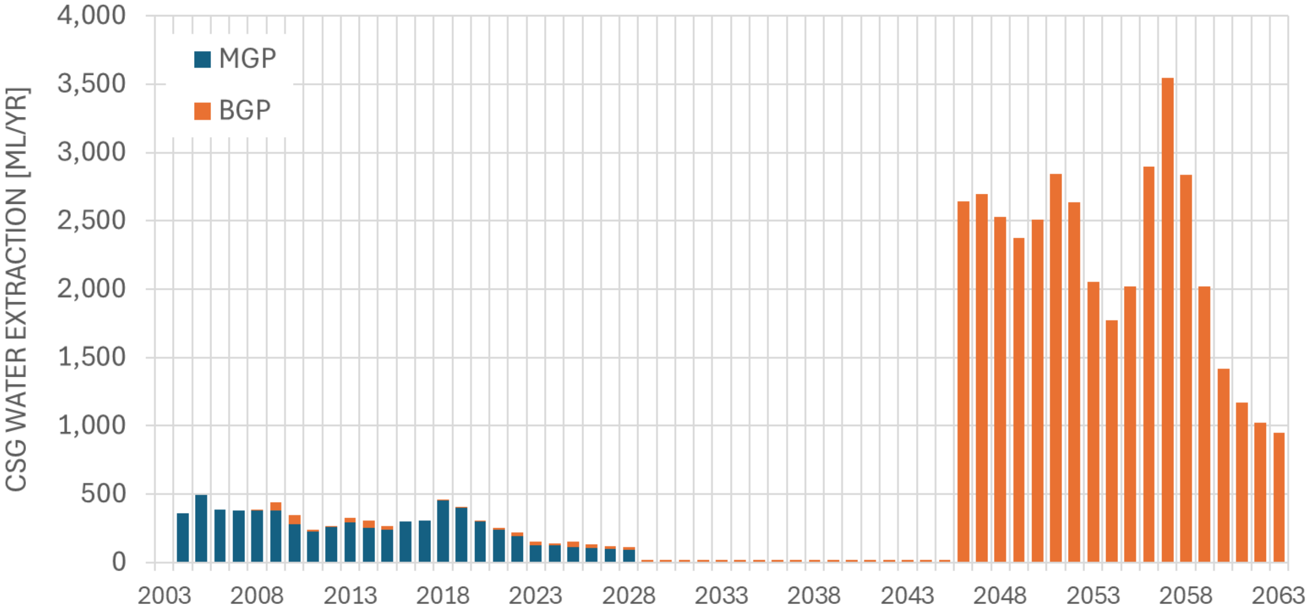


Figure 20: FDP - Timeseries of CSG Extraction Rates for the MGP and BGP

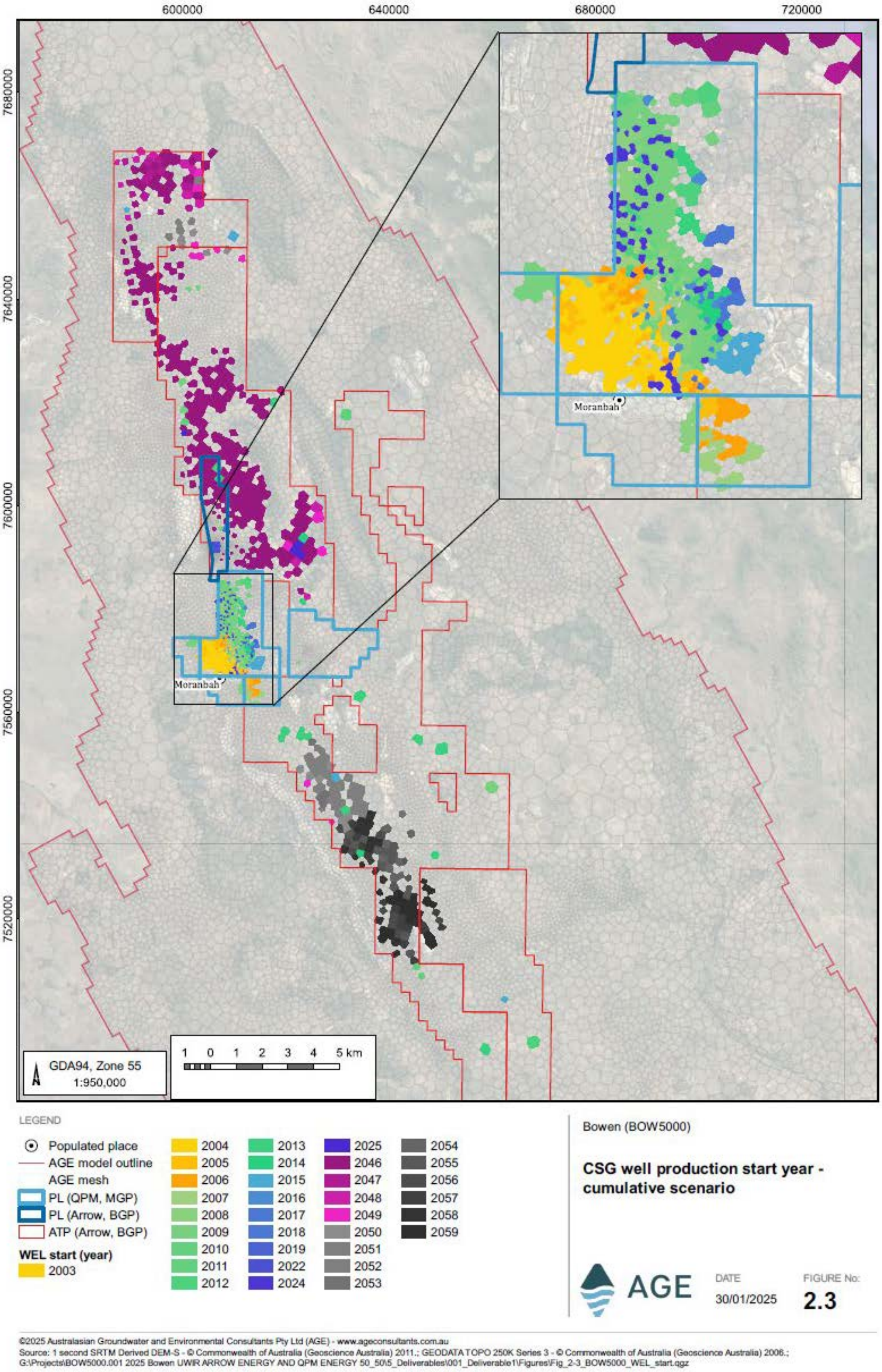


Figure 21: CSG Well Production Start Year – Cumulative Scenario

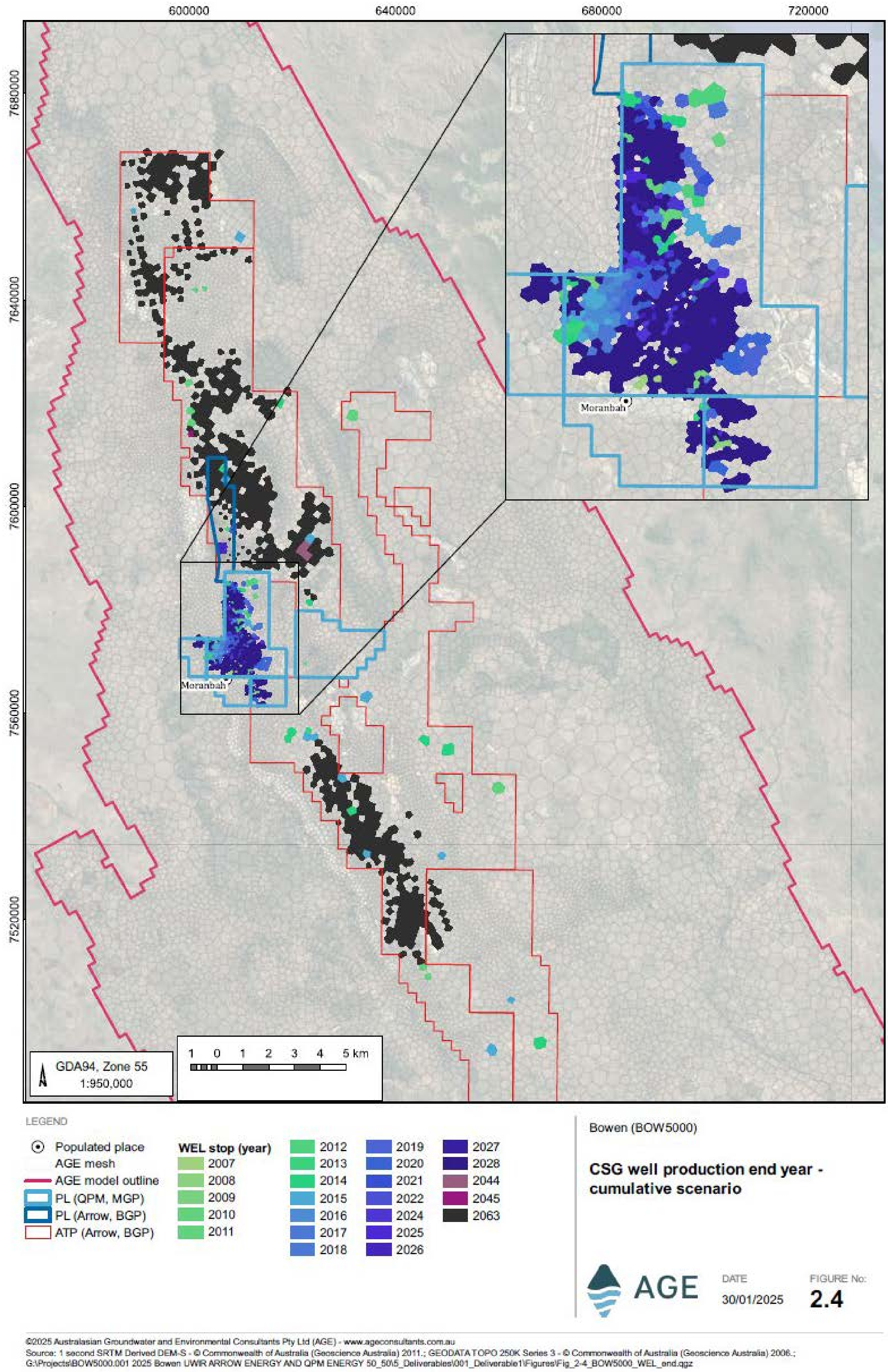


Figure 22: CSG Well Production Start Year – Cumulative Scenario

7.2 Calibration

The calibration was performed using a combined pre-CSG steady state and transient simulation for the period January 2003 to January 2024. It was undertaken with reference to an updated groundwater level observation dataset for this period using automated parameter estimation software PEST_HP (Watermark Numerical Computing, 2021) to determine optimal hydraulic parameters and recharge rates.

As per the previous calibration (AGE, 2019) a total of 6,705 model parameters were estimated. As noted earlier (Section 7.1.5), initial parameter values were primarily based on previously calibrated parameters, other than specific storage where the initial values were adjusted to avoid exceeding the upper bound values reported in Rau et al. (2018). Due to the large number of parameters, singular-value-decomposition was adopted to assist with model calibration and preferred value regularisation was also used to restrict parameter changes that are not informed by the calibration dataset.

7.3 Calibration Dataset

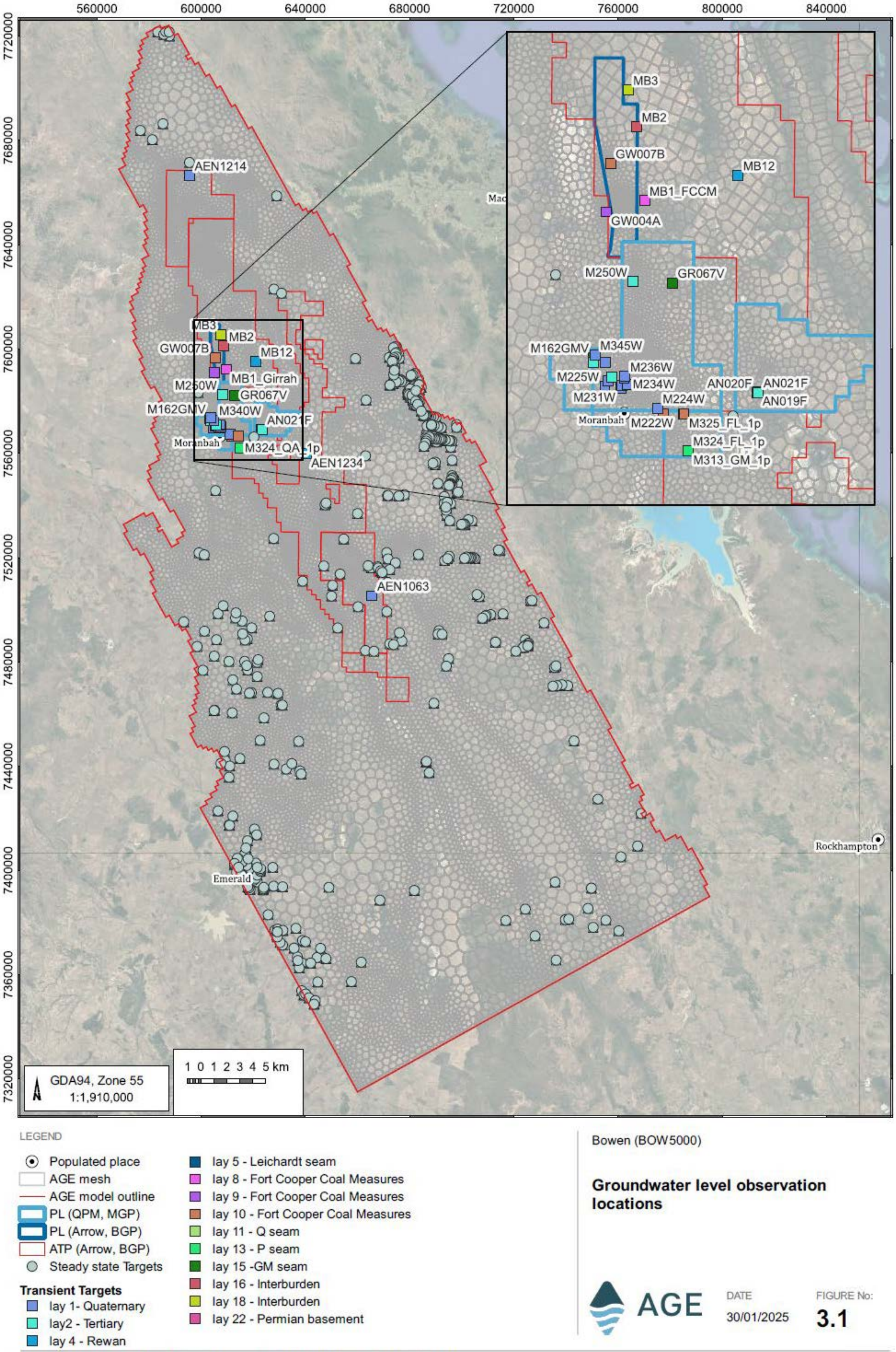
Transient calibration was undertaken with reference to updated data for 38 monitoring points for which time series groundwater level data are available. The steady state part of the calibration uses data for a substantially larger number of 481 monitoring points which includes single time of drilling readings for a large number of landholder monitoring points. The locations of steady-state and transient monitoring points are shown in Figure 23.

The steady-state calibration data set was the same as that used for the previous calibration (AGE, 2019). Details of the 41 transient monitoring points considered for use in the 2025 recalibration reported herein are presented in Appendix C (Table 3.1 and Table 3.2), for shallow and deep monitoring points, respectively. Ultimately data for only 38 transient monitoring points were used for calibration. The following monitoring points were excluded from calibration:

- Data for monitoring bores MB2 and MB3 were excluded as observed groundwater levels for these bores show recovering groundwater levels related to pilot production testing and water extraction activities between 2011 and 2018 (Arrow, 2024) which are not represented in the 2025 Bowen model; and
- Data for monitoring point M325_FL_1P was excluded due to observed groundwater levels being affected by sampling and erroneous measurements (Arrow, 2019).

Early records for GR067V were also excluded as these are affected by depressurisation activities associated with the conversion of the CSG production well to a monitoring point (Arrow and QPM, 2024).

Observation weights were initially assigned based on the number of observations for each monitoring point and subsequently adjusted using the PEST utility PWTADJ1 to ensure that no single observation group dominates the calibration.



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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\BOW5000.001 2025 Bowen UWIR ARROW ENERGY AND QPM ENERGY 50_50\5_Deliverables\001_Deliverable1\Figures\Fig_3-1_BOW5000_Observations_Location.qgz

Figure 23: Groundwater Level Observation Locations

7.4 Pilot Points

As per the previous calibration (AGE, 2019), a total of 1,672 pilot points were used to calibrate the hydraulic properties of the 2025 Bowen Basin model, using 76 pilot points in each of the 22 model layers, the locations of which are presented in Figure 24. The values assigned to each of the pilot points were interpolated across the model domain in each layer of the model using ordinary automatic kriging through PLPROC (Watermark Numerical Computing, 2016). Pilot point multipliers were allowed to vary ±2 orders of magnitude from the starting parameters and estimated hydraulic properties were capped based on the parameter bounds summarised in Table 16.

Table 16: General Parameter Constraints

Unit	Model Layers	Horizontal hydraulic conductivity, Kx (m/day)	Horizontal hydraulic conductivity, Kz (m/day)	Specific yield, Sy (%)	Specific storage, Ss (m-1)	Maximum anisotropy, Kx:Kz
Alluvium, weathered materials	1	1.0E-05 – 150	1.0E-05 - 10	0.1 – 20	9.0E-07 - 2.1E-05	0.5
Tertiary Basalt	2	1.0E-05 – 100	1.0E-05 - 1	0.1 – 20	9.0E-07 - 2.1E-05	1
Sandstone	3	1.0E-05 - 1	1.0E-05 - 1	0.1 – 20	9.0E-07 - 2.1E-05	1
Interburden	4, 6, 12, 14, 16, 18, 20	8.6E-06 - 1.0E-02	1.0E-08 - 5.0E-03	0.1 – 6	7.0E-07 – 7.5E-05	0.5
Coal seams	5, 7, 8, 9, 10, 11, 13, 15, 17, 19, 21	8.6E-06 - 1.0E-01	8.6E-06 - 1.0E-01	0.1 – 6	2.0E-06 – 2.7E-05	1

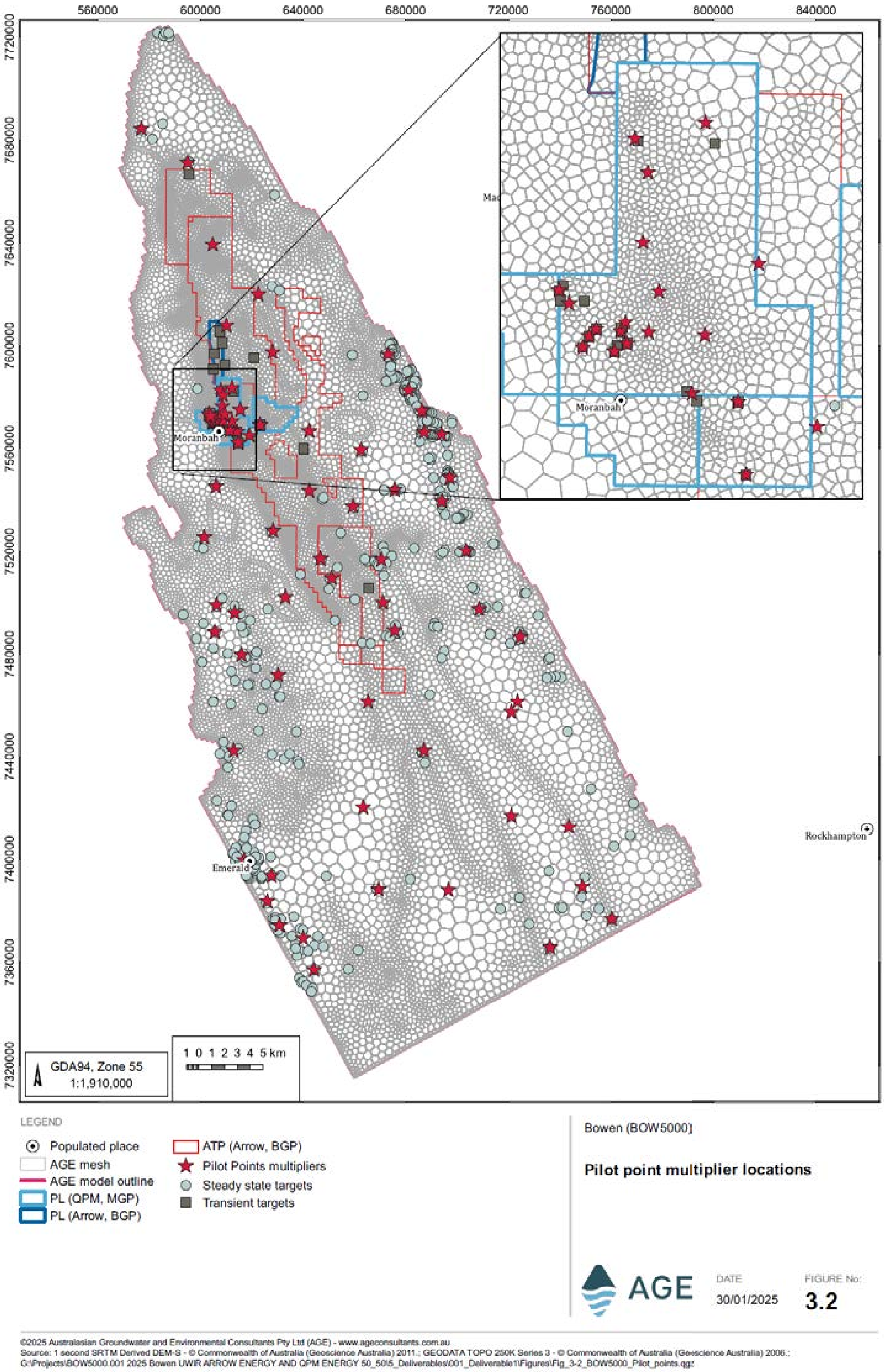

Figure 24: Pilot Point Multiplier Locations

7.5 Calibration Results

7.5.1 *Groundwater levels*

Figure 25 presents a comparison of observed and simulated groundwater levels resulting from the calibration as a scattergram. For both the steady-state simulation and transient simulation a high level of agreement between observed and modelled levels has been achieved as shown in Figure 25 and evidenced by the statistics presented in Table 17. In particular a scaled root mean square (SRMS) discrepancy between observed and simulated values of 2.9% has been achieved for the updated transient simulation. This transient SRMS statistic is substantially better than equivalent statistics related with either previous iteration of the model, which were 5.2 % in 2018 (AGE, 2019) and 13.7% in 2021 (AGE, 2021).

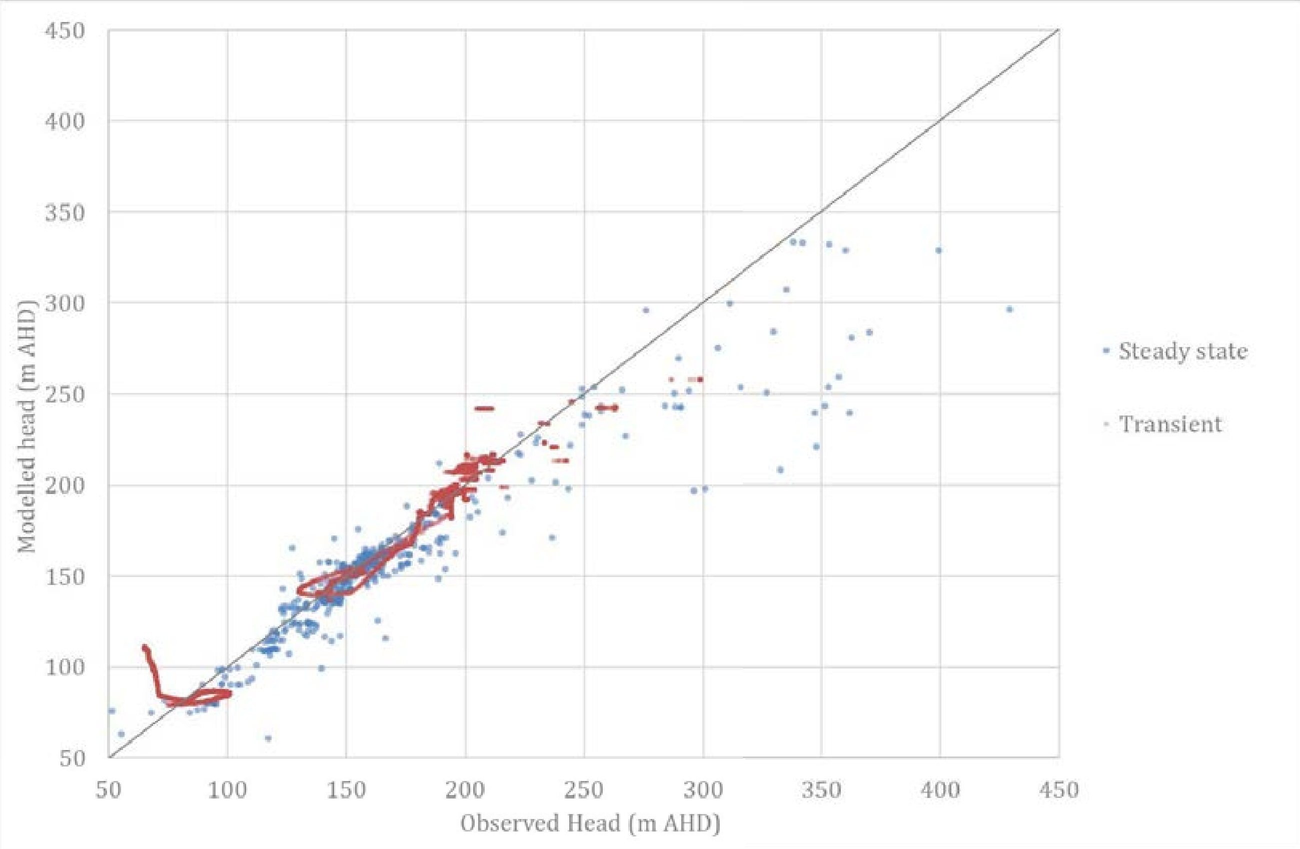

Figure 25: Measured vs. Simulated Groundwater Levels - 2025 Bowen UWIR model

Table 17: Statistical Analysis

Calibration performance measure	Transient data	Steady-state data
Sum of Residuals (SR) (m)	-33,875	4,195
Mean Sum of Residuals (MSR) (m)	-1.04	8.72
Scaled Mean Sum of Residuals (SMSR) (%)	-0.4	2.3
Sum of Squares (SSQ) (m)	1,462,409	234,329
Mean Sum of Squares (MSSQ) (m)	44.73	487.17
Root Mean Square (RMS) (m)	6.69	22.07
Root Mean Fraction Square (RMFS) (%)	0.5	0.9
Scaled RMFS (SRMFS) (%)	0.4	0.4
Scaled RMS (SRMS) (%)	2.9	5.8

Comparisons of observed and modelled head time series at each transient monitoring point used for model calibration are presented in Appendix C. In general, as per the overall statistics discussed above, a relatively good fit to the observed data has been achieved.

7.5.2 *Modelled water balance*

Table 18 presents the water budget for the steady state (pre-CSG) model. 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 transient simulation was also 0%. This value indicates that the model is stable and achieves an accurate numerical solution.

Table 18: Model Water Budget - Steady State

Parameter	In (m^3/day)	Out (m^3/day)	In - Out (m^3/day)
Rainfall recharge	211,021	0	211,021
Groundwater discharge to surface water courses	0	87,978	-87,978
Evapotranspiration	0	237,383	-237,383
In/outflow from/to lateral model boundaries	221,497	107,157	114,340
Total	**432,518**	**432,518**	**0**

7.5.3 *CSG Extraction*

As discussed in Section 7.1.6, historic and future CSG (water) extraction rates have been simulated in the model using actual and anticipated water extraction volumes (provided by Arrow and QPM). The volumes have been input to the groundwater flow model via the MODFLOW WEL package and hence are referred to as “Model input” in Figure 26. Since MODFLOW automatically switches off extractions which occur from dry cells then in some situations the total modelled output (i.e. the amount extracted in the simulation) can be less than the input. As shown in Figure 26, this is not considered to be a significant source of error in this model since the modelled input and output time series plot on top of each other for the majority of the simulation period, hence confirming that the actual modelled extraction volumes are not materially different from those provided by Arrow and QPM. In addition, a comparison between total model input and output extraction volumes at the end of the simulation show only a 1% difference between the total model input extraction volume and the total volume actually extracted from the model.

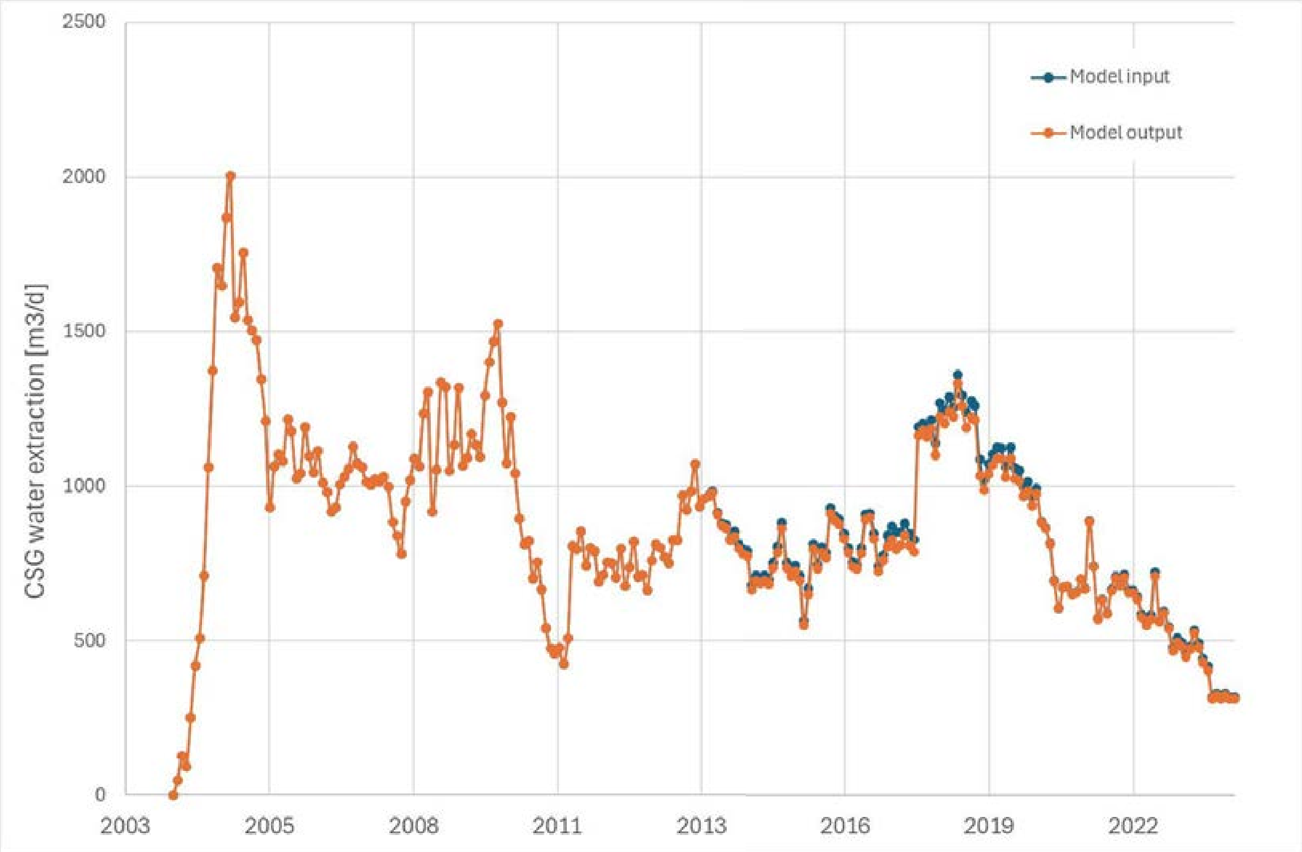

Figure 26: Input Extraction Rates for the WEL-package vs. Modelled CSG Extraction Rates

7.5.4 *Calibrated hydraulic parameters*

Appendix C (Table 3.6) summarises the average hydraulic conductivity, specific storage and specific yield for each geology unit in the model domain. The re-calibrated parameter values show the following minor changes compared to the previous calibrated values (AGE, 2019), which were re-used in 2021 (AGE, 2021) and adopted as initial values for this work:

- lower horizontal and vertical hydraulic conductivity (around 10 to 20% lower compared to the previously calibrated values for the Q and GM seam layers in the Moranbah Coal Measures (model layers 9 and 15, respectively); and
- increased vertical hydraulic conductivity for most layers by around 10% compared to the previous calibration, except for the Q and GM coal seam layers (see previous bullet point).

7.6 Predictions of Impacts

The following three predictive model scenarios were simulated for the purposes of estimating the cumulative impacts of the MGP and BGP and as well as the individual contribution of each:

- A baseline or **No CSG scenario** which does not include CSG related extraction.
- An **MGP only scenario** which assumes that there is no extraction from CSG wells associated with the BGP project, note that any recorded actual extraction from BGP pilot wells is also excluded from this scenario.
- A **Cumulative scenario** which includes actual historic and proposed future water extraction from the MGP and BGP projects at the rates shown in Figure 20.

Based on outputs from these three scenarios predicted drawdown impacts have been estimated as follows:

- Cumulative drawdowns associated with the MGP and BGP have been calculated by subtracting the simulated heads in the 'Cumulative scenario' from the 'No CSG scenario' heads;
- Drawdowns associated with the BGP only (which is referred to as BGP only scenario in the present report) have been calculated by subtracting the simulated heads in the 'cumulative scenario' from the 'MGP only scenario'.

It is noted that the BGP only scenario impacts in particular could have been calculated in a number of different ways, including by undertaking a further BGP only scenario and estimating BGP impacts by comparison of this run with the 'No CSG scenario'. The adopted approach whereby BGP only impacts have been calculated by comparison of the cumulative and MGP only scenario has several advantages over other approaches. In particular the adopted approach is consistent with methodologies applied by OGIA in the neighbouring Surat CMA UWIR (OGIA, 2021) and reflects the actual timing of operations in the Bowen Basin. Furthermore, the adopted approach also ensures that the sum of the estimated impacts of each individual project is at all times equal to and hence consistent with the estimated cumulative impact. This is unlikely to occur with other approaches.

Since the Moranbah (MCM) and Rangal Coal Measures (RCM) span multiple model layers, drawdown impact results – e.g. IAA and LAA – for these units were generated by processing drawdown for each coal seam within the associated coal measure. These results were then subsequently combined and used to obtain a spatial composite of the maximum predicted drawdown in any of the coal layers. For example, the IAA and LAA areas for the RCM were computed by processing drawdown results in both modelled coal seam layers (i.e. layers 7 and 9) prior to further processing these results to identify the maximum drawdown within each cell. 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.

7.6.1 *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 (i.e., up to February 2028). In the present report IAA has been presented for both cumulative and BGP only scenarios, enabling the comparison of IAA in these scenarios.

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 19 shows the layers with an IAA exceeding the trigger threshold, indicating that drawdown greater than trigger thresholds will be restricted to the MCM and RCM.

Table 19: IAA Exceeding the Trigger Threshold

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

Figure 27 shows that the IAA for the consolidated aquifers, with the impacts associated with the BGP Area restricted to the MCM and RCM. The following key observations have been made:

- within PL486 an IAA exists for the MCM associated with production of CSG. There are no useable water supply bores in the aquifer of this IAA, and therefore there are no make good obligations in this UWIR for Arrow Energy;
- within ATPs 742, 1103 and 1031 there are small areas of IAA for the MCM and RCM associated with historic or proposed production testing in these tenures. There are no existing or useable water supply bores located in the aquifers within these IAA areas, and therefore there are no make good obligations in this UWIR for Arrow Energy;
- there are no IAAs in any of the other aquifers (including Alluvial and Tertiary aquifers) modelled within the project area;
- The IAA areas for the RCM in the cumulative scenario overlap with those in the BGP only scenario, occurring solely within the BGP Area; and
- The operation of the MGP may potentially impact the BGP area, as the IAA for the MCM, associated with CSG production, extends into ATP1103. However, the impact is considered minimal, as currently only four bores – AEN1800 (could not be found, assumed abandoned and destroyed), AEN2135 (abandoned but useable, 32m deep), AEN2138 (existing, 60m deep), and AEN2139 (existing, 50m deep) – are located within the IAA area footprint of the MCM, and were identified not to exist or to be constructed in shallower aquifers than the MCM during the baseline assessments. Refer to Appendix D for the simulated IAA 5m drawdown for the MGP-only scenario.

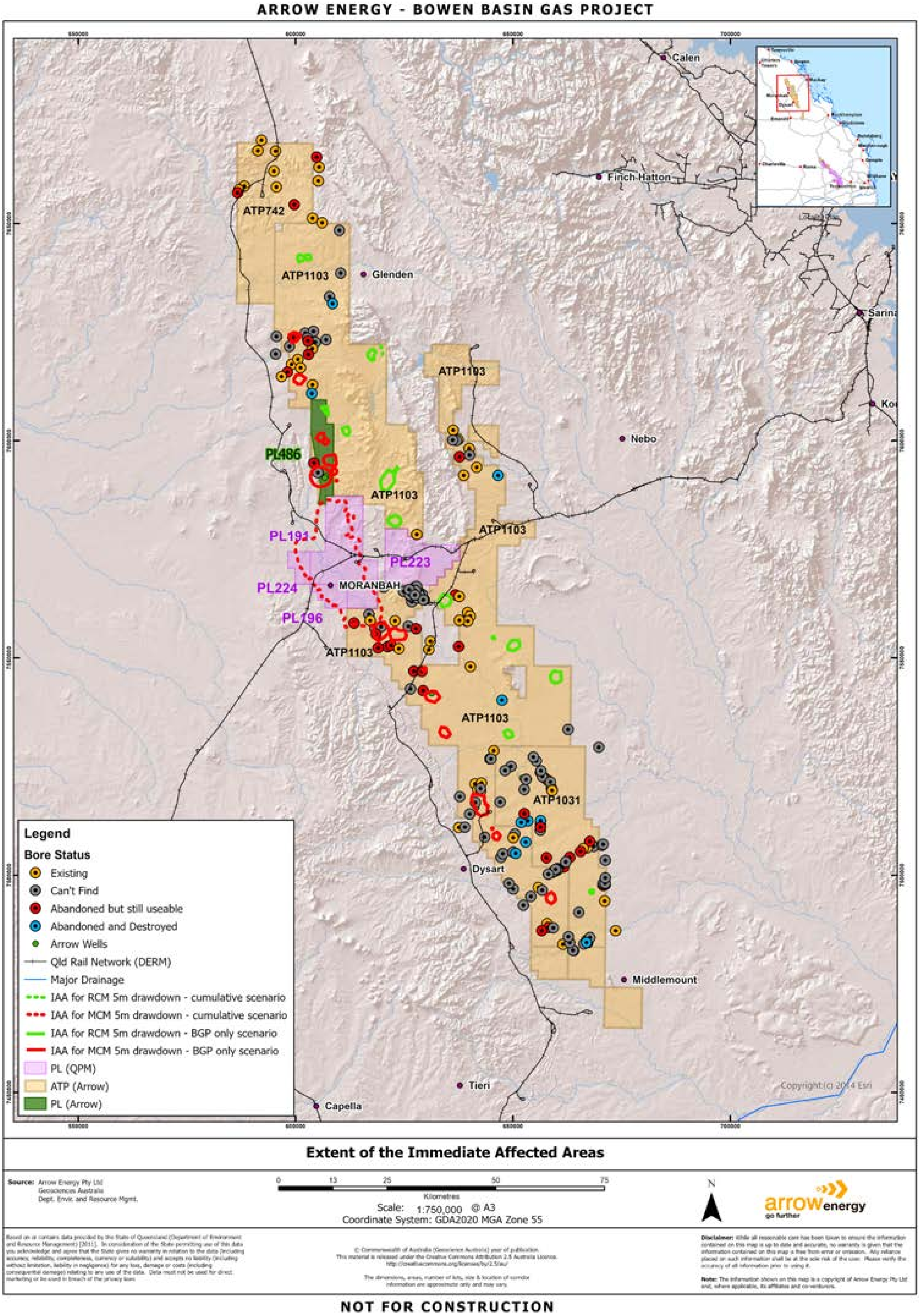

Figure 27: Extent of the Immediately Affected Areas

7.6.2 *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 2180.

Figure 28 presents the extent of the LAA for the MCM, RCM, and FCCM for both cumulative and BGP only scenarios. The following key observations have been made:

- 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;
- the LAA for the MCM covers most of ATP742 and PL486, as well as the western part of ATPs 1103 and 1031 in the north-south direction within the BGP;
- similar to the LAA for the MCM, the LAA for the RCM stretches north-south within the BGP but covers a smaller area and does not extend much over PL486. The RCM footprint is generally positioned further east of the MCM footprint as RCM is located above the MCM and dips to the east;
- the LAA for the FCCM is much smaller than for the MCM and RCM and is limited to a smaller area within ATP1103, mainly overlapping with MCM and RCM footprints in the south;
- 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 MCM and RCM in areas away from planned BGP development;
- there is no predicted LAA in any other consolidated aquifers;
- The LAA areas for the RCM and FCCM in the cumulative scenario overlap with those in the BGP only scenario, indicating impact is mostly due to proposed BGP production; and
- As discussed in Section 7.6.1 above, in the cumulative scenario the operation of the MGP may potentially impact the BGP area, as the LAA for the MCM, associated with CSG production, extends into ATP1103. Refer to Appendix D for the simulated LAA 5m drawdown for the MGP-only scenario.

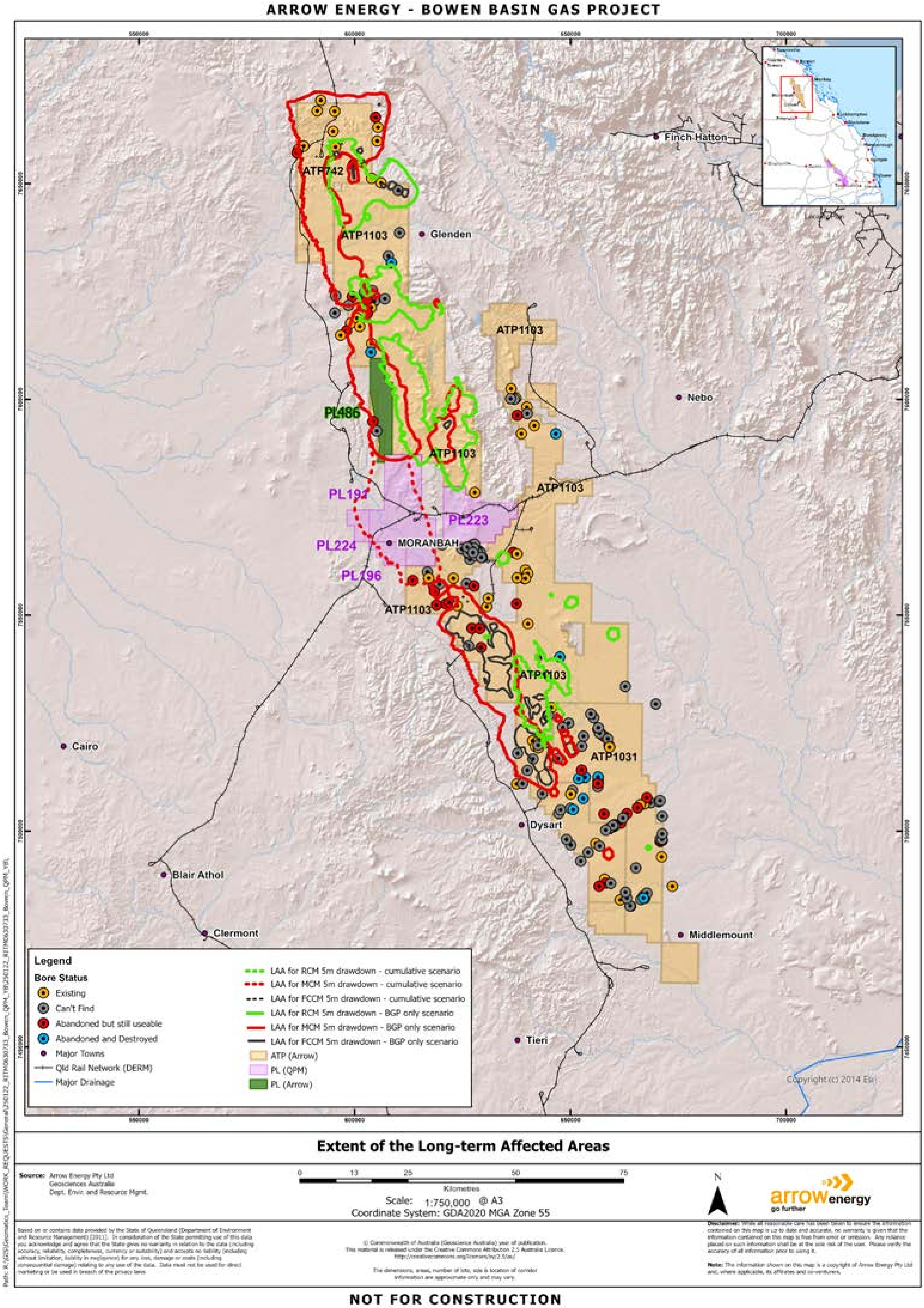

Figure 28: Extent of the Long-term Affected Areas

8 ENVIRONMENTAL VALUES

This section identifies and describes the groundwater-related environmental values in the Bowen Basin based on the 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 single points 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. DETSI 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 ATP1103. 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 the watercourse springs, and where the water level is predicted to decline in 0.2m in the shallow and deep aquifer are shown in Figure 29. 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.

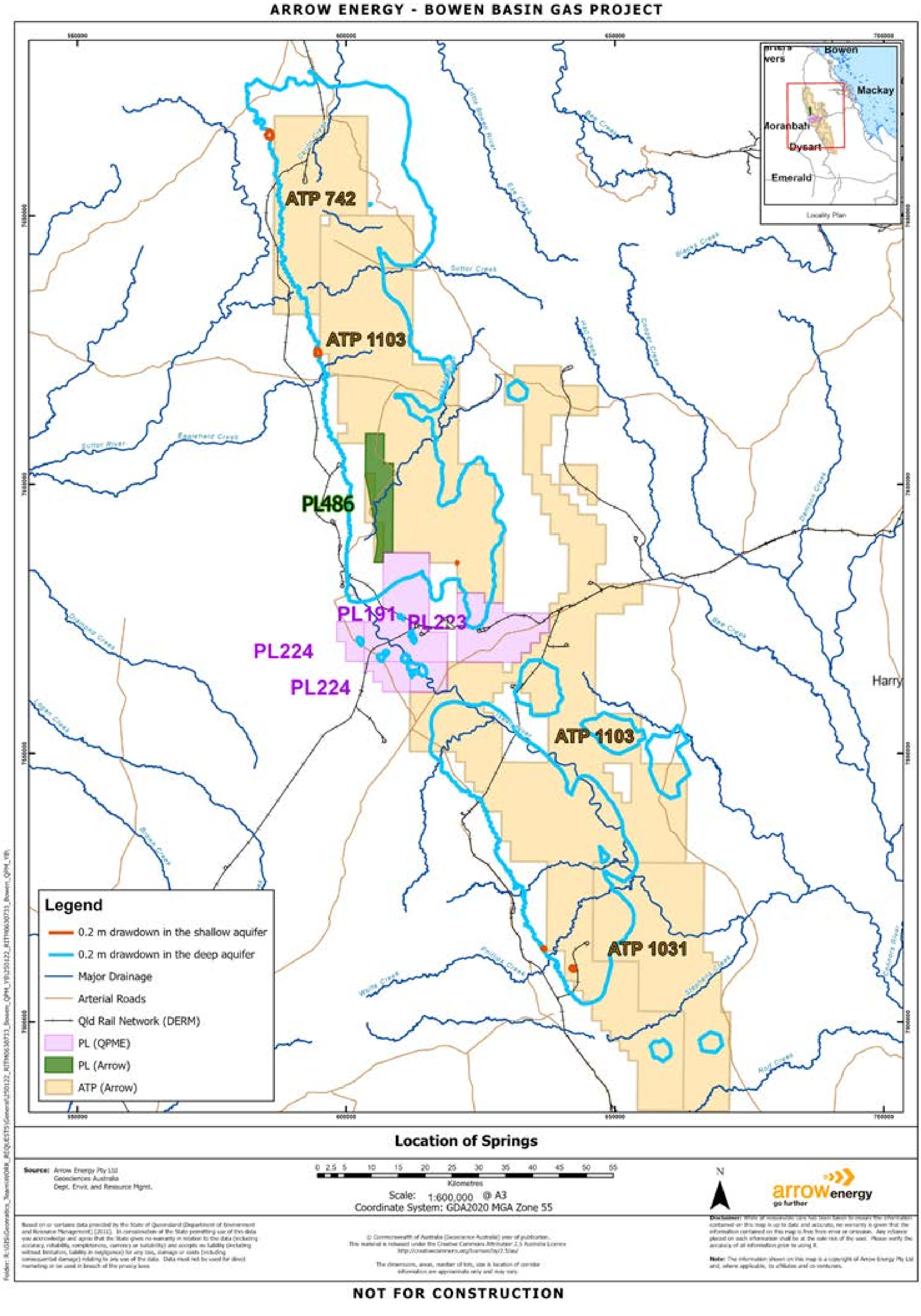

Figure 29: Springs and Drawdown in Shallow and Deep Aquifers

The identification of landscapes that may contain groundwater dependent ecosystems (GDEs) is documented in detail in the BGP EIS/SREIS and includes 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 conducted at the end of 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; and
    - 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; and
    - 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 2025 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 Energy 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 30).

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.

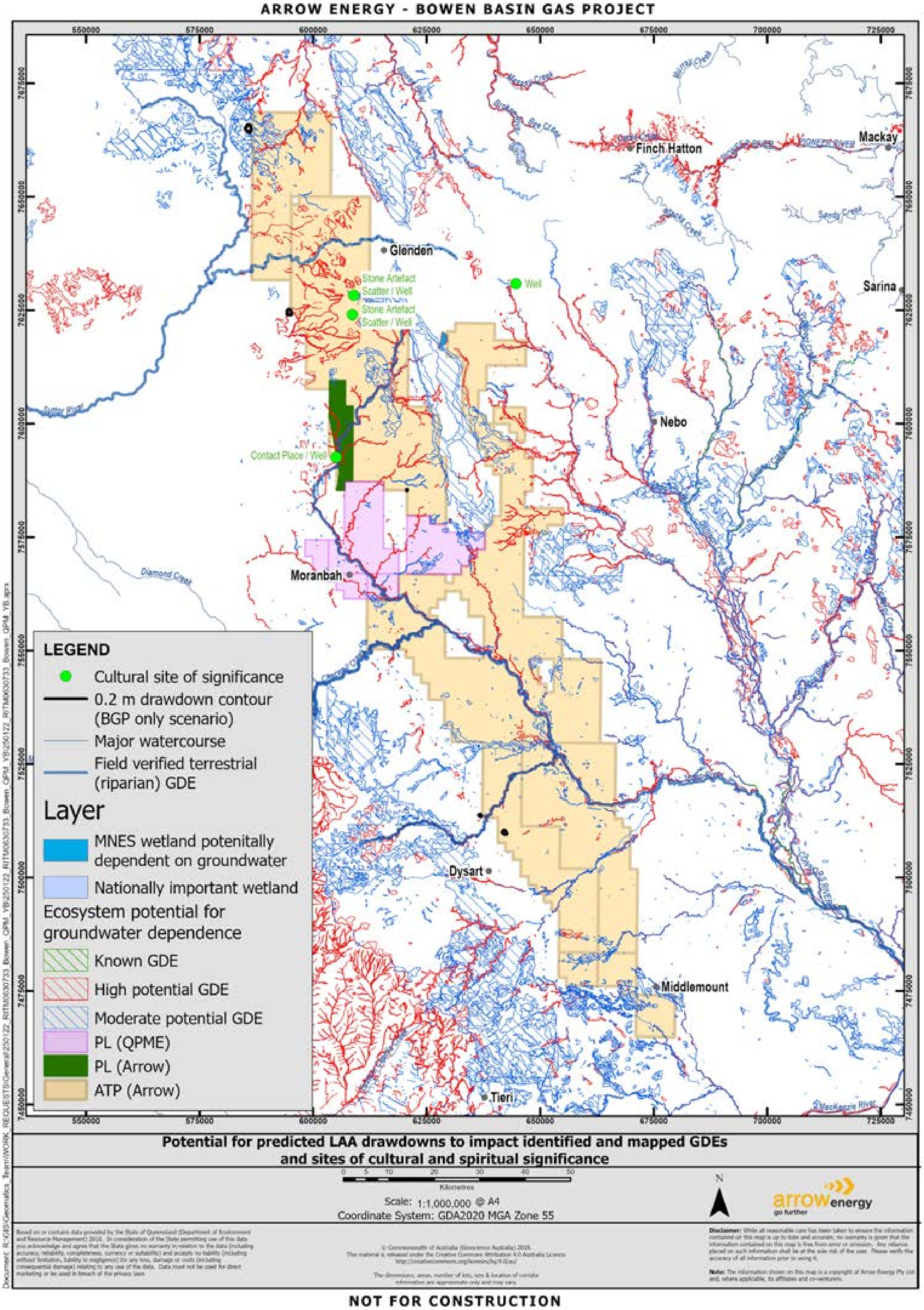

Figure 30: GDE and Sites of Cultural and Spiritual Significance

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 the 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. There is no 0.2m drawdown impact predicted that overlap watercourses and potential associated alluvial areas as shown in Figure 30 above.

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 limited to small areas on the edge of ATPs 742, 1031, and 1103 (refer to Figure 29). These areas 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 27 and Figure 28 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 30). 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 Potential Impacts to Formation Integrity and Surface Subsidence

Coal seam gas occurs within coal formations through adsorption to the surface of the coal under hydrostatic pressure. Depressurisation of the water from the coal seams below a threshold by groundwater extraction reduces hydrostatic pressure and facilitates methane desorption and subsequent coal shrinkage. At any point below the ground surface, the weight of overlying strata is supported partly by water pressure and partly by the fabric of the rock mass. Any reduction in water pressure therefore results in an increased proportion of the load being carried by the rock mass. The combination of the reduction in water pressure and coal shrinkage results in compaction of the formation. The combined compaction over the thickness of the formation, together with any attenuation by the overburden, results in subsidence at the ground surface. The magnitude and extent of the compaction are influenced by the magnitude and extent of the drawdown, the geomechanical properties of the coal, interburden and overburden, and the total thickness of the coal in which the drawdown occurs. It can be conservatively assumed that any compaction of the coal seams will directly translate to subsidence at the surface. OGIA (2021), in the UWIR for the Surat Cumulative Management Area, suggests that for hundreds of meters of drawdown of pressure in the coal seams, only a few centimetres of subsidence will occur at the surface. More information on the mechanisms of CSG induced subsidence can be found in the literature (Leonardi, 2024), including recent literature on assessing the potential for formation bridging (Aghighi et al, 2024a) and the contribution of desorption induced coal shrinkage (Aghighi et al, 2024b) to CSG induced 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 MGP area was assessed in the SREIS as an analogue to potential impacts that could occur in the BGP.

Geomechanical calculation of estimates for potential subsidence were 40 mm, with a range of 15 to 75 mm. Interpreted ground movement from satellite interferometry (InSAR) data collected between 2006 and 2011 showed movement over most of the study area was less than 10 mm (uplift or subsidence). 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 (comparable in scale to ground motion occurring due to natural processes), 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.

The magnitude of compression that occurs at depth in the coal measures is likely to be closely reflected at the surface, the stresses and strains induced in the overburden will be significantly lower than in the case of underground mining. Consequently it is far less likely that CSG induced subsidence could lead to fracturing of overburden materials and therefore cause an increased interconnection between the coal measures and overlying aquifers.

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 a 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 DETSI 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.
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.

Term	Meaning
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).
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.

Term	Meaning
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.
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.

Term	Meaning
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.
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

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APPENDIX A – GROUNDWATER LEVEL MONITORING RESULTS

SHALLOW MONITORING BORES

Bore Name	SWL (mAHD)								
	12/11/2019	**22/11/2020**	**24/05/2021**	**30/10/2021**	**9/06/2022**	**29/11/2022**	**23/05/2023**	**21/11/2023**	**28/05/2024**
GW004A	235.16	234.69	234.54	234.44	234.54	234.44	234.20	234.03	234.07
GW007A	dry								
MB1S	263.51	262.72	262.75	262.70	262.75	262.79	262.62	262.18	262.16
GW004B	232.09	230.95	231.80	231.74	232.74	231.67	231.45	231.59	231.49
AEN1214		215.12	217.32	215.32		216.18	217.69	215.59	210.89
AEN1234		185.34	185.44	185.35	185.45	185.35	185.60	185.64	185.57
AEN1063		143.12	142.85	142.53	142.64	142.97	143.36	142.89	143.02
MB12	294.26	296.01	298.28	298.51	298.62	298.65	299.00	298.87	298.71

APPENDIX B – WATER QUALITY RESULTS

DEEP MONITORING BORE MB1-D

Monitoring Bore ID	Sample Date	Field pH	Electrical Conductivity	Total Dissolved Solids (grav)	Hydroxide Alkalinity (OH-) as CaCO3	Carbonate Alkalinity as CaCO3	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as CaCO3	Sulphate, SO4	Chloride, Cl	Calcium - Dissolved	Magnesium - Dissolved	Sodium - Dissolved	Potassium - Dissolved	Arsenic-Dissolved	Beryllium-Dissolved	Barium-Dissolved	Chromium-Dissolved	Cobalt-Dissolved	Copper-Dissolved	Lead-Dissolved	Manganese-Dissolved	Molybdenum	Nickel-Dissolved	Selenium	Vanadium-Dissolved	Zinc-Dissolved	Boron	Iron	Fluoride, F	Phosphate as P in water
			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	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
MB1-D	17/11/2019	7.95	8790	5110	<1	<1	817	817	<1	2550	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	0.45
MB1-D	14/05/2020	8.26	9370	5210	<1	<1	1390	1390	<1	2560	9	10	2050	20	0.003	<0.001	3.89	<0.001	<0.001	0.002	0.006	0.015	0.011	0.032	<0.01	<0.01	0.024	1.11	1.14	2.0	0.87
MB1-D	20/11/2020	7.82	8930	5190	<1	<1	1600	1600	<1	2390	14	9	2410	24	0.003	<0.001	4.12	<0.001	<0.001	<0.001	0.005	0.013	0.017	0.031	<0.01	<0.01	0.013	1.68	1.08	2.0	0.97
MB1-D	21/12/2021	7.9	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	0.010	<0.01	<0.01	<0.005	1.19	0.56	2.0	1.28
MB1-D	27/11/2022	7.86	8670	5230	<1	40	1550	1590	11	1940	6	6	2020	21	0.002	<0.001	2.97	0.002	0.001	<0.001	0.002	0.009	0.015	0.050	<0.01	<0.01	0.008	1.39	0.68	2.1	1.31
MB1-D	22/11/2023	7.78	8610	5040	<1	48	1760	1810	<1	1790	4	5	2120	20	0.001	<0.001	2.41	<0.001	<0.001	<0.001	0.001	0.008	0.018	0.014	<0.01	<0.01	<0.005	1.80	0.48	2.2	1.18

Australasian
Groundwater
& Environmental
Consultants

Report on

Bowen UWIR 2025
Groundwater Modelling Report

Prepared for
Arrow Energy Pty Ltd and QPM Energy

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Bowen UWIR 2025 – Groundwater Modelling Report

1 Introduction

1.1 Background

Arrow Energy Pty Ltd (Arrow) and QPM Energy (QPME) appointed Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) to update an existing numerical groundwater modelling tool developed by AGE (2021) and AGE (2018), which was originally developed by Ausenco and Norwest (2012), in order to assess the impacts of coal seam gas activities in the Bowen Basin related to:

- Petroleum Leases (PLs) 191, 196, 223 and 224 which form part of the Moranbah Gas Project (MGP) for which QPME is the responsible tenure holder; and
- PL 486 and other Authority to Prospect (ATP) areas 1103, 742 and 1031 which form part of the Bowen Basin Gas Project (BGP) for which Arrow Energy is the responsible tenure holder.

The MGP has been producing gas for the domestic market since 2003 and was initially operated by Arrow and acquired by QPME in August 2023. The BGP is operated by Arrow and includes production testing since 2008. Previous UWIR reports for the MGP and BGP include:

- UWIR for PLs 191, 196, 223, 224 (Arrow Energy, 2012a);
- UWIR for ATP 1103 (Arrow Energy, 2012b);
- UWIR for ATP 1031 (Arrow Energy, 2014);
- 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); and
- UWIR for PL 191, 196, 223, 224 and ATP 644, 831, 742, 1031 and 1103 (Arrow Energy, 2022).

The most recent 2022 UWIR for the MGP and BGP was approved with conditions and took effect on 2 August 2022. Subsequent the acquisition of the MGP by QPME in August 2023, QPME, rather than Arrow Energy, have become the responsible tenure holder for the MGP and separate UWIRs will have to be submitted in 2025 to DETSI for the BGP and MGP.

1.2 In this report

This report presents a summary of work completed to update the Bowen Basin numerical groundwater flow model previously developed by AGE (AGE, 2021; AGE, 2018). This report provides a description of the model construction, revised 2025 calibration results and setup of the predictive scenarios to assess the regional scale groundwater impacts of the MGP and BGP. This report is intended to be included as an appendix in separate UWIR reports relating to these two projects. Similarly predictive outputs generated using the groundwater flow model described herein will also be included in the 2025 MGP and BGP UWIR reports. It should be noted that the updated groundwater model described in this report does not simulate the impacts on groundwater due to coal mining occurring in the Bowen Basin.

2 Model construction details

2.1 Introduction

The Northern Bowen Basin numerical groundwater model was originally developed for Arrow by Ausenco and Norwest (Ausenco and Norwest, 2012) to predict and delineate groundwater impacts where drawdowns exceed the Queensland Department of Environmental and Heritage Protection (DEHP) threshold criteria. The model was developed using MODFLOW-SURFACT™.

For the 2019 Bowen UWIR (Arrow Energy, 2019), AGE converted the Ausenco and Norwest Bowen model to MODFLOW-USG in order to increase the resolution of the model mesh around the MGP area and better delineate groundwater structures (AGE, 2018).

For the 2022 Bowen UWIR (Arrow Energy, 2022), the groundwater model was further updated by AGE, including further mesh refinement, a revised stress-period setup, specific storage values and updated MGP and BGP field development plans (AGE, 2021).

Relative to the previous version of the model (AGE, 2021) which was used to assess groundwater impacts in the previous UWIR (Arrow Energy, 2022) the following changes have been made:

- extend the model calibration period from January 2018 to January 2024 (see Section 2.4, Section 2.7 and Section 3.1);
- update the MODFLOW well (WEL) package based on actual historic CSG related water extraction data provided for the BGP and MGP by Arrow Energy (Section 2.7);
- update the MODFLOW recharge (RCH) package based on updated historic actual climate records from Bureau of Meteorology (BoM) SILO website; and
- generate revised predictions based on revised calibrated model parameters (Section 2.6) and revised MGP and BGP field development plans provided by Arrow Energy and QPME (Chapter 4).

Although model features such as layering and mesh remain unchanged compared to the 2022 Bowen model, a summary of the 2025 Bowen model construction details is provided below in Sections 2.2 to 2.7.

2.2 Model domain, mesh and layering

No changes have been made to the model domain, mesh or layering relative to the previous Bowen Basin model (AGE, 2021). The text below therefore provides a brief description of these features of the model for completeness.

The model domain is approximately 157 km wide (west to east direction) and 395 km long (north to south direction) as shown in Figure 2.2. This area has been 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 as follows:

- MGP area, approximately 200 x 200 m hexagonal cells aligned to in seam wells;
- BGP area, approximately 1,500 x 1,500 m voronoi/rectangle cells centred on downhole CSG production wells;
- Faults, approximately 1,000 x 1,000 m centred on either side of modelled faults;
- Surficial aquifer systems (e.g. basalt), approximately 1,000 x 1,000m centred either side of the mapped limit of each unit;
- Major drainage systems, approximately 500 x 500 m centred along river lines proximal to the MGP;
- 150 m cells within the Red Hill Production area in PL486 which forms part of the BGP; and
- 150 m cells centred at the location of each monitoring well.

Overall, the 2025 Bowen model comprises 212,667 cells across the 22 layers. Table 2.1 presents a summary of the model layers. Groundwater layer types were prescribed as convertible layers, with unsaturated flow represented using the 'upstream weighting' function.

Table 2.1 Bowen model layering

Model layer	Primary 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	Rangal Coal Measures (RCM)	Leichardt seam
6		Interburden
7		Vermont seam
8	Fort Cooper Coal Measures (FCCM)	FCCM
9		FCCM
10		FCCM
11	Moranbah Coal Measures (MCM)	Q Seam
12		Interburden
13		P seam
14		Interburden
15		GM seam
16		Interburden
17		GML seam
18		Interburden
19		DYU seam
20		Interburden
21		DYR seam
22	Collinsville, Back Creek Group	Permian basement

2.3 Stress period setup

No changes have been made to the stress period setup relative to the previous Bowen Basin model (AGE, 2021). The text below therefore provides a brief description of this feature of the model for completeness.

Model simulations comprise the following 405 stress-periods:

- December 2003, a single steady state stress period to simulate pre-CSG initial conditions.
- December 2003 to May 2030, 318 monthly stress periods to simulate historical and anticipated near-future CSG developments in the model domain which include all historical and future MGP developments.
- June 2030 to December 2099, one seven-month and 68 annual stress periods to simulate long-term future CSG developments that form part of the BGP and initial post-CSG recovery.
- January 2100 to 2180, one six-year and 15 five-year stress periods for long-term post-CSG recovery simulations.

2.4 Boundary conditions

The boundary conditions of the 2025 Bowen model are based on the 2022 Bowen model developed by AGE (2021). No changes were made to the following input packages:

- The MODFLOW River package (RIV) was used to represent the perennial reaches of the Bowen and Isaac Connors River system with river elevations, stage heights, incisions depths and vertical conductivity rates based on the Isaac Connors Groundwater Project (SKM, 2009).
- A general head boundary (GHB) package was used at all model boundaries to replicate regional groundwater gradients.
- Potential and actual evapotranspiration dataset was applied to the model using the MODFLOW evapotranspiration (EVT) package using a constant maximum evapotranspiration rate of 0.00274 m/day and an extinction depth of 15 m (i.e. when groundwater levels fall below this extinction depth no evapotranspiration losses occur).

As part of extending the calibration period of the previous Bowen basin model to January 2024, changes were made to recharge (RCH) package to represent rainfall recharge (see Section 2.5) and the MODFLOW WEL-package to simulate CSG water extraction (see Section 2.7).

2.5 Rainfall recharge

Rainfall recharge rates were derived base on soil-moisture bucket (SMB) model calculations, which computes a daily balance of water entering the soil zone via rainfall and exiting via evapotranspiration. On any days where soil moisture storage capacity is exceeded i.e., the soil moisture deficit reaches zero, then any rainfall in excess of evapotranspiration forms recharge to the underlying groundwater. Inputs to the SMB calculations are daily rainfall and evapotranspiration using climate data downloaded from the Bureau of Meteorology (BOM) for grid point coordinates -21.05 and 147.95. Calculated SMB recharge seepage rates were aggregated for each stress-period of the Bowen groundwater model and applied to the MODFLOW recharge package.

2.6 Initial hydraulic properties

As the Bowen Basin model was not re-calibrated for the 2022 UWIR (Arrow Energy, 2022) then, other than specific storage, initial (pre-calibration) hydraulic properties were assigned based the previous 2018 calibration (AGE, 2018). With regard to specific storage, a number of papers, in particular Rau et al. (2018), have been released since completion of the previous calibration (AGE, 2018) suggesting that the calibrated specific storage values may be unrealistically high. Rau et al. (2018) suggest an upper bound for specific storage of 2.0×10^{-5} m^{-1} and hence the previously calibrated values were adjusted downwards where necessary to prevent initial values exceeding this bound.

As per the previous model iterations (AGE, 2018; AGE, 2021) initial hydraulic properties of different formations in the Moranbah and Rangal Coal Measures also feature a depth-dependency. These depth relationships, presented in AGE (2018), are based on aquifer parameters reported by Ausenco and Norwest (2012) for different subregions in these hydrogeological units. A summary of initial hydraulic properties per model layer is provided in Table 2.2, which also indicates whether the hydraulic conductivity is depth-dependent for each model layer. Upper and lower bound used for model calibration are discussed in Section 3.3 and listed in Table 3.3.

Similar to AGE (2018) and AGE (2021), two-phase flow relative permeability effects encountered in the vicinity of CSG production wells are not considered in the model. These effects comprise a reduction of effective permeability due to the presence of gas and as reported in AGE (2018) lead to a potential misrepresentation of drawdowns in the immediate vicinity of the CSG production wells. In addition to this, there is a considerable amount of upscaling for regional scale models representing the interburden units surrounding the in-seam wells. This further contributes to the uncertainty of the groundwater pressures proximal to CSG production wells. As reported in AGE (2018), these effects are considered local, with minimal implications to regional groundwater drawdown predictions.

2.7 CSG extraction

Both historical and future CSG field development plan (FDP) data was provided by Arrow Energy and QPME.

Historical FDP data included monthly historical water extraction rates for each individual existing CSG well which form part of the MGP and BGP. This data was used to extend the historical CSG extraction period in the model to the end of the calibration period (i.e. January 2025) using the MODFLOW WEL package. Many of these existing CSG wells are non-vertical and also penetrate multiple model layers. Hence, prior to using the supplied well extraction volumes it was first necessary to distribute these volumes across several model nodes. This was carried out using inhouse AGE software which distributes the reported volumes based on the nodes intersected by each well and the modelled hydraulic conductivity of these nodes.

Information on expected future CSG well locations and forecast water extraction relating to both existing and proposed wells based on current FDPs for the MGP and BGP were also provided. Relative to the previous UWIR (Arrow Energy, 2022) the following changes have been made to simulate the MGP and BGP FDPs:

- revised FDP data provided for the BGP for the period 2025 to 2045 includes an additional 15 CSG wells on ATP 1103 and seven additional wells on PL486;
- no changes have been made to the BGP FDP for the period 2045 to 2063; and
- no changes have been made to MGP FDP and hence the predicted water extraction related to this project are the same as reported in the previous UWIR (Arrow Energy, 2022).

Modelled CSG extraction start and end dates based on updated information provided by Arrow Energy and QPME are presented in Figure 2.3 and Figure 2.4. During the model calibration period (i.e. to January 2025) only CSG production wells related to the MGP are active, although several pilot CSG wells associated with the BGP are also operating over this period. Figure 2.1 graphically illustrates the total daily production for the BGP and MGP with time.

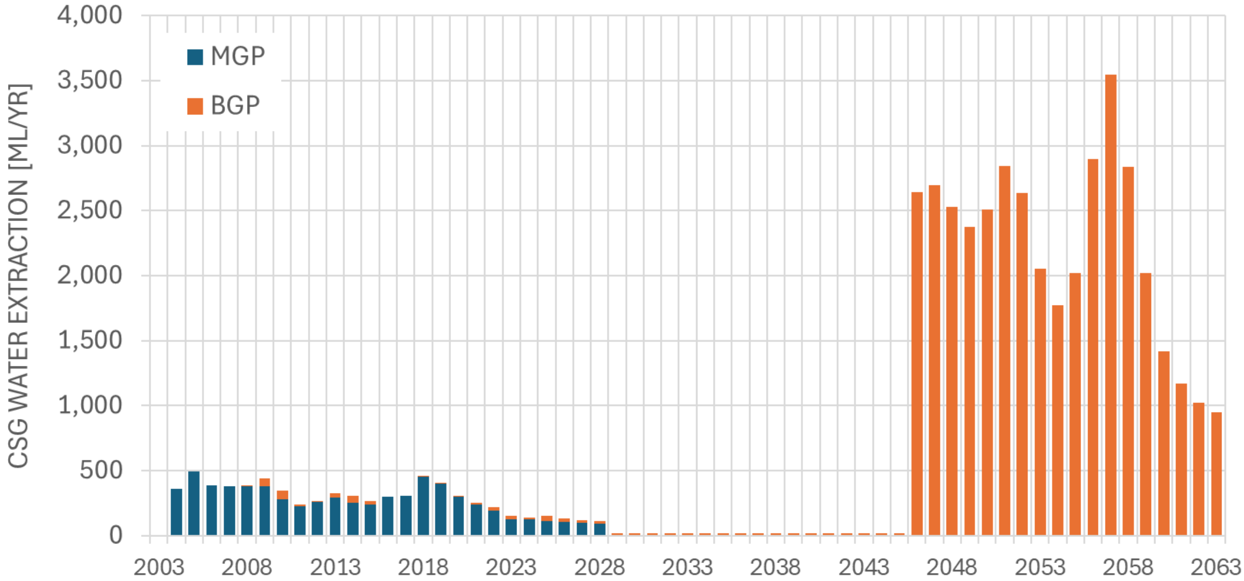
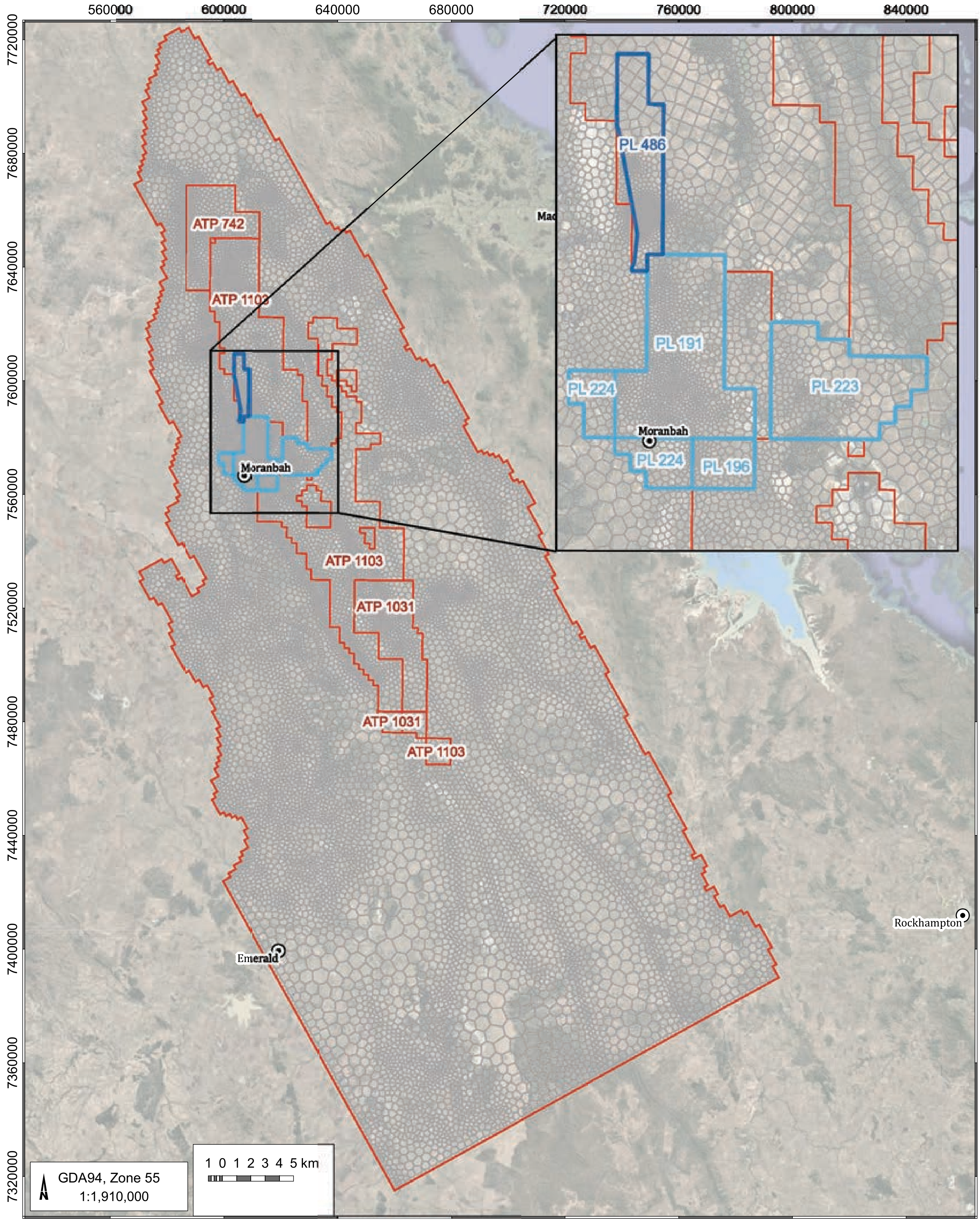


Figure 2.1 2025 FDP – timeseries of CSG extraction rates for the MGP and BGP



LEGEND

- Populated place
- AGE mesh
- AGE model outline
- PL (QPM, MGP)
- PL (Arrow, BGP)
- ATP (Arrow, BGP)

Bowen (BOW5000)

Bowen Basin model domain and mesh

AGE

DATE 30/01/2025

FIGURE No: **2.2**

©2025 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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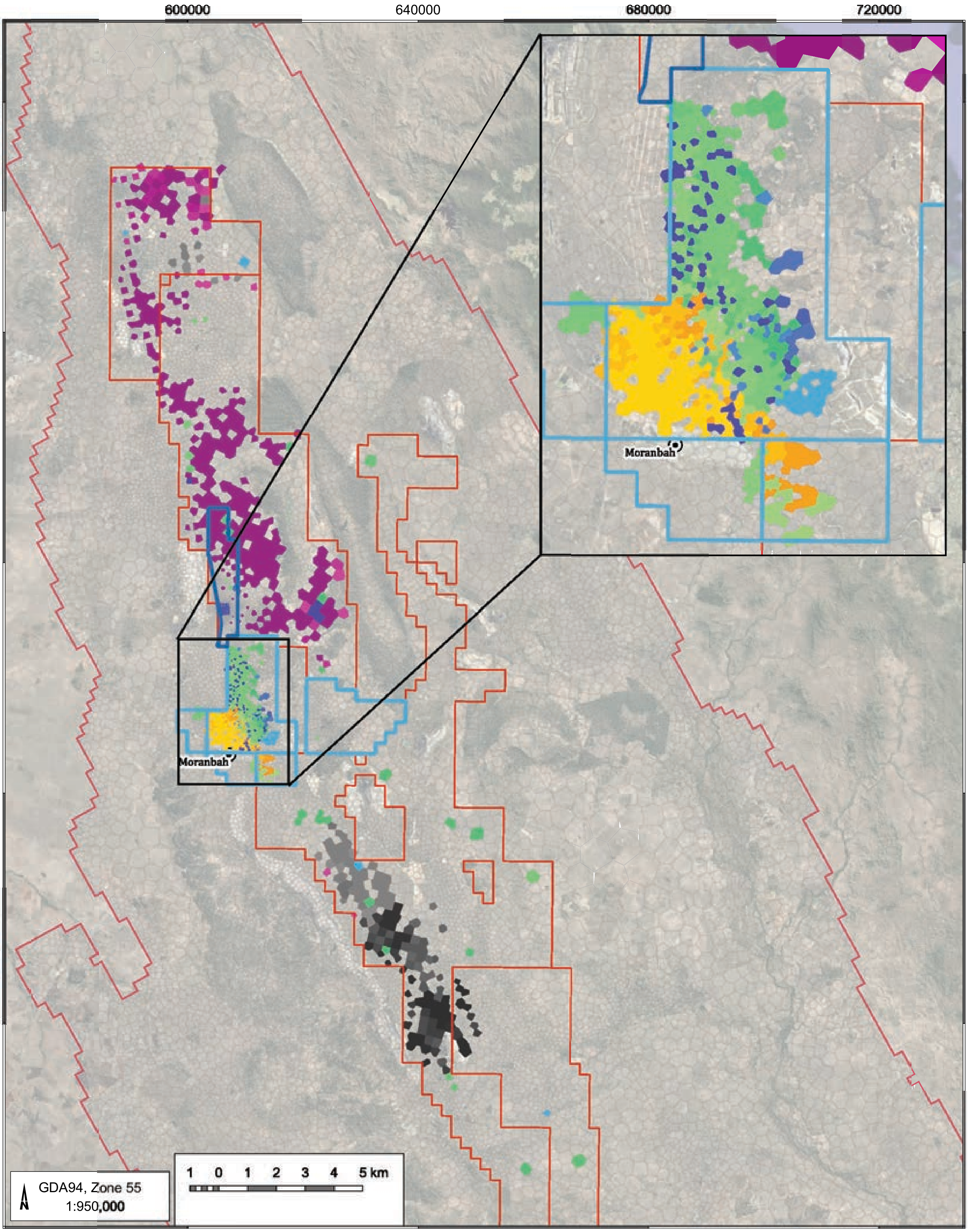

LEGEND

- Populated place
- AGE model outline
- AGE mesh
- PL (QPM, MGP)
- PL (Arrow, BGP)
- ATP (Arrow, BGP)

WEL start (year)

2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2022, 2024, 2025, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059

Bowen (BOW5000)

CSG well production start year - cumulative scenario

AGE

DATE 30/01/2025

FIGURE No: **2.3**

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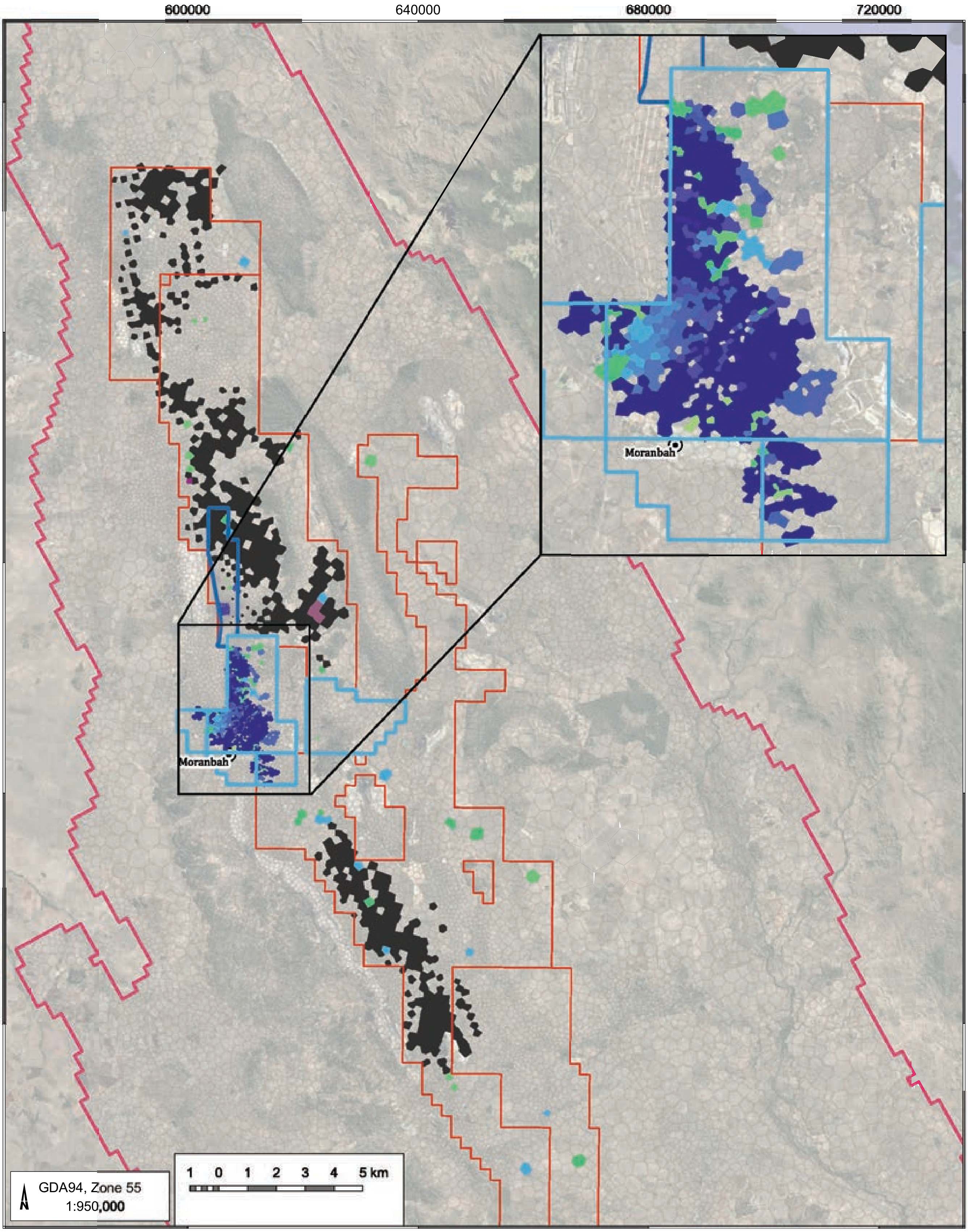
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\BOW5000.001 2025 Bowen UWIR ARROW ENERGY AND QPM ENERGY 50_50\5_Deliverables\001_Deliverable1\Figures\Fig_2-3_BOW5000_WEL_start.qgz



LEGEND

- Populated place
- AGE mesh
- AGE model outline
- PL (QPM, MGP)
- PL (Arrow, BGP)
- ATP (Arrow, BGP)

WEL stop (year)

2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2024, 2025, 2026, 2027, 2028, 2044, 2045, 2063

Bowen (BOW5000)

CSG well production end year - cumulative scenario

AGE

DATE 30/01/2025

FIGURE No: **2.4**

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Table 2.2 Summary of initial hydraulic parameters

Layer	Primary formation	Unit	Hydraulic conductivity average and max-min range			Specific storage average and max-min range (m-1)	Specific yield average and max-min range (%)
			Horizontal (Kh) (m/day)	Vertical (Kv) (m/day)	Depth Dependency		
1	Quaternary Alluvium, weathered materials	Surficial coverage	8.44E+00 (8.50E-03 - 1.40E+02)	1.61E+00 (8.50E-05 - 1.00E+01)	No	2.0E-05 (2.0E-05 - 2.0E-05)	19.1% (18.0% - 20.0%)
2	Tertiary sediments (Duringa), Basalts (Anakie) & Moolayember	Tertiary, Triassic	4.76E+00 (1.40E-05 - 6.20E+01)	2.53E+00 (2.60E-09 - 1.40E+02)	No	1.6E-05 (9.9E-07 - 2.0E-05)	14.7% (5.0% - 50.0%)
3	Clematis Sandstone	Triassic	2.06E-02 (6.30E-03 - 5.50E-02)	2.07E-03 (3.60E-04 - 7.50E-03)	No	2.0E-05 (2.0E-05 - 2.0E-05)	17.0% (17.0% - 17.0%)
4	Rewan	Triassic	1.08E-03 (7.50E-04 - 1.00E-02)	1.54E-07 (9.70E-08 - 5.50E-06)	No	1.0E-06 (9.9E-07 - 1.0E-06)	6.0% (6.0% - 6.0%)
5	Rangal Coal Measures	Leichardt seam	2.56E-02 (8.60E-06 - 1.00E-01)	6.90E-03 (8.60E-06 - 5.40E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
6		Interburden	1.00E-04 (1.00E-04 - 1.00E-04)	1.00E-08 (1.00E-08 - 1.00E-08)	No	1.0E-06 (9.9E-07 - 1.0E-06)	6.0% (6.0% - 6.0%)
7		Vermont seam	2.08E-02 (8.60E-06 - 1.00E-01)	5.25E-03 (8.60E-06 - 5.40E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
8	Fort cooper coal measures	Girrah	1.00E-04 (1.00E-04 - 1.00E-04)	8.60E-06 (8.60E-06 - 8.60E-06)	No	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
9		Fccm	4.40E-03 (4.40E-03 - 4.40E-03)	8.00E-05 (8.00E-05 - 8.00E-05)	No	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
10		FHF	1.00E-04 (1.00E-04 - 1.00E-04)	8.60E-06 (8.60E-06 - 8.60E-06)	No	2.0E-05 (1.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
11	Moranbah Coal Measures	Q seam	1.62E-02 (8.60E-06 - 1.00E-01)	5.31E-03 (8.60E-06 - 1.00E-01)	Yes	1.9E-05 (9.0E-07 - 2.1E-05)	5.0% (5.0% - 5.0%)
12		Interburden	9.98E-05 (8.80E-05 - 1.00E-04)	2.08E-08 (2.00E-08 - 9.20E-08)	No	9.6E-07 (7.0E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)

Layer	Primary formation	Unit	Hydraulic conductivity average and max-min range			Specific storage average and max-min range (m-1)	Specific yield average and max-min range (%)
			Horizontal (Kh) (m/day)	Vertical (Kv) (m/day)	Depth Dependency		
13	Moranbah Coal Measures	P seam	1.16E-02 (8.60E-06 - 1.00E-01)	4.28E-03 (8.60E-06 - 1.00E-01)	Yes	1.9E-05 (9.0E-07 - 2.0E-05)	5.0% (5.0% - 5.0%)
14		Interburden	9.69E-05 (1.30E-05 - 1.00E-04)	6.69E-08 (1.00E-08 - 7.10E-08)	No	9.7E-07 (7.0E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)
15		GM seam	7.72E-03 (8.60E-06 - 1.00E-01)	1.61E-03 (8.60E-06 - 3.20E-02)	Yes	1.8E-05 (9.0E-07 - 2.0E-05)	5.0% (5.0% - 5.0%)
16		Interburden	1.03E-04 (9.90E-05 - 3.40E-04)	8.29E-08 (6.90E-08 - 3.00E-06)	No	1.2E-06 (9.7E-07 - 6.5E-05)	5.0% (5.0% - 5.0%)
17		GML seam	6.90E-03 (8.60E-06 - 1.00E-01)	1.59E-03 (8.60E-06 - 3.20E-02)	Yes	2.0E-05 (1.9E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
18		Interburden	1.00E-04 (1.00E-04 - 1.00E-04)	7.00E-08 (7.00E-08 - 7.00E-08)	No	1.0E-06 (9.8E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)
19		DYU seam	6.47E-03 (8.60E-06 - 1.00E-01)	1.50E-03 (8.60E-06 - 3.20E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
20		Interburden	1.00E-04 (1.00E-04 - 1.00E-04)	7.00E-08 (7.00E-08 - 7.00E-08)	No	1.0E-06 (9.9E-07 - 1.0E-06)	5.0% (5.0% - 5.0%)
21		DYR seam	6.40E-03 (8.60E-06 - 1.00E-01)	1.50E-03 (8.60E-06 - 3.20E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
22		Permian basement	4.40E-04 (4.40E-04 - 4.40E-04)	8.80E-06 (8.80E-06 - 8.80E-06)	No	1.0E-06 (9.9E-07 - 1.0E-06)	6.0% (6.0% - 6.0%)

3 Calibration

3.1 Calibration method

The calibration was performed using a combined pre-CSG steady state and transient simulation for the period January 2003 to January 2024. It was undertaken with reference to an updated groundwater level observation dataset for this period using automated parameter estimation software PEST_HP (Watermark Numerical Computing, 2021) to determine optimal hydraulic parameters and recharge rates. As per the previous calibration (AGE, 2018) a total of 6,705 model parameters were estimated. As mentioned previously (Section 2.6) initial parameter values were primarily based on previously calibrated parameters, other than specific storage where the initial values were adjusted to avoid exceeding the upper bound values reported in Rau et al. (2018). Due to the large number of parameters, singular-value-decomposition was adopted to assist with model calibration and preferred value regularisation was also used to restrict parameter changes that are not informed by the calibration dataset.

3.2 Calibration dataset

Transient calibration was undertaken with reference to updated data for 38 monitoring points for which time series groundwater level data are available. The steady state part of the calibration uses data for a substantially larger number of 481 monitoring points which includes single time of drilling readings for a large number of landholder monitoring points. The locations of steady-state and transient monitoring points are shown in Figure 3.1.

The steady-state calibration data set was the same as that used for the previous calibration (AGE, 2018). Details of the 41 transient monitoring points considered for use in the 2025 recalibration reported herein are presented in Table 3.1 and Table 3.2, for shallow and deep monitoring points, respectively. Ultimately data for only 38 transient monitoring points were used for calibration. As per notes provided in Table 3.2 data for the following monitoring points were excluded:

- Data for monitoring bores MB2 and MB3 were excluded as observed groundwater levels for these bores show recovering groundwater levels related to pilot testing and water extraction activities between 2011 and 2018 (Arrow Energy, 2024) which are not represented in the 2025 Bowen model; and
- Data for monitoring point M325_FL_1P was excluded due to observed groundwater levels being affected by sampling and erroneous measurements (Arrow Energy, 2019).

Early records for GR067V were also excluded as these are affected by depressurisation activities associated with the conversion of the bore to a monitoring point (Arrow Energy, 2024).

Observation weights were initially assigned based on the number of observations for each monitoring point and subsequently adjusted using the PEST utility PWTADJ1 to ensure that no single observation group dominates the calibration.

Table 3.1 Shallow groundwater monitoring points

Bore	Easting (GDA 94, Zone 55)	Northing (GDA 94, Zone 55)	Network	Total depth (m)	Screened interval (mbgl)	Screened formation	Date of first measurement	Date of last measurement
aen1063	665553	7505403	BGP	52.6	39.6 – 45.7	Blackwater Group	30/11/2020	30/11/2023
aen1214	595555	7666510	BGP	37.32	-	Rangal Coal Measures	30/11/2020	30/11/2023
aen1234	640332	7559908	BGP	102	48.2 – 102.0	Blackwater Group	30/11/2020	30/11/2023
gw004a	604933	7590892	BGP	13.5	7.5 – 13.5	Tertiary Sediment	30/11/2019	30/11/2023
gw004b	604933	7590892	BGP	59	53.0 – 59.0	Fort Cooper Coal Measures	30/11/2019	30/11/2023
mb12	620847	7595279	BGP	59.1	56.0 – 59.0	Rewan Formation	30/06/2018	30/11/2023
an020f	623192	7569070	MGP	77	70.0 – 72.0	Rewan Formation	19/01/2016	23/05/2023
m225w	604808	7569886	MGP	34	23.0 – 34.0	Weathered Tertiary Basalt	12/05/2014	21/11/2023
m230w	605636	7570996	MGP	32	29.0 – 32.0	Weathered Tertiary Basalt	12/05/2014	22/11/2020
m229w	605218	7570555	MGP	23	14 -23	Clayey sand (Tertiary sediment/alluvium)	24/11/2016	16/06/2017
m231w	606756	7569648	MGP	13.4	7.4 - 13.4	Weathered Tertiary basalt	12/05/2014	15/11/2016
m232w	606898	7570000	MGP	14.2	8.2 - 14.2	Quaternary alluvium	21/11/2016	15/06/2017
m234w	607536	7570127	MGP	17.2	11.2 - 17.2	Quaternary alluvium	12/05/2014	15/06/2017
m235w	607140	7570864	MGP	-	-	Weathered Tertiary basalt	20/11/2016	14/06/2017
m236w	607239	7571073	MGP	-	-	Weathered Tertiary basalt	21/11/2016	14/06/2017
m237w	607168	7571087	MGP	-	-	Quaternary alluvium	19/11/2016	14/06/2017
m345w	603623	7573671	MGP	32.3	21.8 - 30.8	Tertiary sediment/alluvium	12/05/2014	17/06/2017
an021f	623297	7569128	MGP	27	20.0 – 22.0	Tertiary Sediment	31/05/2016	30/11/2023
m222w	611811	7566589	MGP	30.2	20.0 – 26.0	Weathered Fort Cooper Coal Measures	30/06/2012	30/11/2023
m224w	611155	7567225	MGP	32.5	26.5 – 32.5	Quaternary Alluvium	30/06/2012	30/11/2023
m250w	608185	7582505	MGP	56.5	44.5 – 56.5	Tertiary Sediment	30/06/2012	30/11/2023
m300w	605636	7570996	MGP	30	24.0 – 30.0	Weathered Tertiary Basalt	31/10/2021	30/11/2023
m339w	603459	7572764	MGP	41	35.0 – 41.0	Weathered Tertiary Basalt	30/06/2012	30/11/2023
m340w	604903	7572726	MGP	27.3	19.3 – 27.3	Weathered Tertiary Basalt	30/06/2012	30/06/2017

Table 3.2 Deep groundwater monitoring points

Bore	Easting (GDA 94, Zone 55)	Northing (GDA 94, Zone 55)	Network	Total depth (m)	Screened interval (mbgl)	Screened formation	Date of first measurement	Date of last measurement	Comment
gw007b	605488	7596712	BGP	181.5	175.5 - 181.5	Fort Cooper Coal Measures	30/11/2019	30/11/2022	-
mb1_fccm	609595	7592256	BGP	550	336 - 340	Fort Cooper Coal Measures	30/11/2019	31/12/2023	-
mb1_girrah	609595	7592256	BGP	550	-	Fort Cooper Coal Measures (Girrah Seam)	30/11/2019	31/12/2023	-
mb1_mcm	609595	7592256	BGP	550	423.9 - 506.6	Moranbah Coal Measures	30/11/2019	31/12/2023	-
mb2	608621	7601119	BGP	834	701.1 - 814.7	Moranbah Coal Measures	28/02/2019	31/12/2023	Excluded from calibration as groundwater levels are still recovering after pilot tests and water extraction at this location between 2012 and 2018 (Arrow Energy, 2024).
mb3	607616	7605553	BGP	796.3	712.3 - 717.9	Moranbah Coal Measures	28/02/2019	31/12/2023	Excluded from calibration as groundwater levels are still recovering due to pilot testing at this location in 2011 (Arrow Energy, 2024).
mb1_s	609595	7592256	BGP	60	45.0 - 50.0	Fort Cooper Coal Measures (Girrah Seam)	30/11/2019	30/11/2023	-
an019f	623219	7569209	MGP	290	269.0 - 271.0	Fort Cooper Coal Measures	12/11/2015	18/08/2023	-
gr067v	612935	7582334	MGP	610.9	543.2 - 610.9	Moranbah Coal Measures	27/02/2016	16/01/2024	Early observations discarded due to depressurisation activities in this bore associated with the conversion of the bore to a monitoring point (Arrow Energy, 2024).
m162gmv	603365	7573356	MGP	276	252.0 - 256.0	Moranbah Coal Measures	10/12/2015	16/01/2024	-
m313_bk_1p	614825	7562084	MGP	532.4	507.0 - 510.0	Back Creek Group	4/09/2014	16/01/2024	-

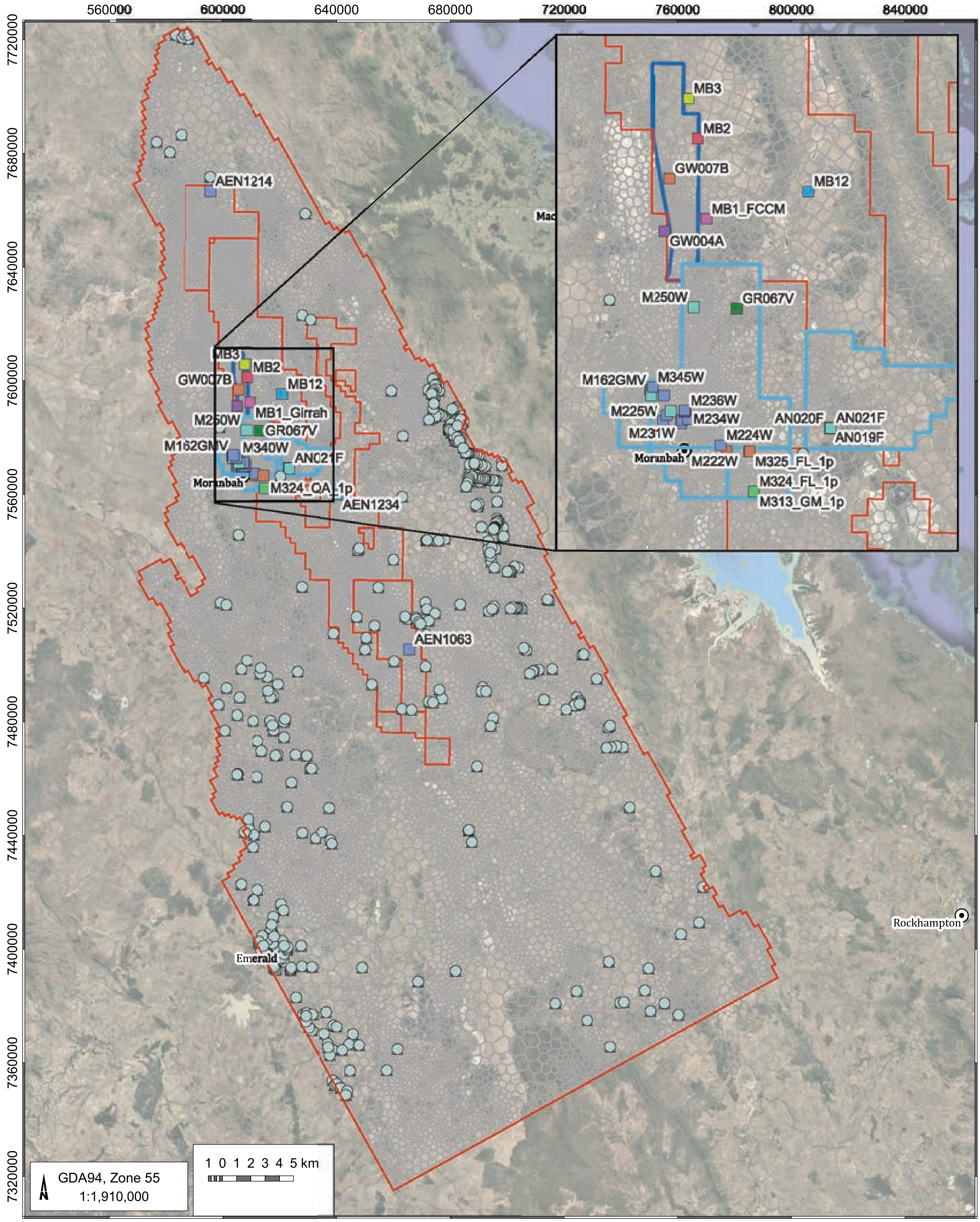
Bore	Easting (GDA 94, Zone 55)	Northing (GDA 94, Zone 55)	Network	Total depth (m)	Screened interval (mbgl)	Screened formation	Date of first measurement	Date of last measurement	Comment
m313_gm_1p	614825	7562084	MGP	532.4	313.0 - 316.5	Moranbah Coal Measures (QA Seam)	4/09/2014	16/01/2024	-
m314_bk_1p	614324	7566535	MGP	560.5	551.5 - 553.5	Back Creek Group	5/09/2014	19/01/2024	-
m314_mcmq	614324	7566535	MGP	560.5	210.5 - 213.5	Moranbah Coal Measures (QA Seam)	5/09/2014	18/01/2024	-
m324_fl_1p	614828	7562106	MGP	240	163.0 - 166.0	Fort Cooper Coal Measures	6/09/2014	16/01/2024	-
m324_qa_1p	614828	7562106	MGP	240	187.0 - 190.0	Moranbah Coal Measures (QA Seam)	5/09/2014	16/01/2024	-
M325_FL_1P	614343	7566542	MGP	202.3	180.5 - 182.0	Fort Cooper Coal Measures	18/02/2015	19/01/2024	Excluded from calibration, local drawdown observed due to sampling and/or erroneous measurements (Arrow Energy, 2019).

3.3 Pilot points

As per the previous calibration (AGE, 2018), a total of 1,672 pilot points were used to calibrate the hydraulic properties of the 2025 Bowen Basin model, using 76 pilot points in each of the 22 model layers, the locations of which are presented in Figure 3.2. Values assigned to each pilot points were interpolated across the model domain in each layer of the model using ordinary automatic kriging through PLPROC (Watermark Numerical Computing, 2016). Pilot point multipliers were allowed to vary ±2 orders of magnitude from the starting parameters and estimated hydraulic properties were capped based on the parameter bounds summarised in Table 3.3.

Table 3.3 General parameter constraints

Unit	Model Layers	Horizontal hydraulic conductivity Kx (m/day)	Horizontal hydraulic conductivity Kz (m/day)	Specific yield Sy (%)	Specific storage Ss (m^{-1})	Maximum anisotropy Kx:Kz
Alluvium, weathered materials	1	1.0E-05 – 150	1.0E-05 - 10	0.1 – 20	9.0E-07 - 2.1E-05	0.5
Tertiary Basalt	2	1.0E-05 – 100	1.0E-05 - 1	0.1 – 20	9.0E-07 - 2.1E-05	1
Sandstone	3	1.0E-05 - 1	1.0E-05 - 1	0.1 – 20	9.0E-07 - 2.1E-05	1
Interburden	4, 6, 12, 14, 16, 18, 20	8.6E-06 - 1.0E-02	1.0E-08 - 5.0E-03	0.1 – 6	7.0E-07 – 7.5E-05	0.5
Coal seams	5, 7, 8, 9, 10, 11, 13, 15, 17, 19, 21	8.6E-06 - 1.0E-01	8.6E-06 - 1.0E-01	0.1 – 6	2.0E-06 – 2.7E-05	1



LEGEND

- Populated place
- AGE mesh
- AGE model outline
- PL (QPM, MGP)
- PL (Arrow, BGP)
- ATP (Arrow, BGP)
- Steady state Targets

Transient Targets

- lay 1- Quaternary
- lay2 - Tertiary
- lay 4 - Rewan
- lay 5 - Leichardt seam
- lay 8 - Fort Cooper Coal Measures
- lay 9 - Fort Cooper Coal Measures
- lay 10 - Fort Cooper Coal Measures
- lay 11 - Q seam
- lay 13 - P seam
- lay 15 -GM seam
- lay 16 - Interburden
- lay 18 - Interburden
- lay 22 - Permian basement

Bowen (BOW5000)

Groundwater level observation locations

AGE

DATE 30/01/2025

FIGURE No: **3.1**

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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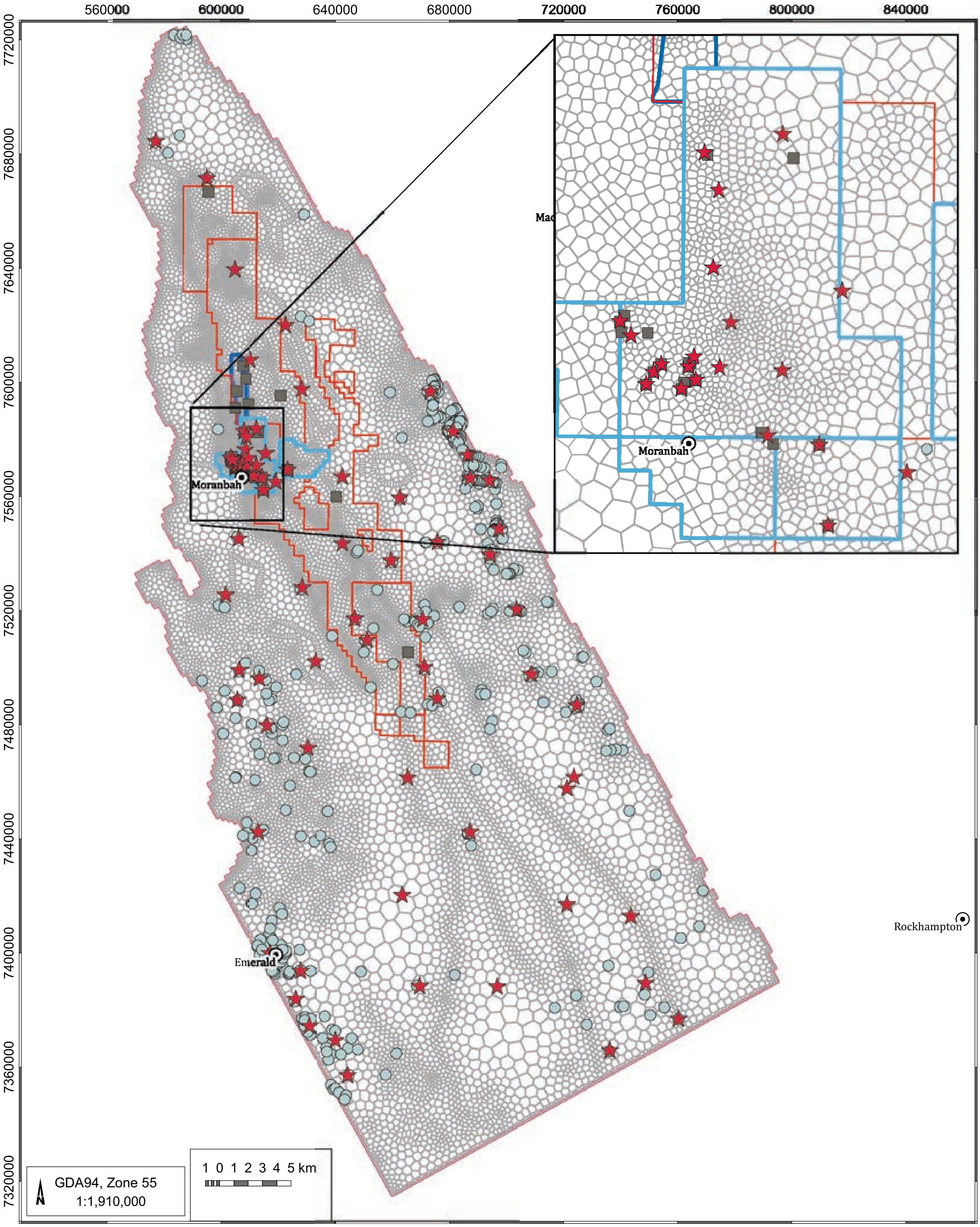

LEGEND

- Populated place
- AGE mesh
- AGE model outline
- PL (QPM, MGP)
- PL (Arrow, BGP)
- ATP (Arrow, BGP)
- Pilot Points multipliers
- Steady state targets
- Transient targets

Bowen (BOW5000)

Pilot point multiplier locations

AGE

DATE 30/01/2025

FIGURE No: **3.2**

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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3.4 Calibration results

3.4.1 Groundwater levels

Figure 3.3 presents a comparison of observed and simulated groundwater levels resulting from the calibration as a scattergram. For both the steady-state simulation and transient simulation a high level of agreement between observed and modelled levels has been achieved as shown in Figure 3.3 and evidenced by the statistics presented in Table 3.4. In particular a scaled root mean square (SRMS) discrepancy between observed and simulated values of 2.9% has been achieved for the updated transient simulation. This transient SRMS statistic is substantially better than equivalent statistics related with either previous iteration of the model, which were 5.2 % in 2018 (AGE, 2018) and 13.7% in 2021.

Comparisons of observed and modelled head time series at each transient monitoring point used for model calibration are presented in Appendix A. In general, as per the overall statistics discussed above, a relatively good fit to the observed data has been achieved.

Table 3.4 Statistical analysis

Calibration performance measure	Transient data	Steady-state data
Sum of Residuals (SR) (m)	-33,875	4,195
Mean Sum of Residuals (MSR) (m)	-1.04	8.72
Scaled Mean Sum of Residuals (SMSR) (%)	-0.4	2.3
Sum of Squares (SSQ) (m)	1,462,409	234,329
Mean Sum of Squares (MSSQ) (m)	44.73	487.17
Root Mean Square (RMS) (m)	6.69	22.07
Root Mean Fraction Square (RMFS) (%)	0.5	0.9
Scaled RMFS (SRMFS) (%)	0.4	0.4
Scaled RMS (SRMS) (%)	2.9	5.8

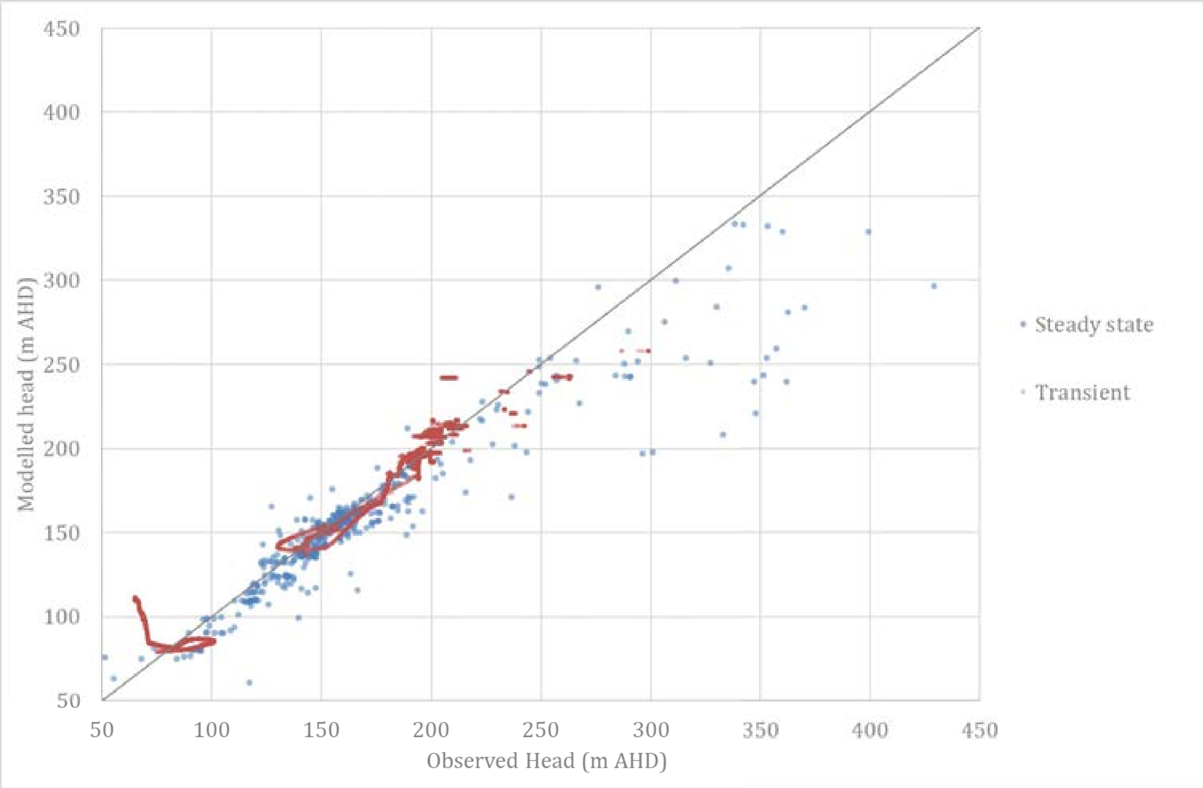

Figure 3.3 Scattergram measured vs. simulated groundwater levels - 2025 Bowen UWIR model

3.4.2 Modelled water balance

Table 3.5 shows the water budget for the steady state (pre-CSG) model. 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 transient simulation was also 0%. This value indicates that the model is stable and achieves an accurate numerical solution.

Table 3.5 Model water budget -steady state

Parameter	In (m^3/day)	Out (m^3/day)	In - Out (m^3/day)
Rainfall recharge	211,021	0	211,021
Groundwater discharge to surface water courses	0	87,978	-87,978
Evapotranspiration	0	237,383	-237,383
In/outflow from/to lateral model boundaries	221,497	107,157	114,340
Total	**432,518**	**432,518**	**0**

3.4.3 CSG extraction

As discussed in Section 2.7 historic and future CSG extraction rates have been simulated in the model using actual and anticipated water extraction volumes provided by Arrow and QPME. The volumes have been input to the groundwater flow model via the MODFLOW WEL package and hence are referred to as “Model input” in Figure 3.4. Since MODFLOW automatically switches off extractions which occur from dry cells then in some situations the total modelled output (i.e. the amount actually extracted from the simulation) can be less than the input. As shown in Figure 3.4 this is not considered to be a significant source of error in this model since the modelled input and output time series plot on top of each other for the majority of the simulation period, hence confirming that the actual modelled extraction volumes are not materially different from those provided by Arrow and QPME. In addition, a comparison between total model input and output extraction volumes at the end of the simulation show only a 1% difference between the total model input extraction volume and the total volume actually extracted from the model.

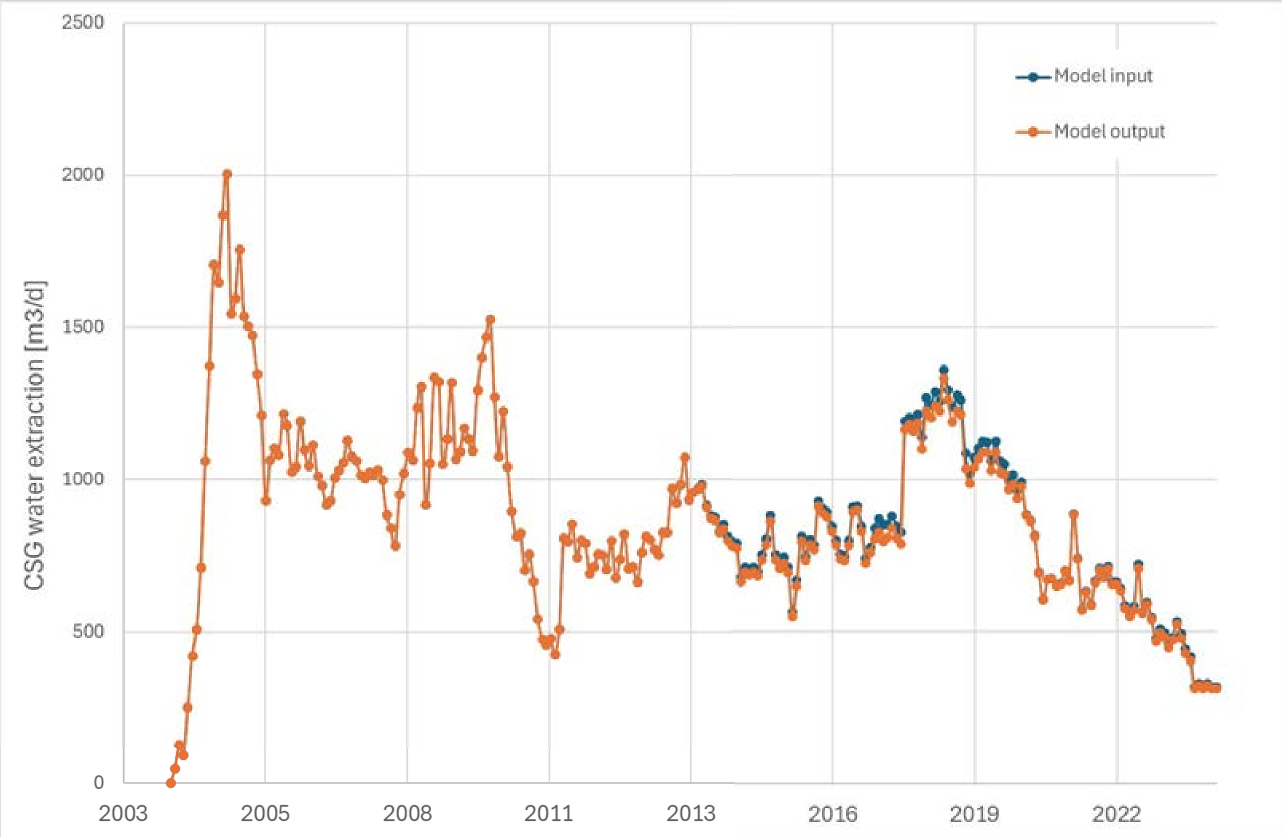

Figure 3.4 Input extraction rates for the WEL-package vs. modelled CSG extraction rates

3.4.4 Calibrated hydraulic parameters

Table 3.6 summarises the average hydraulic conductivity, specific storage and specific yield for each geology unit in the model domain. The re-calibrated parameter values show the following minor changes compared to the previous calibrated values (AGE, 2018), which were re-used in 2021 (AGE, 2021) and adopted as initial values for this work:

- lower horizontal and vertical hydraulic conductivity (around 10 to 20% lower compared to the previously calibrated values for the Q and GM seam layers in the Moranbah Coal Measures (model layers 9 and 15, respectively); and
- increased vertical hydraulic conductivity for most layers by around 10% compared to the previous calibration, except for the Q and GM coal seam layers (see previous bullet point).

Table 3.6 Summary of calibrated hydraulic parameters

Layer	Primary formation	Unit	Hydraulic conductivity average and max-min range			Specific storage average and max-min range (m-1)	Specific yield average and max-min range (%)
			Horizontal (Kh) (m/day)	Vertical (Kv) (m/day)	Depth Dependency		
1	Quaternary Alluvium, weathered materials	Surficial coverage	8.32E+00 (8.40E-03 - 1.20E+02)	1.61E+00 (8.90E-05 - 1.00E+01)	No	2.0E-05 (2.0E-05 - 2.1E-05)	19.2% (18.0% - 20.0%)
2	Tertiary sediments (Duringa), Basalts (Anakie) & Moolayember	Tertiary, Triassic	5.00E+00 (1.50E-05 - 9.80E+01)	3.02E+00 (2.90E-09 - 3.20E+02)	No	1.6E-05 (9.9E-07 - 2.1E-05)	14.7% (5.0% - 50.0%)
3	Clematis Sandstone	Triassic	2.28E-02 (6.60E-03 - 6.80E-02)	2.48E-03 (3.90E-04 - 9.00E-03)	No	2.0E-05 (2.0E-05 - 2.1E-05)	17.0% (17.0% - 18.0%)
4	Rewan	Triassic	1.26E-03 (1.90E-04 - 1.00E-02)	2.39E-07 (3.70E-08 - 6.50E-06)	No	1.0E-06 (9.9E-07 - 1.0E-06)	6.0% (6.0% - 6.0%)
5	Rangal Coal Measures	Leichardt seam	2.62E-02 (8.60E-06 - 1.00E-01)	7.74E-03 (8.60E-06 - 6.50E-02)	Yes	2.0E-05 (2.0E-05 - 2.0E-05)	5.0% (5.0% - 5.0%)
6		Interburden	1.08E-04 (9.60E-05 - 1.20E-04)	1.11E-08 (1.00E-08 - 1.20E-08)	No	1.0E-06 (9.9E-07 - 1.1E-06)	6.0% (6.0% - 6.0%)
7		Vermont seam	2.15E-02 (8.60E-06 - 1.00E-01)	5.96E-03 (8.60E-06 - 6.60E-02)	Yes	2.0E-05 (2.0E-05 - 2.1E-05)	5.0% (5.0% - 5.0%)
8	Fort cooper coal measures	Girrah	1.05E-04 (8.50E-05 - 1.20E-04)	8.60E-06 (8.60E-06 - 8.60E-06)	No	2.0E-05 (2.0E-05 - 2.1E-05)	5.0% (5.0% - 5.0%)
9		Fccm	4.54E-03 (2.00E-03 - 9.40E-03)	8.95E-05 (3.80E-05 - 2.00E-04)	No	2.0E-05 (2.0E-05 - 2.1E-05)	5.0% (5.0% - 5.0%)
10		FHF	1.09E-04 (9.80E-05 - 1.20E-04)	8.60E-06 (8.60E-06 - 8.60E-06)	No	2.0E-05 (1.0E-05 - 2.1E-05)	5.0% (5.0% - 5.0%)
11	Moranbah Coal Measures	Q seam	1.37E-02 (8.60E-06 - 1.00E-01)	4.95E-03 (8.60E-06 - 1.00E-01)	Yes	1.9E-05 (9.0E-07 - 2.1E-05)	5.0% (5.0% - 5.0%)
12		Interburden	1.04E-04 (8.70E-05 - 1.20E-04)	2.30E-08 (1.90E-08 - 1.30E-07)	No	9.7E-07 (7.0E-07 - 1.1E-06)	5.0% (5.0% - 5.3%)
13		P seam	1.22E-02 (8.60E-06 - 1.00E-01)	4.71E-03 (8.60E-06 - 1.00E-01)	Yes	1.9E-05 (9.0E-07 - 2.3E-05)	5.0% (5.0% - 5.0%)
14		Interburden	1.01E-04 (1.20E-05 - 1.20E-04)	7.23E-08 (1.00E-08 - 8.70E-08)	No	9.7E-07 (7.0E-07 - 1.1E-06)	5.0% (5.0% - 5.3%)
15		GM seam	6.48E-03 (8.60E-06 - 1.00E-01)	1.48E-03 (8.60E-06 - 3.70E-02)	Yes	1.8E-05 (9.0E-07 - 2.7E-05)	5.0% (5.0% - 5.0%)
16		Interburden	1.07E-04 (8.00E-05 - 2.20E-04)	8.48E-08 (4.40E-08 - 1.30E-06)	No	1.3E-06 (8.7E-07 - 7.5E-05)	5.0% (5.0% - 5.3%)
17		GML seam	7.07E-03 (8.60E-06 - 1.00E-01)	1.76E-03 (8.60E-06 - 3.80E-02)	Yes	2.0E-05 (1.9E-05 - 2.1E-05)	5.0% (5.0% - 5.0%)

Layer	Primary formation	Unit	Hydraulic conductivity average and max-min range			Specific storage average and max-min range (m-1)	Specific yield average and max-min range (%)
			Horizontal (Kh) (m/day)	Vertical (Kv) (m/day)	Depth Dependency		
18	Moranbah Coal Measures	Interburden	1.00E-04 (1.00E-04 - 1.00E-04)	7.00E-08 (7.00E-08 - 7.00E-08)	No	1.0E-06 (9.8E-07 - 1.1E-06)	5.0% (5.0% - 5.0%)
19		DYU seam	6.72E-03 (8.60E-06 - 1.00E-01)	1.70E-03 (8.60E-06 - 3.80E-02)	Yes	2.0E-05 (2.0E-05 - 2.1E-05)	5.0% (5.0% - 5.0%)
20		Interburden	1.06E-04 (6.20E-05 - 1.30E-04)	7.75E-08 (4.70E-08 - 9.90E-08)	No	1.0E-06 (9.9E-07 - 1.1E-06)	5.0% (5.0% - 5.3%)
21		DYR seam	6.64E-03 (8.60E-06 - 1.00E-01)	1.72E-03 (8.60E-06 - 4.00E-02)	Yes	2.0E-05 (2.0E-05 - 2.1E-05)	5.0% (5.0% - 5.0%)
22		Permian basement	4.66E-04 (2.50E-04 - 7.70E-04)	9.77E-06 (5.60E-06 - 1.80E-05)	No	1.0E-06 (9.9E-07 - 1.1E-06)	6.0% (6.0% - 6.0%)

4 Predictions

4.1 Impact calculations

The following three predictive model scenarios were undertaken for the purposes of estimating the cumulative impacts of the MGP and BGP and as well as the individual contribution of each:

1. A baseline or **No CSG scenario** which does not include and CSG related extraction.
2. An **MGP only scenario** which assumes that there is no extraction from CSG wells associated with the BGP project, note that any recorded actual extraction from BGP pilot wells is also excluded from this scenario.
3. A **Cumulative scenario** which includes actual historic and proposed future water extraction from the MGP and BGP projects at the rates shown in Figure 2.1.

Based on outputs from these three scenarios predicted drawdown impacts have been estimated as follows:

- cumulative drawdowns associated with the MGP and BGP have been calculated by subtracting the simulated heads in the 'Cumulative scenario' from the 'No CSG scenario' heads;
- drawdowns associated with the MGP only have been calculated by subtracting the simulated heads in the 'MGP only scenario' from the 'No CSG scenario'; and
- drawdowns associated with the BGP only have been calculated by subtracting the simulated heads in the 'Cumulative scenario' from the 'MGP only scenario'.

It is noted that the BGP only impacts in particular could have been calculated in a number of different ways, including by undertaking a further BGP only scenario and estimating BGP impacts by comparison of this run with the 'No CSG scenario'. The adopted approach whereby BGP only impacts have been calculated by comparison of the cumulative and MGP only scenario has several advantages over other approaches. In particular the adopted approach is consistent with methodologies applied by OGIA in the neighbouring Surat CMA UWIR (OGIA, 2021) and reflects the actual timing of operations in the Bowen Basin. As shown in Figure 2.1 field scale extraction from the MGP commenced in 2003 and an 18-year gap is anticipated between the conclusion of extraction from the MGP in 2028 and when the majority of field scale extraction starts from the BGP in 2046. Furthermore, the adopted approach also ensures that the sum of the estimated impacts of each individual project is at all times equal to and hence consistent with the estimated cumulative impact. This is unlikely to occur with other approaches.

4.2 Processing of predicted IAA and LAA areas

For UWIR reporting purposes four primary predictions are required based on groundwater flow modelling outputs these being the estimated extent of the immediately and long-term affected areas, the baseline assessment area and potentially impacted springs and other GDEs in each aquifer which in the case of the Bowen Basin can be further defined as follows:

- IAA (Immediately Affected Area) – areas where maximum cumulative and/or MGP/BGP only drawdown impacts exceed 5 m in consolidated units or 2 m for unconsolidated units within the next 3 years (i.e. January 2028).
- LAA (Long term Affected Area) – areas where maximum cumulative and/or MGP/BGP only drawdown impacts exceed 5 m in consolidated units or 2 m for unconsolidated units at any time in the future.
- Identification of baseline assessment areas in relevant aquifers (i.e. those areas where more than 1 m of drawdown is expected within the next 3 years (used for baseline assessment program planning).
- Springs and other GDEs where drawdown impacts of more than 0.2 m are predicted at any point in the future.

Since the Moranbah (MCM) and Rangal Coal Measures (RCM) span multiple model layers, drawdown impact results (e.g. IAA areas and LAA areas) for these units were generated by processing drawdown for each coal seam within the associated coal measure. These results were then subsequently combined and used to obtain a spatial composite of the maximum predicted drawdown in any of the coal layers. For example, the IAA and LAA areas for the RCM were computed by processing drawdown results in both modelled coal seam layers (i.e. layers 7 and 9) prior to further processing these results to identify the maximum drawdown within each cell.

Note that to avoid duplication the aforementioned predictions are deliberately not included in this modelling report appendix as these will be presented in the main body of the respective UWIR's prepared by Arrow Energy and QPME. The text provided above is therefore intended to confirm the approach used to calculating the predictions presented in the UWIRs.

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Appendix A

Groundwater Level Calibration Hydrographs

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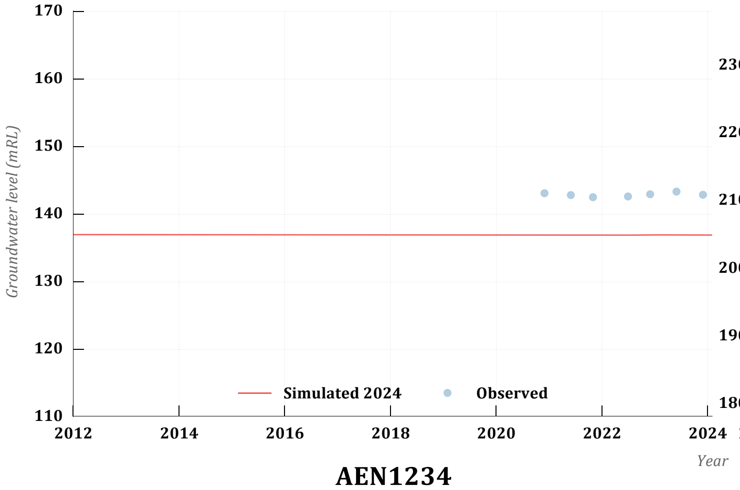

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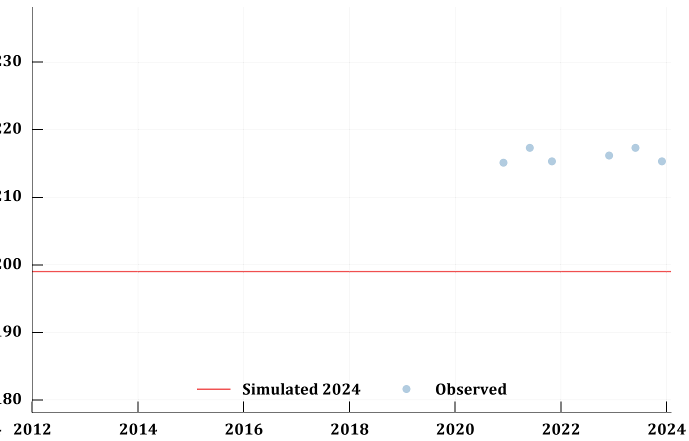

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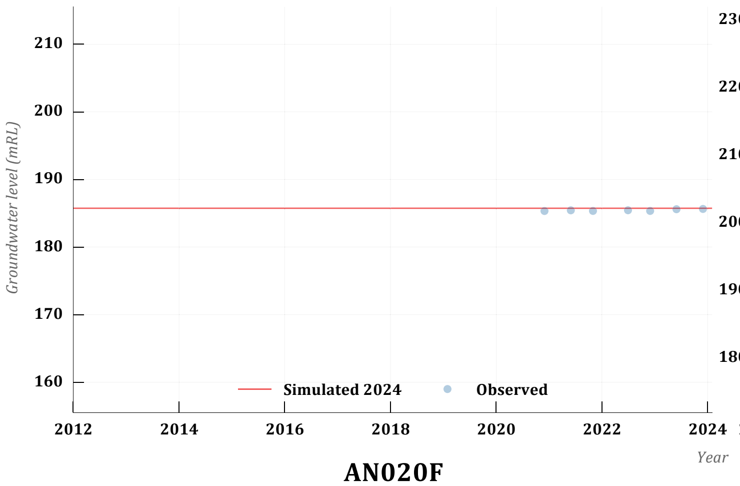

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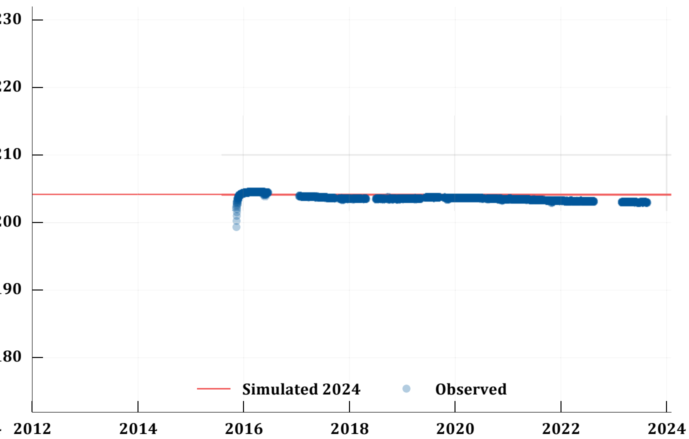

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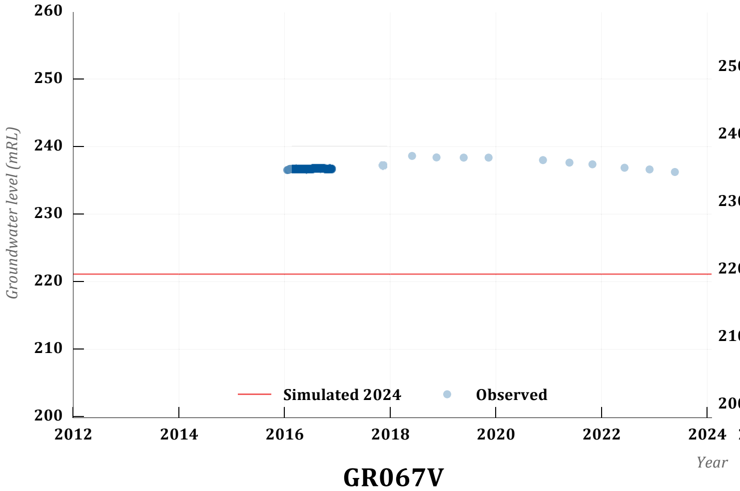

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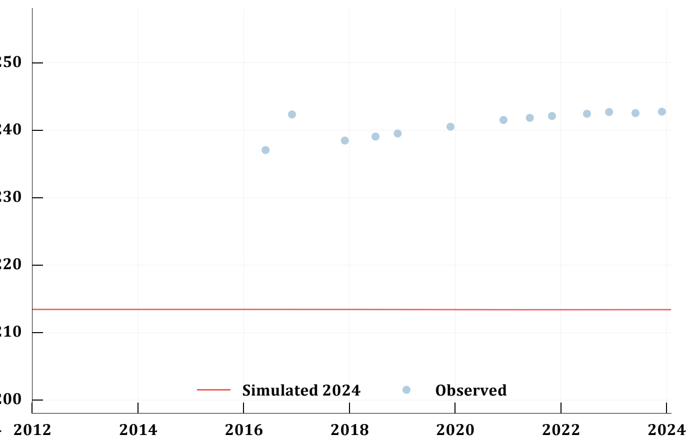

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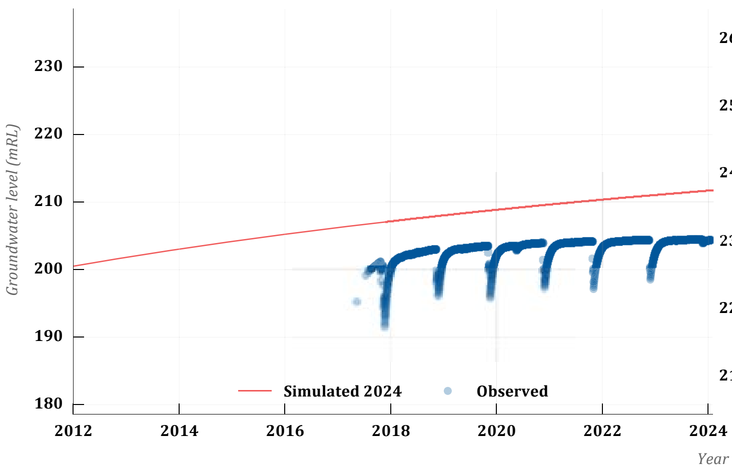

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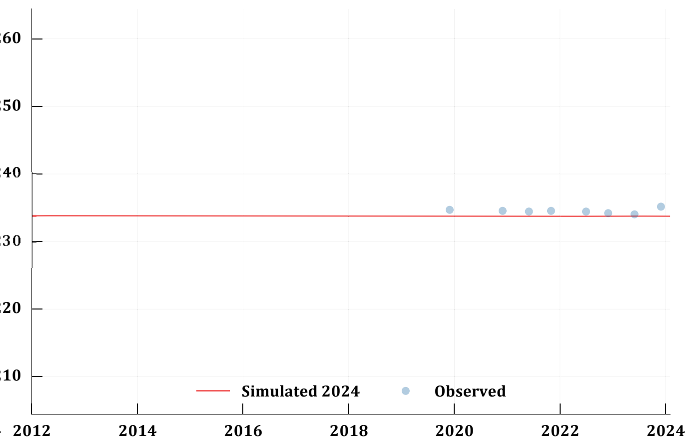
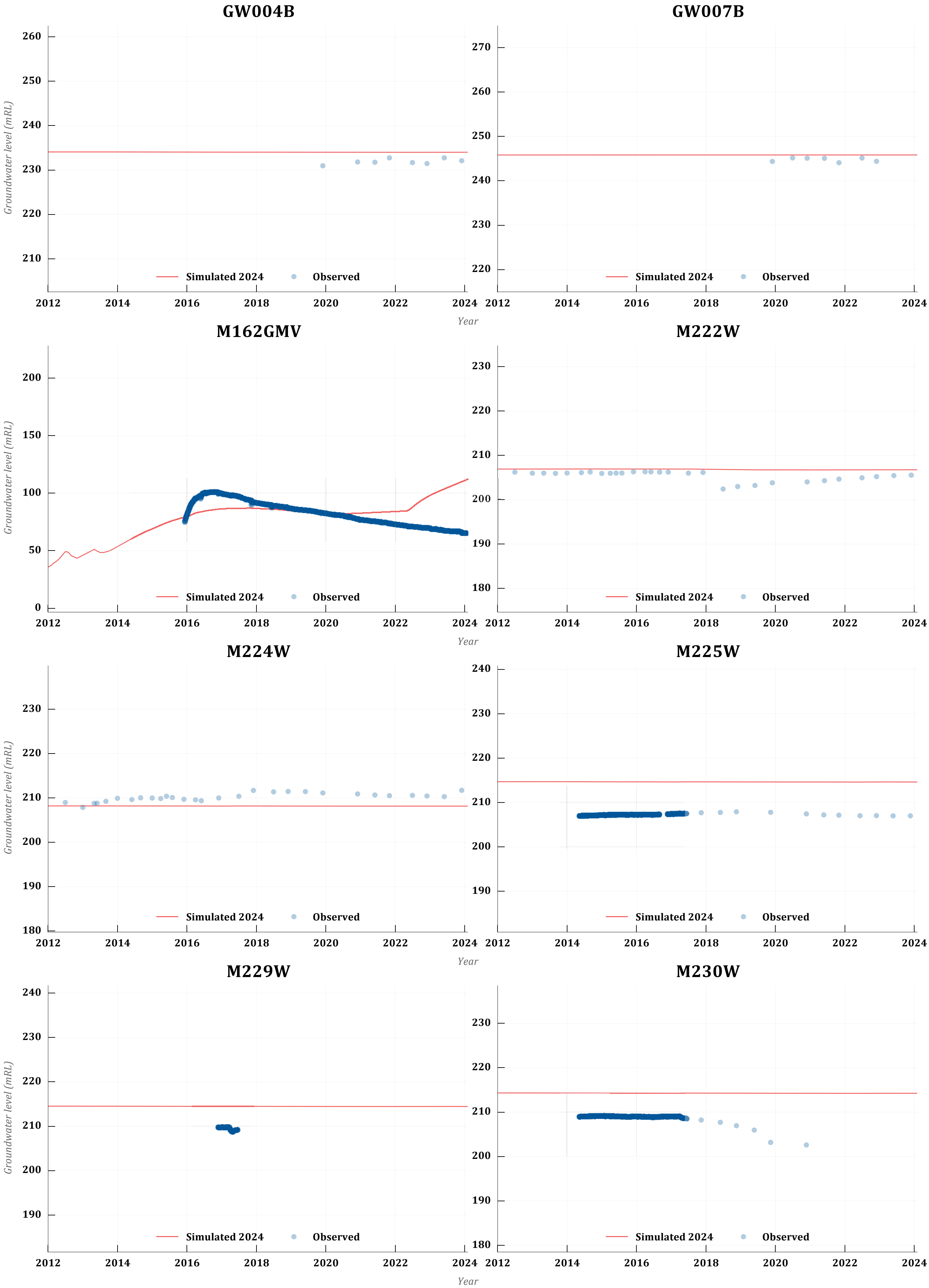
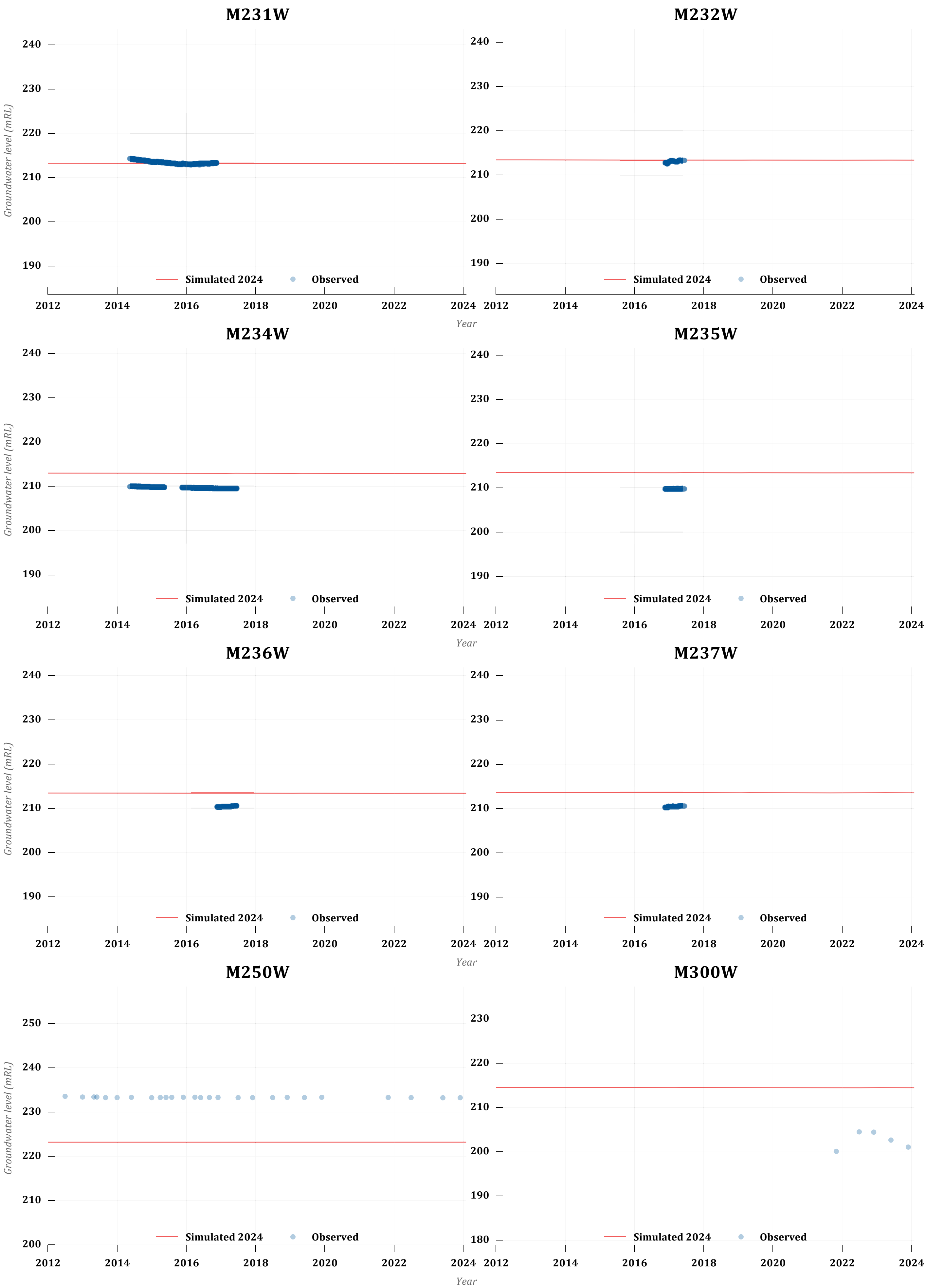



GW004B
GW007B
M162GMV
M222W
M224W
M225W
M229W
M230W
Groundwater level (mRL)
Year
Simulated 2024
Observed
2012
2014
2016
2018
2020
2022
2024


M231W
M232W
M234W
M235W
M236W
M237W
M250W
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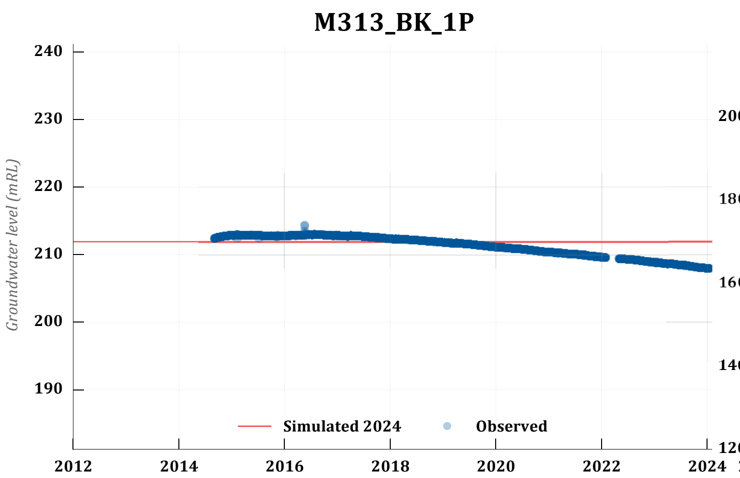
Groundwater level (mRL)
Year
Simulated 2024
Observed
2012
2014
2016
2018
2020
2022
2024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220
210
200
190
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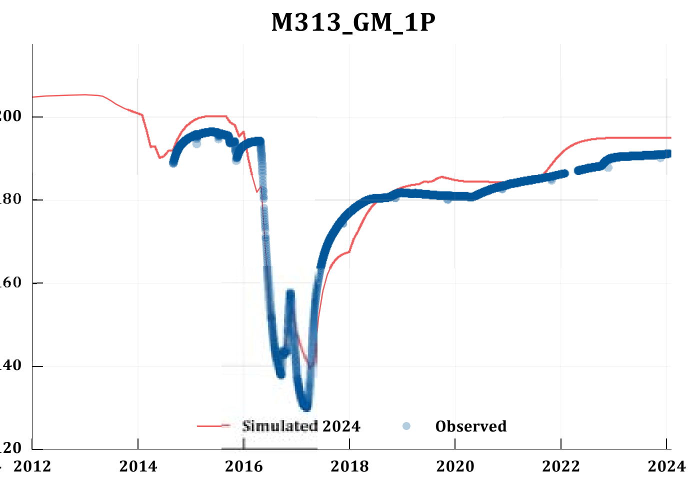
Observed
2012
2014
2016
2018
2020
2022
2024
Year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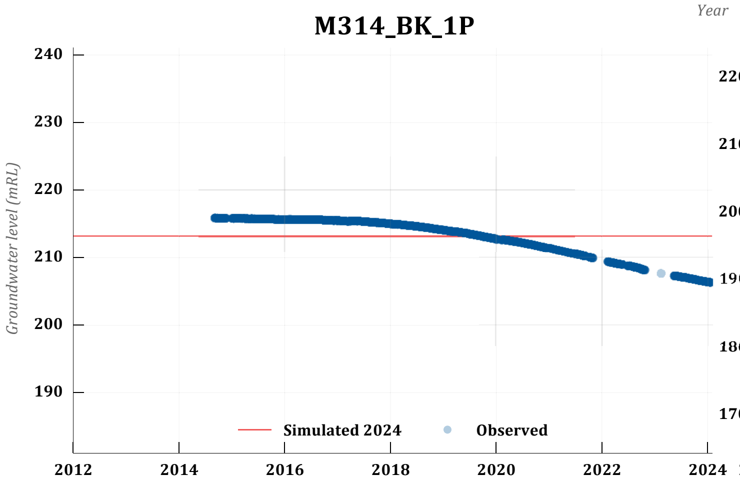
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2016
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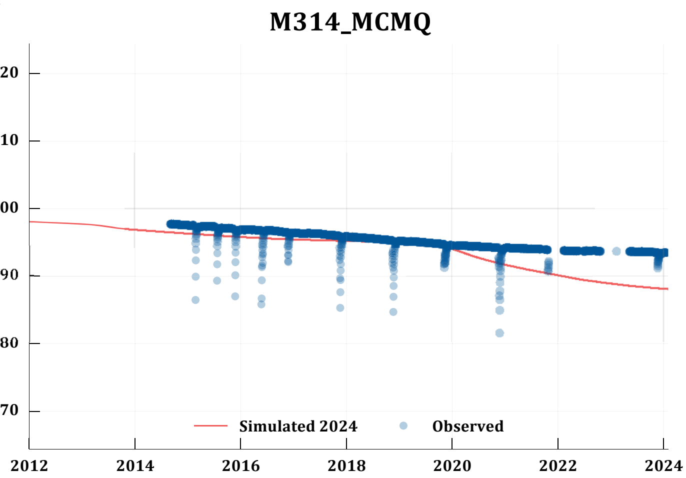
2022
2024
Year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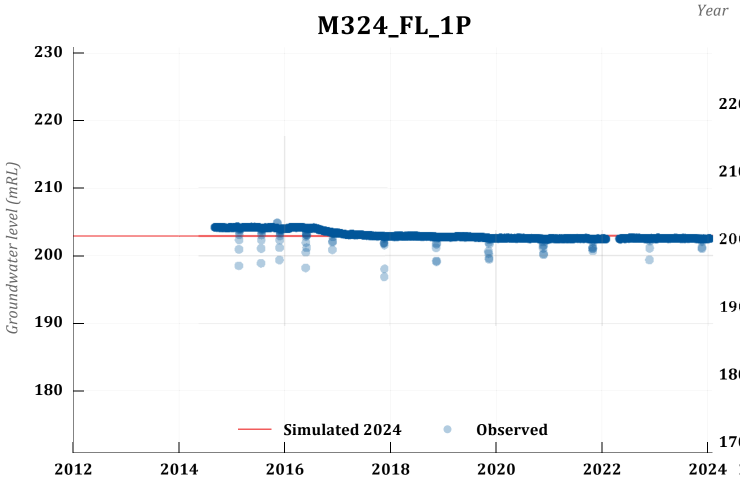
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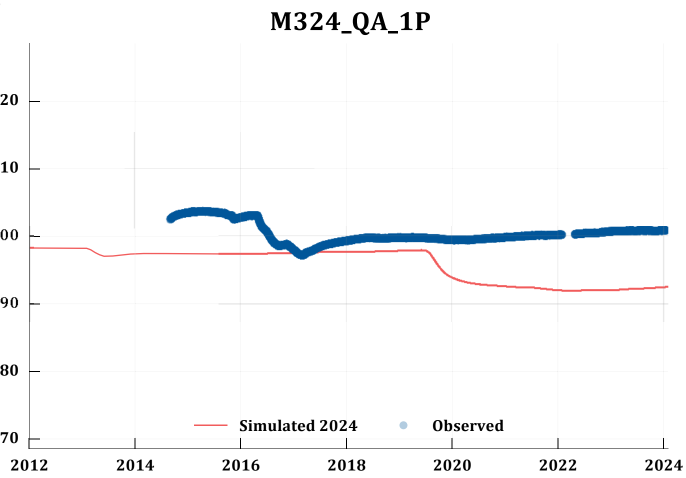
2022
2024
Year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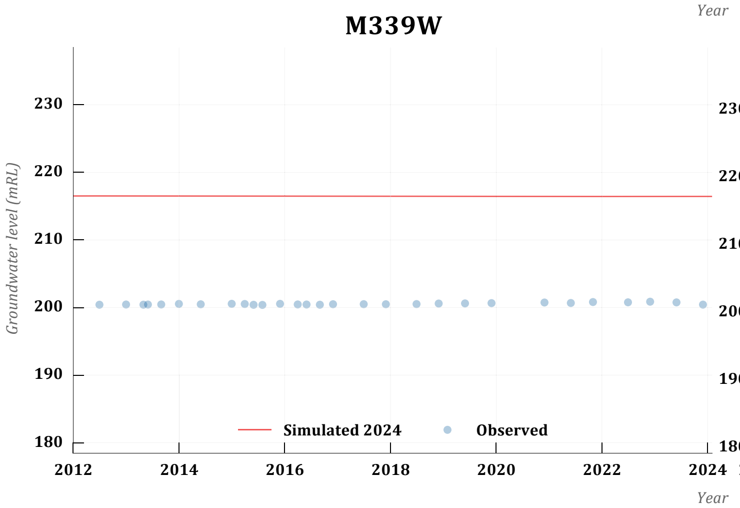
2024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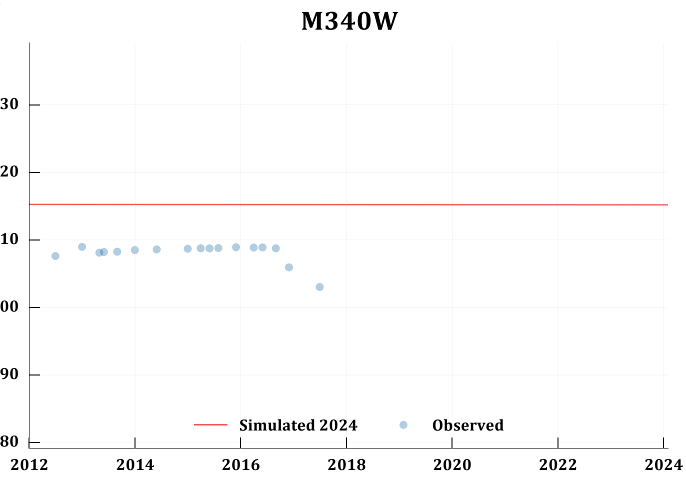
Year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2020
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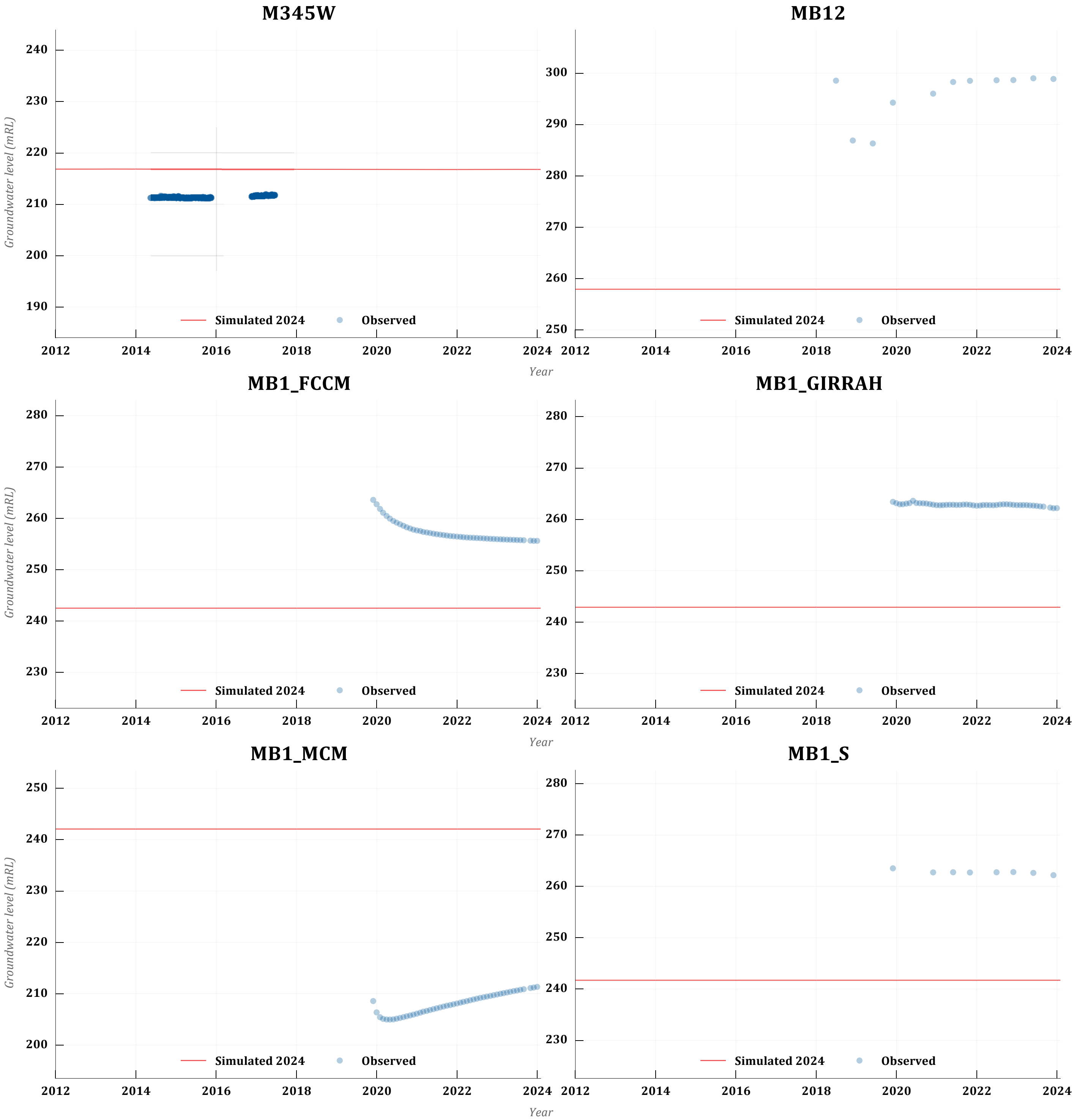
2024


M345W
MB12
MB1_FCCM
MB1_GIRRAH
MB1_MCM
MB1_S
Groundwater level (mRL)
Year
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Observed
2012
2014
2016
2018
2020
2022
2024

Appendix D – IAA and LAA 5m Drawdown for the MGP-only Scenario

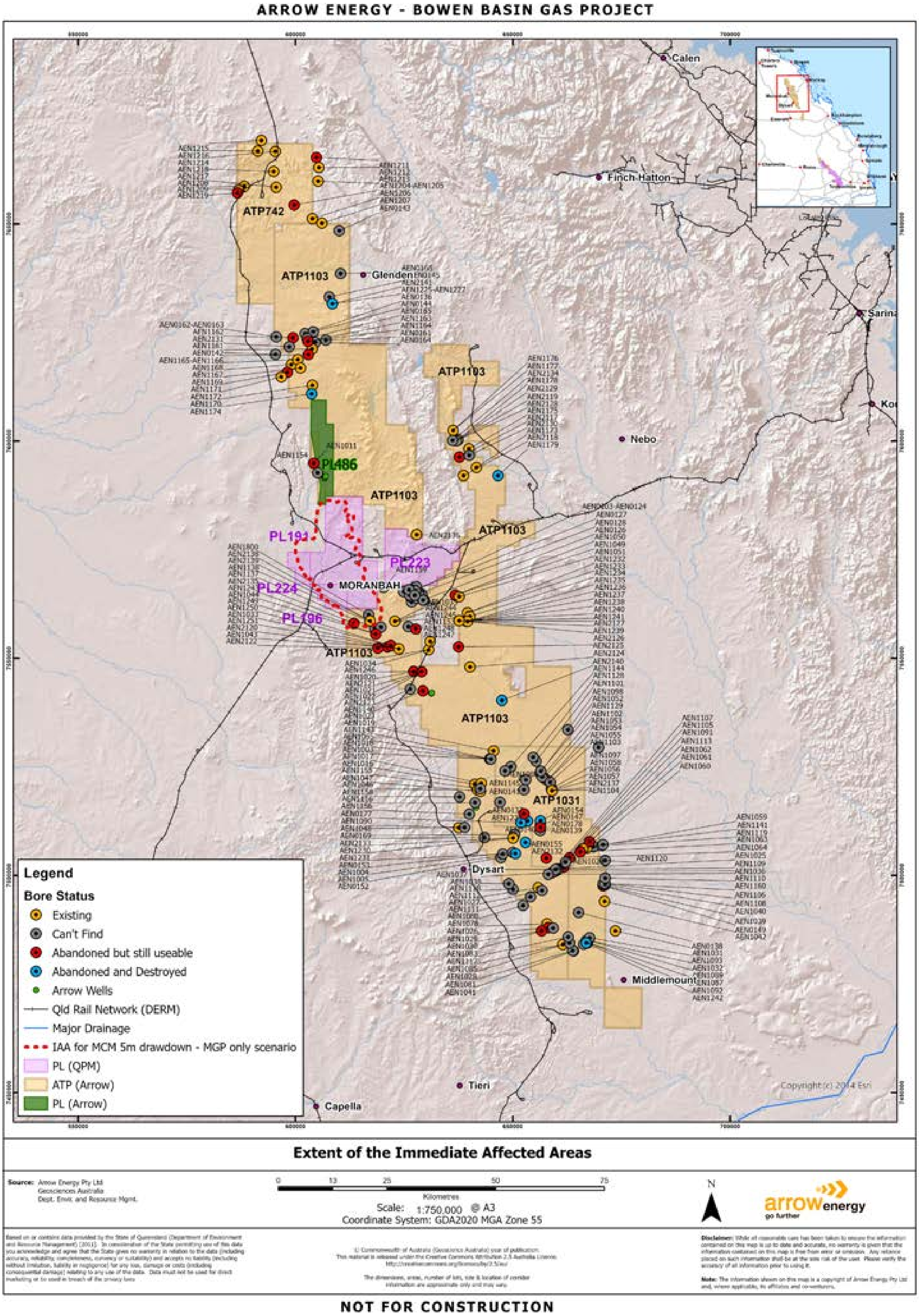

Figure D-1: IAA 5m Drawdown for the MGP-only Scenario

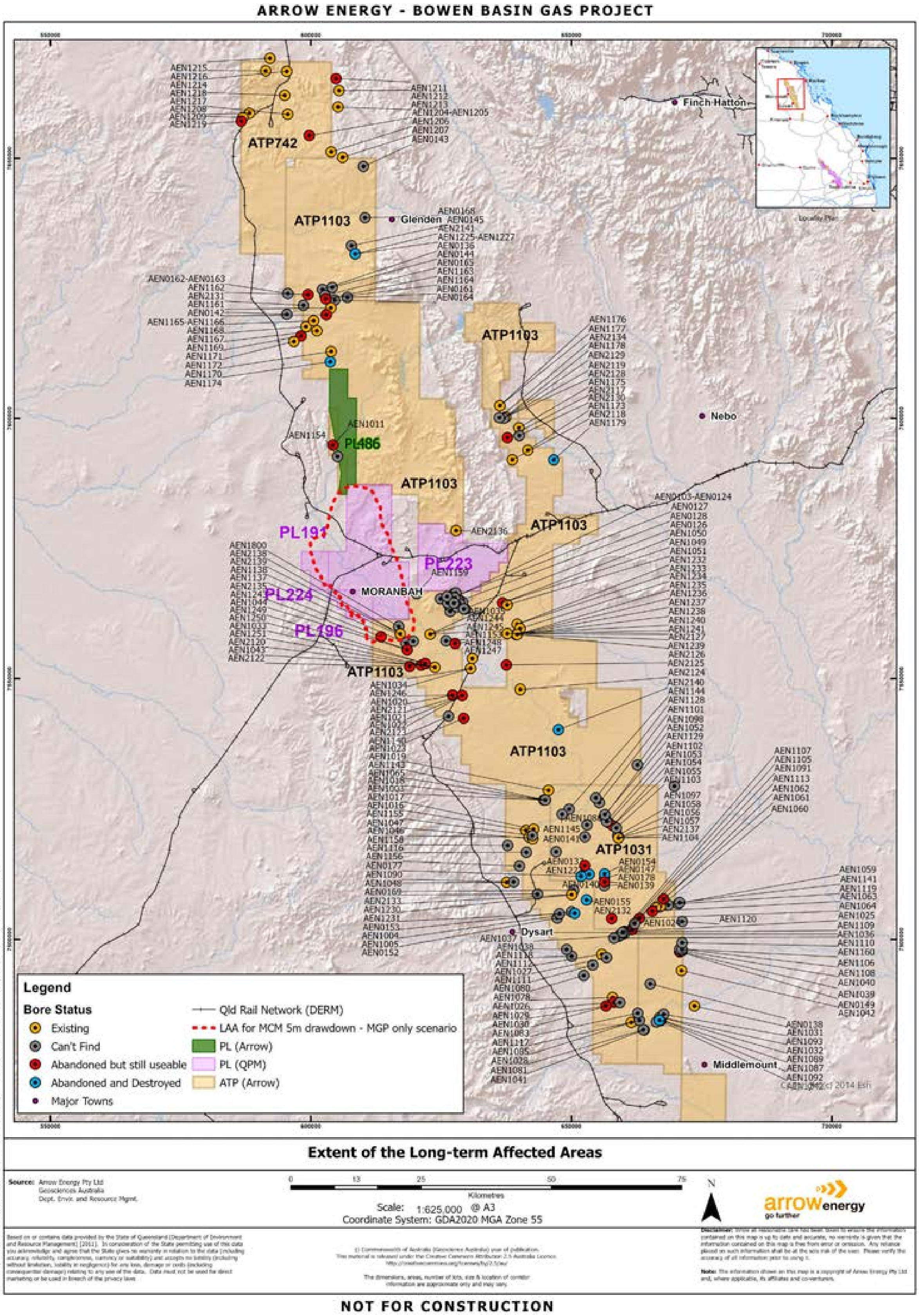

Figure D-2: LAA 5m Drawdown for the MGP-only Scenario