Underground Water Impact Report

Final Report

For Authority to Prospect 831

arrow energy
go further

4 April 2019

TABLE OF CONTENTS

Figures:

Tables:

EXECUTIVE SUMMARY

The registered holders of Authority to Prospect (ATP) 831 are Pure Energy Resources Pty Limited ACN 115 514 880 (50%), Arrow Energy Pty Ltd ACN 078 521 936 (35%), and Arrow CSG (Australia) Pty Ltd ACN 054 260 650 (15%).

The Underground Water Impact Report (UWIR) for the Authority to Prospect (ATP) 831, now referred to as the final report as per s374 of the Water Act 2000, has been compiled and completed as directed in s377 in support of the relinquishment of the ATP 831 tenure. The ATP 831 was previously incorporated and reported as part of the Bowen UWIR 2016. The Annual Reviews of the UWIR's have been completed and submitted and approved by Department of Environment and Science (DES) in March 2017 and 2018 and this report forms the second, but separate UWIR for ATP 831.

There has been no further production testing at Coomooboolaroo and Baralaba on ATP 831 since September 2017 as reported in the last Annual Review 2018. The production testing wells in ATP 831 were plugged and abandoned in 2018.

Key findings for ATP 831 are:

- An LAA was predicted for production testing wells on ATP 831 in the 2016 Bowen UWIR.
- A review was carried out using the latest analytical model predictions of impacts and the Long Term Affected Area (LAA) was revised in accordance with the production testing water production.
- The LAA's are highly localised around the production testing wells indicating minimal lateral impacts.
- There is no existing landholder bores located within 2km from the production testing wells and as no LAA's remain, no "make good" will be required.

Based on this, there are likely to be minimal impacts remaining from the production testing carried out on ATP 831

1 INTRODUCTION

1.1 Preamble

Pursuant to s. 370(3)(b) of the Water Act 2000, the chief executive of the Department of the Environment and Heritage Protection (DES) has directed Arrow Energy Pty. Ltd (Arrow) to submit a single Underground Water Impact Report (UWIR) for Petroleum Leases (PL) 191, 196, 223 and 224 and Authority to Prospect (ATP) 1103, 1031, 831, and 742. A single UWIR was compiled and submitted on 21 March 2016 and thereafter the Annual Reviews were completed and submitted in 2017 and 2018.

The relinquishment of ATP 831 on 31 October 2018 requires the submittal of a final report, as directed by the chief executive of the Department of Environment and Science (DES) per s374 (2) and (4) of the Water Act 2000. . To address the requirement, this UWIR has been developed to be submitted as the final report for the relinquishment of ATP 831.

This report provides information on the expected potential changes in water levels in aquifers due to the taking of water during coal seam gas (CSG) production testing activities in Arrow's Bowen Basin tenure, ATP831, as required by the Water Act 2000.

Arrow Energy has prepared the final report on behalf of the Registered holders of the tenure presented in the table below.

Table 1: Arrow's Tenements, Registered Holder details

Tenure	Registered Holder
ATP 831	Pure Energy Resources Pty Limited ACN 115 514 880 (50%), Arrow Energy Pty Ltd ACN 078 521 936 (35%),and Arrow CSG (Australia) Pty Ltd ACN 054 260 650 (15%)

1.2 Project Area

The spatial distribution of Arrow's tenure in the Bowen Basin is shown in Figure 1 and spans the area, from north to south, around the towns of Glenden, Moranbah, Dysart, Middlemount, Saraji, Norwich, Essex, Dingo and Baralaba.

The Arrow Bowen Tenement (ABT) Area includes ATP 831, within which exploration and production testing has been undertaken, shown in Figure 2, including the wells subjected to production tests over the period 2012 to 2017.

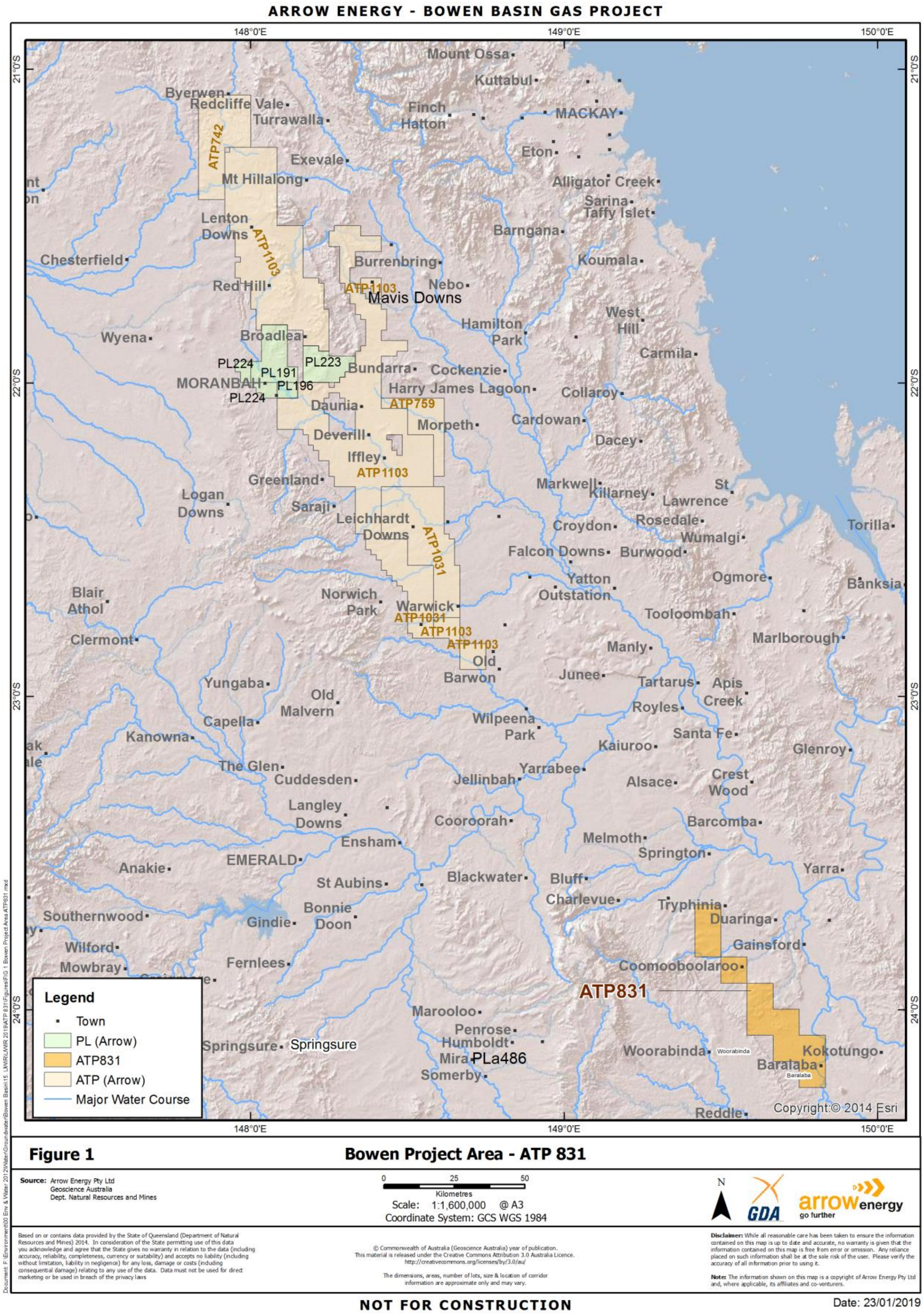

Figure 1: Bowen Project Area - ATP 831

1.3 Requirement of a final report

1.3.1 Cumulative Management Areas

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

The Arrow's operations/project in the Bowen Basin falls outside of the Surat CMA, with the exception of ATP 831 (Figure 2), and under the Water Act (QLD) 2000, there is a requirement to prepare an UWIR.

In the case of ATP 831, which straddles the Surat CMA boundary as depicted in **Error! Reference source not found.**, the DES has instructed Arrow that it must prepare a final report for ATP 831 on the basis that:

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

This requirement is addressed by this final report.

1.3.2 The final report

As indicated in Section 1.1, this final report, as per s374, to be given to the chief executive for the resource tenure is to address Division 4, s376 and s377 of the Water Act (Qld) 2000, which stipulates that the report must include:

1.3.2.1 S376: Content of underground water impact report

a) For the area to which the report relates –

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

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

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

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

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

e) A program for –

   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) Other information or matters prescribed under a regulation.

1.3.2.2 S377: Content of final report

(1) A final report must include each of the matters mentioned in section 376, other than the following:

a) an estimate of the quantity of water mentioned in section 376(a)(ii);
b) a map mentioned in section 376(b)(iv);
c) any of the information mentioned in section 376(d);
d) a program mentioned in section 376(e);
e) if the responsible entity is the office—the proposed responsible tenure holders mentioned in section 376(h).

(2) Also, a final report must include—

a) a summary of information about all water bores in the area shown on a map mentioned in section 376(b)(v), including the number of bores, and the location and authorised use or purpose of each bore; and
b) a summary about how the make good obligations of the responsible tenure holder for each water bore to which the final report relates have been complied with by the holder over the term of the tenure; and
c) a summary of the make good obligations of the responsible tenure holder for each water bore that have not yet been complied with by the holder; and
d) a plan about how the obligations mentioned in paragraph (c) will be complied with.

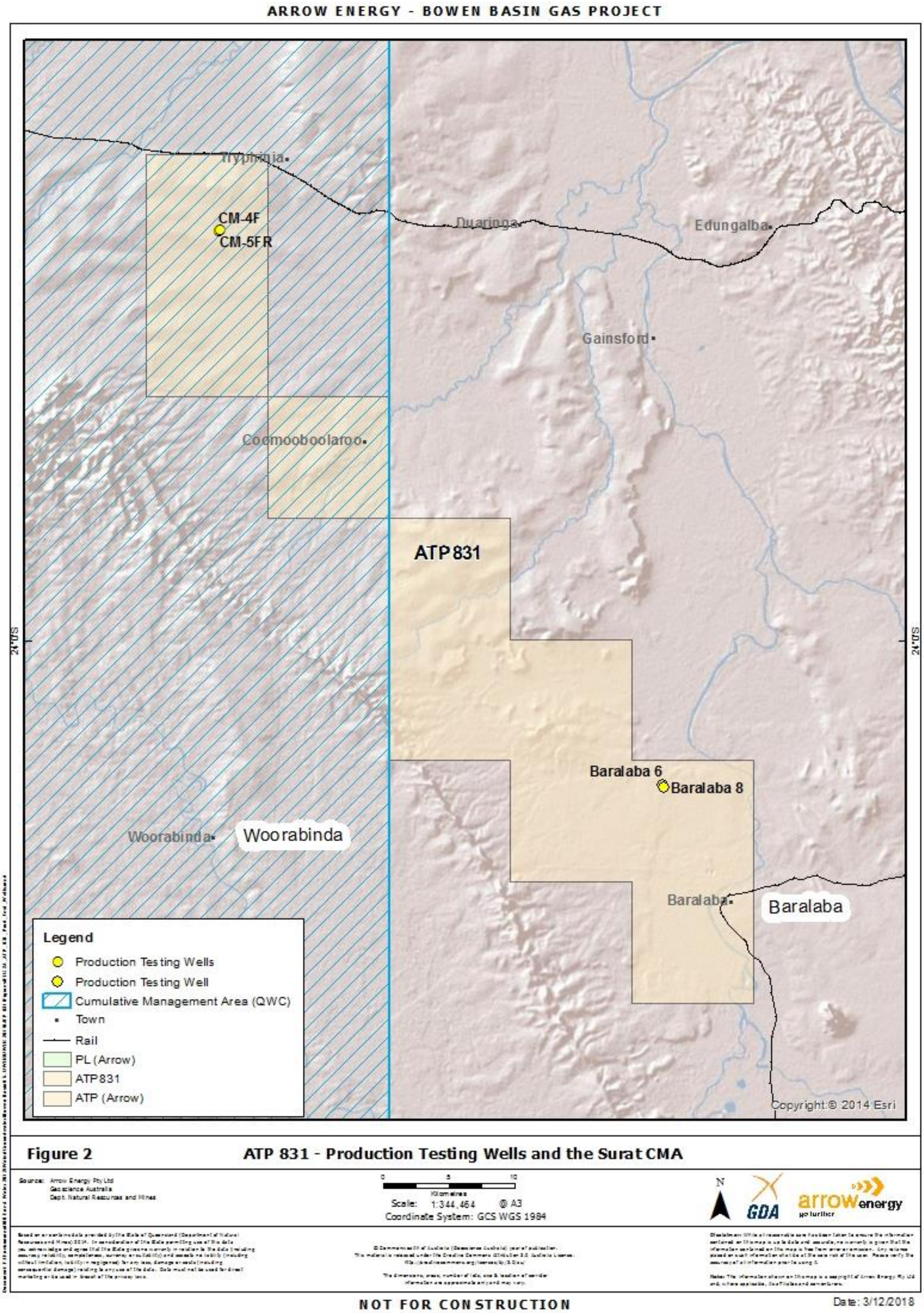

Figure 2: ATP 831 Surat CMA and production testing wells

1.4 Legislation

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

1.4.1 Water Act 2000

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

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

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

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

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

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

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

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

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

1.5 Summary of Methods

This final report builds on information presented in the:

- Bowen Gas Project Environmental Impact Statement (EIS) (Arrow Energy, 2012);
- Bowen Gas Project Supplementary Report to the EIS (Arrow Energy, 2014).
- UWIR for PL 191, 196, 223, 224 and ATP 831, 742, 1031 and 1103 (Arrow Energy 2016)
- 2017 and 2018 Annual Reviews of the UWIR's for PL 191, 196, 223, 224 and ATP 831, 742, 1031 and 1103

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

Following on from the above mentioned groundwater assessments, additional investigations have been undertaken. Collection of new data from site has been presented in this final report to provide an update of the previously developed conceptual models. The latest production testing data has been used to update and review the analytical groundwater model outcomes developed for the 2016 UWIR.

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

- Task 1: Review and analysis of site specific assessment data
- Task 2: Hydrogeological assessment and conceptualisation
- Task 3: Analytical groundwater model development to make predictions of groundwater impacts.
- Task 4: Identification of potential impacts on groundwater

This final report presents an updated analytical model based on the latest production testing data

A summary of the additional reporting requirements as per s377 regarding the content of a final report as stipulated in the *Water Act 2000* for this report have been included in Table 2 below.

Table 2: Content of the final report

Item to address	**Referenced**
1) A final report must include each of the matters mentioned in section 376, other than the following	
(a) an estimate of the quantity of water mentioned in section 376(a)(ii);	Section 2.1
(b) a map mentioned in section 376(b)(iv);	Figure 10
(c) any of the information mentioned in section 376(d);	Section 4.2 and Figure 7
(d) a program mentioned in section 376(e);	Not applicable
(e) if the responsible entity is the office—the proposed responsible tenure holders mentioned in section 376(h)	Not applicable
(2) Also, a final report must include	
(a) a summary of information about all water bores in the area shown on a map mentioned in section 376(b)(v),including the number of bores, and the location and authorised use or purpose of each bore; and	Section 6.1 and 6.2, Figure 10
(b) a summary about how the make good obligations of the responsible tenure holder for each water bore to which the final report relates have been complied with by the holder over the term of the tenure; and	Section 6.1 and 6.2
(c) a summary of the make good obligations of the responsible tenure holder for each water bore that have not yet been complied with by the holder; and	Not applicable
(d) a plan about how the obligations mentioned in paragraph (c) will be complied with	Not applicable

2 WATER PRODUCTION

The historical water production data since the last UWIR 2016 and Annual UWIR's for 2017 and 2018 has been compiled for the production testing wells to provide an indication of the total quantity of water taken over the period 2012 to 2018 and presented in Table 3.

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

2.1 Water Production Summary

Historical water production data for the production testing wells on ATP 831 is summarised in Table 3 below.

Table 3: Summary of Production Testing Volumes in ATP 831

	Data Capture Period	Number of active production testing wells	Total Water Produced (ML)
2016 Bowen UWIR	14 November 2012 – 15 November 15	4	9.903
2017 Annual Review	16 November 2015 – 21 January 2017	2	2.212
2018 Annual Review	22 January 2017 to 31 December 2017	2	3.092
This report	1 January 2018 to 31 December 2018	0	0.000

The cumulative total volume of water produced over the 1757 days of production testing, November 2012 to 31 December 2018, was in the order of 15.207 ML. (~5.91 kl/day).

2.1.1 ATP 831

Historic water production data for the production testing wells in ATP 831 as reported over the periods indicated below, has been summarised in **Table 4**.

Table 4: Summary of Production Testing in ATP 831

Reporting Period	2016 Bowen UWIR					2017 Annual Review					2018 Annual Review					2019 Bowen UWIR					Target Formation
Well Name	**Date Start**	**Date End**	**Total days of water production**	**Average Flow kL/day**	**Cumulative Flow (ML)**	**Date Start**	**Date End**	**Total days of water production**	**Average Flow kL/day**	**Cumulative Flow (ML)**	**Date Start**	**Date End**	**Total days of water production**	**Average Flow kL/day**	**Cumulative Flow (ML)**	**Date Start**	**Date End**	**Total days of water production**	**Average Flow kL/day**	**Cumulative Flow (ML)**	
CM005FR	19-Nov-12	01-May-14	528	10.030	2.958	No Production during 2017 Annual review period					No Production during 2018 Annual review period					No Production during 2019 review period					Baralaba Coal Measures
CM004F	14-Nov-12	22-May-14	554	10.972	3.993	No Production during 2017 annual review period					No Production during 2018 annual review period					No Production during 2019 review period					Baralaba Coal Measures
BR08F	06-Jul-15	15-Nov-15	132	8.843	1.176	16-Nov-15	21-Jan-17	432	6.584	1.330	22-Jan-17	07-Jun-17	136	10.979	0.395	No Production during 2019 review period					Baralaba Coal Measures
BR06F	08-Jul-15	15-Nov-15	130	13.562	1.776	16-Nov-15	21-Jan-17	432	10.376	0.882	22-Jan-17	06-Sep-17	227	21.403	2.697	No Production during 2019 review period					Baralaba Coal Measures
Cumulative Total (ML)					**9.903**					**2.212**					**3.092**					**0.000**	

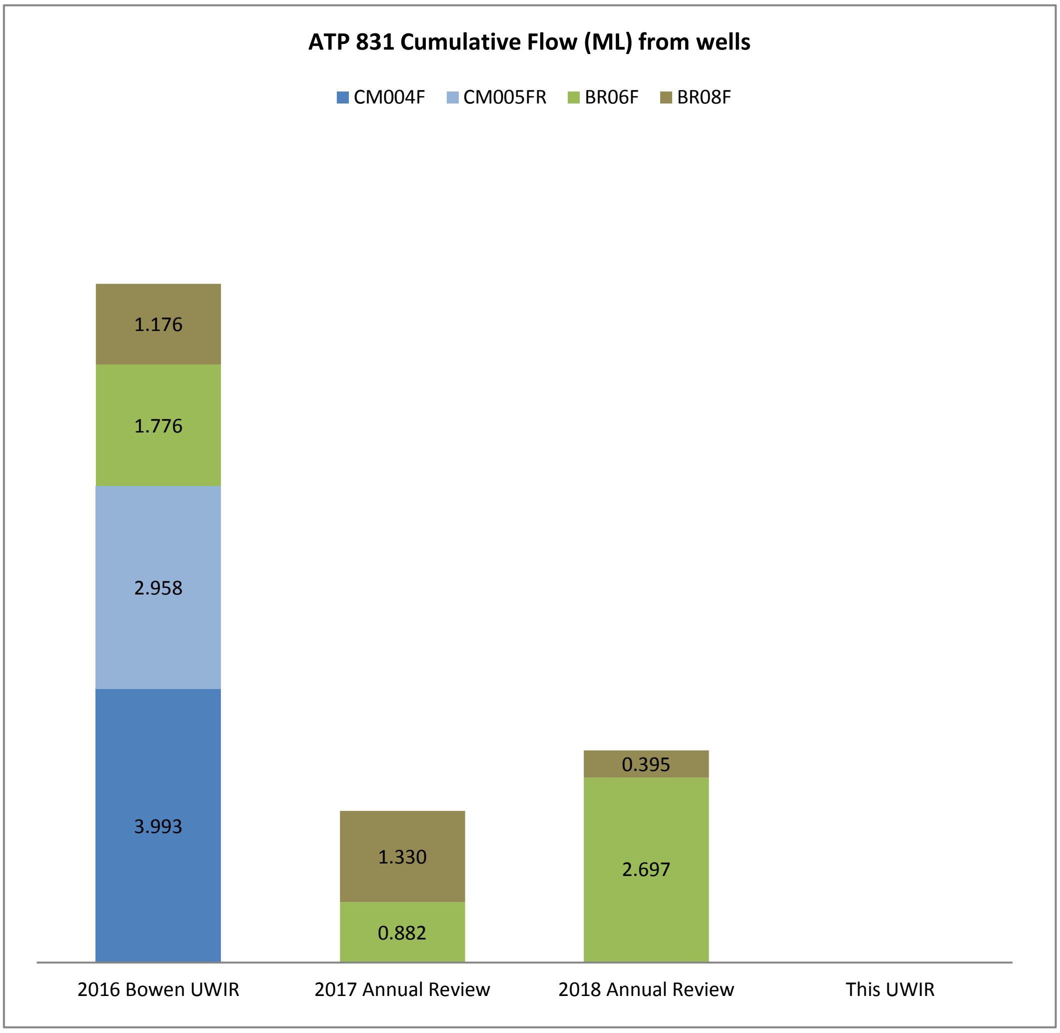

Figure 3: ATP 831 Production Testing Cumulative Totals (ML)

The figure above depicts the changes in the production testing volumes for each reporting period presented in Table 4. The production testing on ATP 831 ceased in September 2017 and the wells were plug and abandoned in October 2018.

3 EXISTING CONCEPTUAL MODEL

The EIS (Arrow Energy, 2012) and SREIS (Arrow Energy 2014) was 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. A summary of the conceptual hydrogeological model (Figure 6), including geology and aquifers is provided in the following sections.

Since the EIS and SREIS, Arrow has undertaken site specific production drilling and testing which provided an update to the understanding of the conceptual hydrogeological model.

3.1 Geological Summary

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

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

The surface geology mapped across the ATP 831 area is shown in Figure 4. The ATP 831 area is covered by Tertiary (Sandstone, mudstone, conglomerate) and Late Tertiary and Quaternary unconsolidated sediments and includes clay, silt, sand, gravel and soil, colluvial and residual deposits.

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 area.

Outcrops of consolidated formations are confined mainly to the northern portion of the Project area. The consolidated formations represented in surface outcrops include: the Late Permian Blackwater Group (Fort Cooper Coal Measures, Moranbah Coal Measures and Rangal Coal Measures) in the northernmost and north-eastern portion of the Project area; the mid-Triassic Moolayember Formation and Clematis Sandstone in the north-central portion of the Project area, and the Early Triassic Rewan Group can be found the northern portion of the Project area.

The stratigraphy of the Bowen Basin is summarised in Table 5. 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) that contain the Baralaba Coal Measures.

Table 5: Regional Stratigraphy Bowen Basin

<table>
<tr><th>Period</th><th colspan="4">Stratigraphic Unit</th><th>Description</th></tr>
<tr><td rowspan="2">Quaternary</td><td colspan="4">Alluvium</td><td rowspan="2">Clay, silts, sand, gravel, floodplain alluvium</td></tr>
<tr><td colspan="4">Alluvium, colluvium and other sediments in floodplains, alluvial fans, and high terraces</td></tr>
<tr><td rowspan="3">Tertiary</td><td colspan="4">Suttor Formation</td><td>Clay, silt, sand, gravel, colluvium, fluvial and lacustrine deposits including cross-bedded quartz sandstone, conglomerate, claystone</td></tr>
<tr><td colspan="4">Basalt</td><td>Olivine rich weathered basaltic sands, weathered basalt, and fresh basalt flows</td></tr>
<tr><td colspan="4">Duaringa Formation</td><td>Mudstone, sandstone, conglomerate, siltstone, oil shale, lignite and basalt</td></tr>
<tr><td rowspan="3">Triassic</td><td colspan="2" rowspan="3">Mimosa Group</td><td colspan="2">Moolayember Formation</td><td>Mudstone, lithic sandstone, interbedded siltstone, mudstone, sandstone and thin coal seams.</td></tr>
<tr><td colspan="2">Clematis Sandstone</td><td>Cross-bedded quartz sandstone, some quartz conglomerate and minor red-brown mudstone.</td></tr>
<tr><td colspan="2">Rewan Formation</td><td>Green lithic sandstone, pebble conglomerate, red and green mudstone</td></tr>
<tr><td rowspan="6">Permian</td><td rowspan="5">Late</td><td rowspan="5">Blackwater Group</td><td colspan="2">Rangal Coal Measures - (Baralaba Coal Measures)</td><td>Coal seams, carbonaceous shale and mudstone, tuff, siltstone and mudstone</td></tr>
<tr><td rowspan="2">Fort Cooper Coal Measures</td><td>Burngrove Formation</td><td>Coal, brown and green sandstone, conglomerate, carbonaceous shale, tuff</td></tr>
<tr><td>Fairhill Formation</td><td>Labile sandstone, quartzose sublabile sandstone, siltstone, mudstone, calcareous and tuffaceous sandstone, volcanic conglomerate, carbonaceous mudstone, coal</td></tr>
<tr><td rowspan="2">Moranbah Coal Measures</td><td>MacMillan Formation</td><td rowspan="2">Quartzose to sublabile, locally argillaceous sandstone, siltstone, mudstone, carbonaceous mudstone and coal</td></tr>
<tr><td>German Creek Formation</td></tr>
<tr><td>Early to Middle</td><td colspan="3">Back Creek Group</td><td>Quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite</td></tr>
</table>

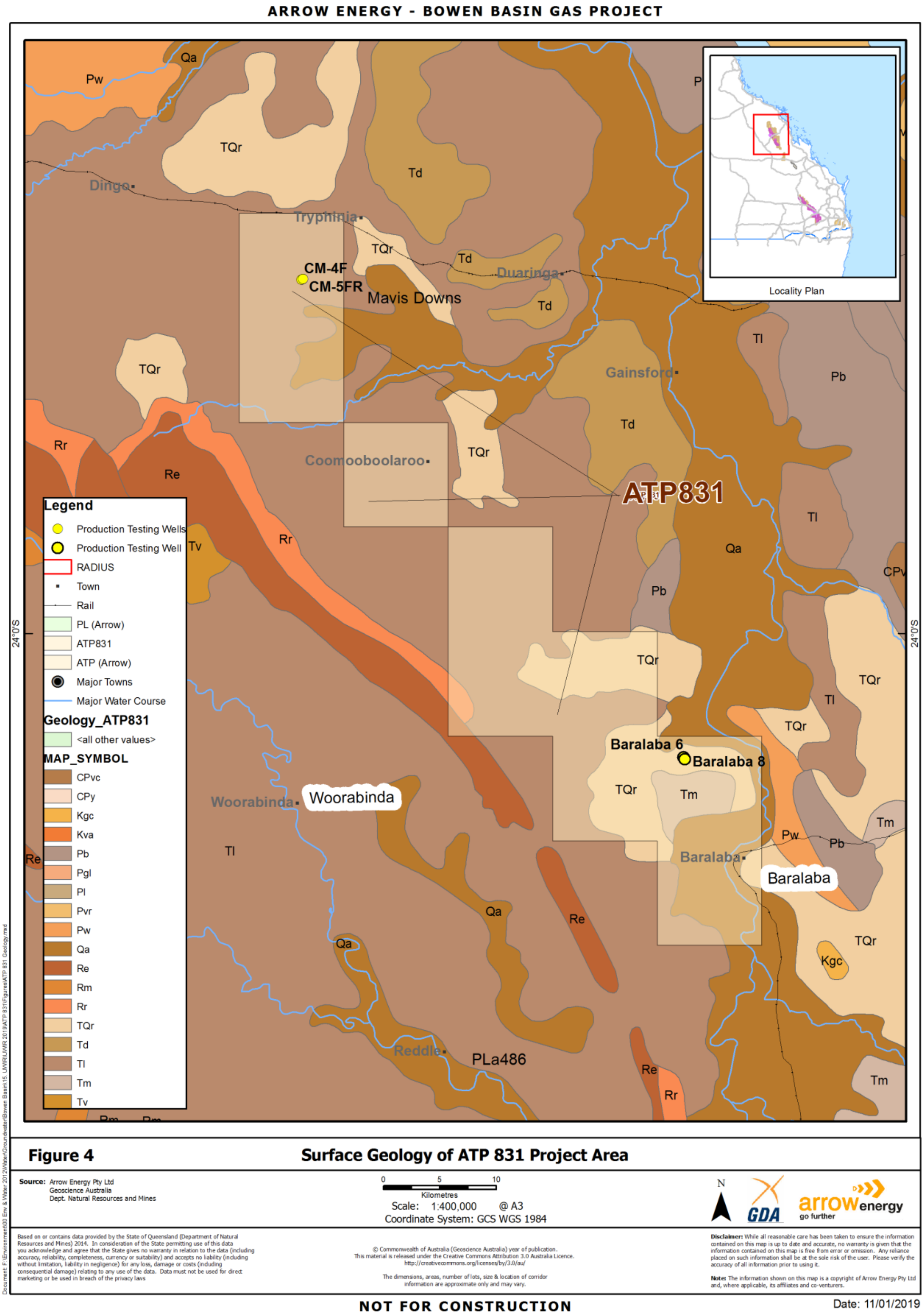

Figure 4: Surface Geology of the Bowen Basin

3.1.1 Target Geological Formations

The principal target in ATP 831 for production testing was the Baralaba Coal Measures within the Rangal Coal Measures.

3.1.1.1 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 5 provides a schematic cross-section through ATP 831 presented as a southwest to northeast orientated section generated from the Arrow geological model using Petrel™ and prepared from the latest geological information.

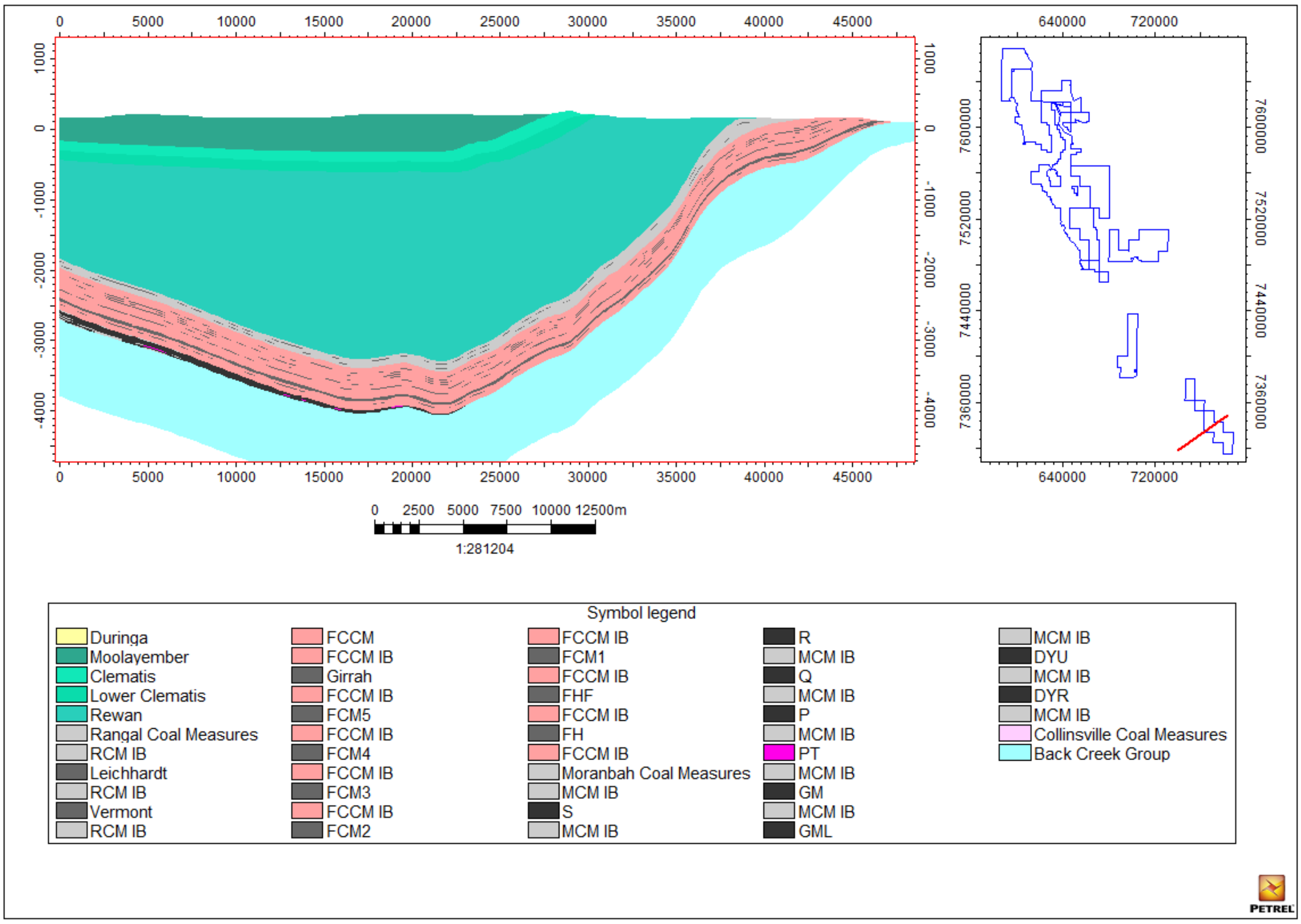

Figure 5: Stratigraphy underlying ATP 831

3.2 Conceptual Hydrogeological Model

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

Table 6: 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 5 and Figure 6 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, 2012) is shown in Figure 6.

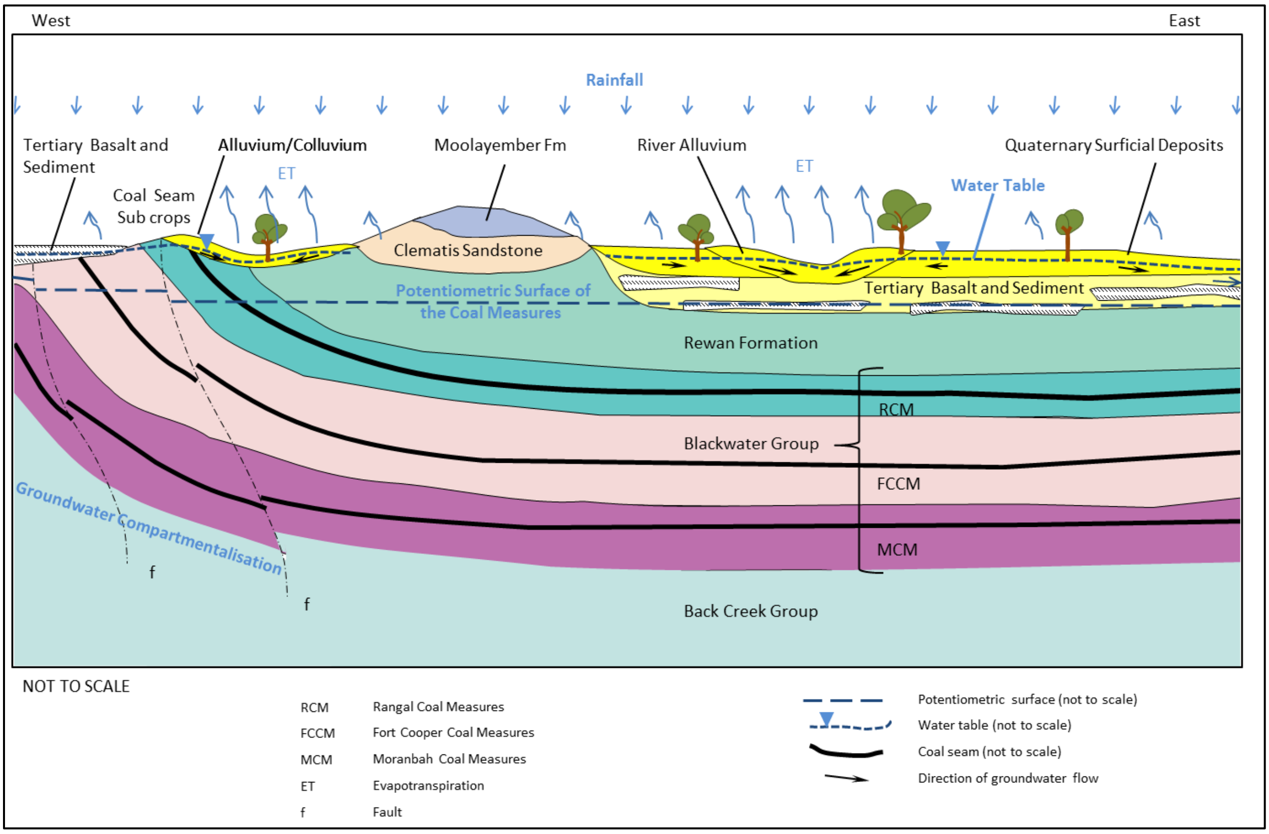

Figure 6: Conceptual Hydrogeological Model (Arrow Energy, 2012)

A summary of the existing understanding of the hydrogeological setting as conceptualised in Figure 6, is provided in the following sections.

3.2.1 Quaternary Alluvium Aquifers

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

Key aquifer characteristics are:

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

3.2.2 Tertiary Sediment Aquifers

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

Key aquifer characteristics are:

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

3.2.3 Triassic Aquifers

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

Key aquifer characteristics are:

- Groundwater may be artesian;
- Clematis Sandstone aquifer has a localised presence to only a few small outcrops in the Project Area;
- The Clematis Sandstone aquifer has moderate to good permeability;
- Recharge is localised and mainly through direct infiltration of rainfall, overland flow and surface water flow in outcrop areas;
- Discharge is localised and generally via through flow into adjacent or underlying older formations and evapotranspiration;
- Groundwater use in the Project Area is unknown. Given the limited extent of this aquifer, groundwater supply is likely to be isolated.

3.2.4 Permian Aquifers

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

Key aquifer characteristics are:

- May contain groundwater from 8 to 55 meters mbgl;
- Confined by low permeability overburden and interburden as well as the overlying Rewan Formation where it exists;
- Low to moderately permeable coal seams;
- Recharge is limited and generally via direct infiltration of rainfall and overland flow as well as downward seepage from overlying aquifers where no clay barriers exist in outcropping/ subcropping areas;

- Discharge is generally through flow into adjacent (outcropping or sub-cropping coal seams) aquifers or seepage into underlying aquifers (via structural discontinuities) and groundwater extraction (CSG, incidental mine gas management, and mine dewatering activities);
- Groundwater quality is generally poor, however varies from being fresh to very saline;
- Groundwater resources associated with the Blackwater Group are typically contained in porous sandstones and fractured shale and siltstones.

4 GROUNDWATER MONITORING

4.1 Groundwater Quality

Groundwater quality monitoring was carried out during the testing phase in CM004F in May 2015 and in BR006 and BR008 in the period August 2015 to December 2015. The pH and Electrical Conductivity average values are shown in Table 7 below.

Table 7: Groundwater Quality

Bore ID	pH	EC (µS/cm)
BR006	7.57	31860
BR008	7.66	29433
CM004F	7.66	11300

The groundwater monitoring results indicate the groundwater quality in the Baralaba Coal Seam is classed as saline (Environmental Protection Agency (EPA) of South Australia). The groundwater is too saline for livestock use.

4.2 Groundwater Use

Data from the Department of Natural Resources, Mines and Energy (DNRME) Groundwater Database indicates four existing water supply bores are located within ATP 831, shown on Figure 7. The relevant bore information available on the database has been included in Table 8.

Only the existing water bores have been included in the table below.

Table 8: DNRME Groundwater Database Bores

Bore ID	Formation	Depth (mbgl)	Aquifer
88711	Tertiary - Undefined	No information	No information
151828	No information	No information	Cainozoic Sediments
91870	Duaringa Formation	55.00	Cainozoic Sediments
33410	Cainozoic Sediments	33.00	Cainozoic Sediments

No water supply bores are located within 2 km from the production testing wells. Therefore no baseline assessments have been carried out.

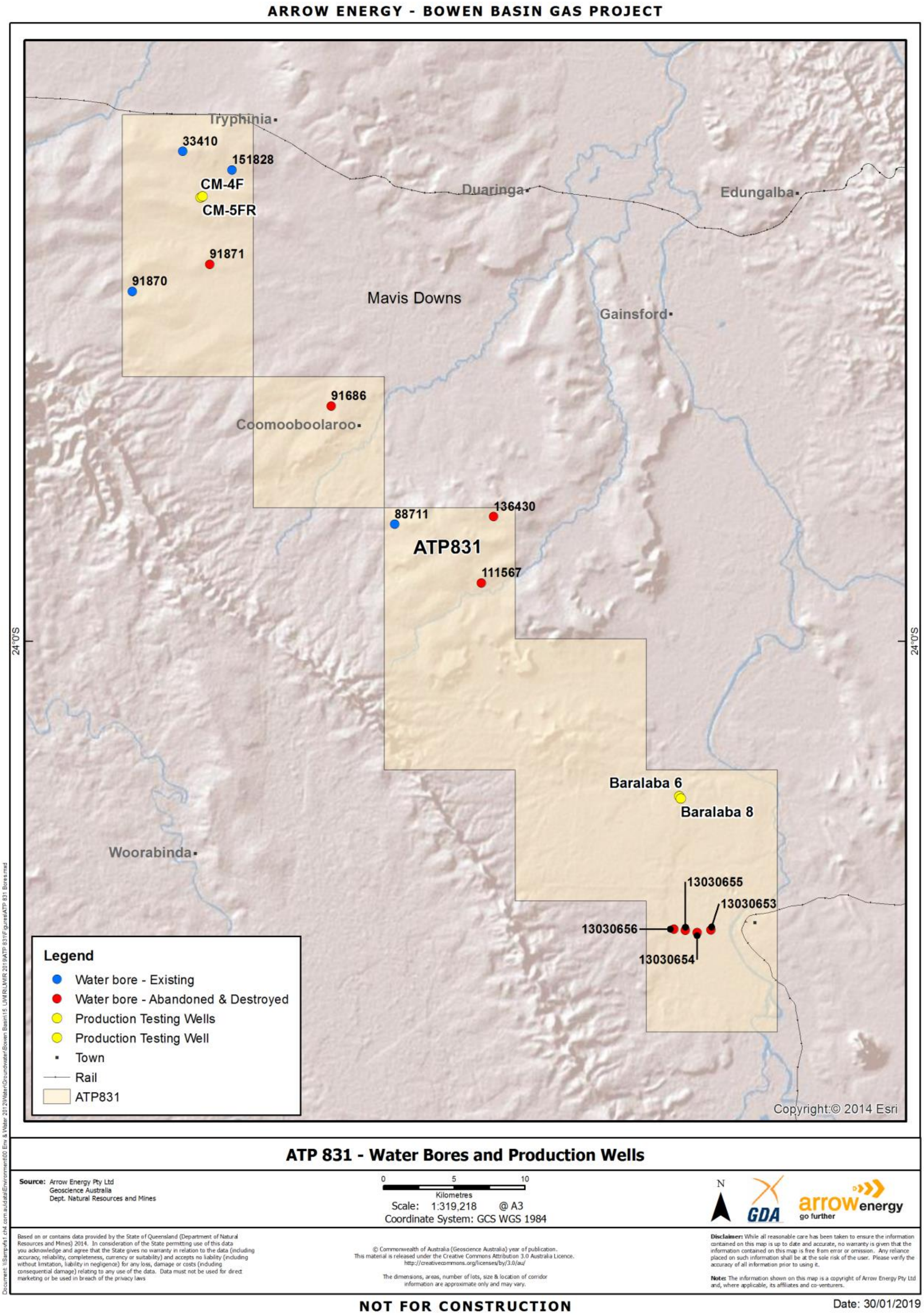

Figure 7: DERM Database Bores

5 UPDATED ANALYTICAL GROUNDWATER MODEL

As per the 2016 UWIR, an analytical technique has been used to assess impacts associated with production testing from the 4 wells located on ATP 831.

5.1.1 Analytical Groundwater Model

Production testing occurs over a limited time for each bore and abstracts a finite amount of water. Section 2 provides details of water production associated with production testing ATP 831.

The four production testing wells in ATP 831 fall outside the Bowen Numerical Model domain that was used in the Bowen UWIR 2016. Analytical modelling has previously and again been used to provide estimates of decline in water level in response to the abstraction of groundwater associated with production testing in the production testing wells. This is described in more detail in the following sections.

5.1.1.1 Analytical Model Set Up

A two dimensional analytical solution has been used to assess the potential impacts of groundwater extraction as a result of production testing undertaken in the wells at ATP 831. Multi-Layer Unsteady state (MLU) for Windows has been used to compute drawdown associated with this production testing. MLU for Windows combines:

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

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

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

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

The model has been set up into 3 layers to represent the target coal seam Baralaba Coal Measures aquifer, the Rewan Formation aquitard and the shallow Quaternary alluvium aquifer. Based on the groundwater assessment undertaken for the Bowen Gas Project EIS, the hydraulic properties of each of the major hydrostratigraphic units were estimated as low, base case, and high values. It should be noted that the production testing wells have been installed in the Baralaba Coal Measures which are equivalent to the Rangal Coal Measures in the north of the basin. The vertical hydraulic conductivity (Kv) ranges from 0.00001 – 0.001 m/day for the Rewan Formation, 0.0001 – 0.005 m/day for the Rangal Coal Measures, and 0.02 – 2 m/day for the Quaternary Alluvium. The storage values range from 0.00005 - 0.0005 for the Rewan Formation and the Rangal Coal Measures, and 0.0005 – 0.005 for the Quaternary Alluvium.

The values used for the analytical model are shown in the below table and represent the “base case” in line with the numerical groundwater model.

Table 9: Layers and parameters used for the analytical model set up

Model Layer	Aquifer/Aquitard	Thickness (m)	Kh (m/day)	Kv (m/day)	Storage
Layer 1	Quaternary Alluvium	50	2	0.2	0.0005
Layer 2	Rewan Formation	399	0.001	0.0001	0.00005
Layer 3	Rangal Coal Measures	167	0.005	0.0005	0.00005

6 PREDICTION OF IMPACTS

The predictions on the decline in the water level based on the analytical model results due to Arrow's production testing are discussed in more detail below.

The production tests carried out in Coomooboolaroo (CM005FR and CM004F) and Baralaba (BR006 and BR008) are discussed in more detail below. A summary of the testing carried out in each area has been tabulated below.

Table 10: Production test data

Production Well Name	Total days of water production	Average Cumulative Flow (kl/day)	End date of the production testing
CM005FR CM004F	554	12.80	22/05/2014
BR006 BR008	789	10.92	07/09/2017

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. The trigger thresholds are specified in the *Water Act 2000* and they are 5 m for consolidated aquifers (such as sandstone) and 2 m for unconsolidated aquifers (such as sands).

The IAA resulting from production testing has been estimated based on analytical model predictions for impacts at each of the production testing well pads based on the volumes abstracted (Table 10) over the number of production testing days.

The two production testing areas are discussed in more detail below.

6.1.1 Coomooboolaroo Production tests

- The groundwater level has recovered to the original water level prior to the production test being carried out.
- The IAA therefore no longer exists in and around the production testing well pad.

6.1.2 Baralaba Production tests

- The water level has recovered to > 90% of the original water level prior to the production tests being carried out.
- The IAA therefore no longer exists in and around the production testing well pad.

6.2 Long Term Affected Area (LAA)

The LAAs for the two production testing areas, where the water level is predicted to decline by more than the bore trigger threshold at any time, is discussed in more detail below.

6.2.1 Coomooboolaroo Production tests

- The production testing resulted in a water level drawdown exceeding the 5m trigger threshold at a distance of up to a maximum 850m from the production testing well. The extent of the LAA is shown on Figure 10.
- The water level exceeded the 5m bore trigger threshold for 603 days (on 10/07/2014) after testing commenced.

The table below provides the calculated maximum drawdown at distances from the production testing wells and the number of days after testing commenced.

Table 11: Maximum drawdown over distance

Distance from pump wells (m)	Max drawdown (m)	Number of days since start of the test
1000	3.58	612
900	4.52	607
850	5.07	603
800	5.71	603
500	12.07	590
100	45.67	583
10	101.42	583

As indicated in the Table 11, the 5m trigger threshold is located approximately of 850m from the production testing wells. As to be expected, the presented maximum drawdowns decrease with increased distance from the production testing wells. In Figure 8 the maximum drawdown over distance is graphically presented.

6.2.2 Baralaba Production tests

- The production testing resulted in a water level drawdown exceeding the 5m trigger threshold at a distance of up to a maximum 800m from the production testing well. The extent of the LAA is shown on Figure 10.
- The water level exceeded the 5m threshold 820 days (on 08/10/2017) after production testing commenced.

Table 12 below provides the calculated maximum drawdown at distances from the production testing wells and the number of days after testing commenced.

Table 12: Maximum drawdown over distance

Distance from pump wells (m)	Max drawdown (m)	Number of days since start of the test
1000	3.23	831
800	5.08	820
750	5.70	819
500	10.55	806
250	21.64	802
100	39.23	794
10	86.72	791

As indicated in the Table 12, the 5m trigger threshold is located approximately of 800m from the production testing wells. In Figure 9 the maximum drawdown over distance is graphically presented.

The following key observations about the LAA are as follows:

- The extent of the LAAs for the production testing wells in the Baralaba Coal Measures at the location of the two production testing locations is shown in Figure 8 and Figure 9.
- The LAA for the Baralaba Coal Seam was localised within the immediate vicinity of the production testing wells.
- The LAA presented in Figure 8 and Figure 9 represents the maximum drawdown over distance that occurred as a result of the production testing.
- No “make good” required due to the following:
    - The 5m LAA area constrained around production wells
    - Groundwater levels have recovered back to levels prior to production testing at Coomooboolaroo and > 90% at Baralaba.
    - There are no water supply bores within 2km from the production testing wells

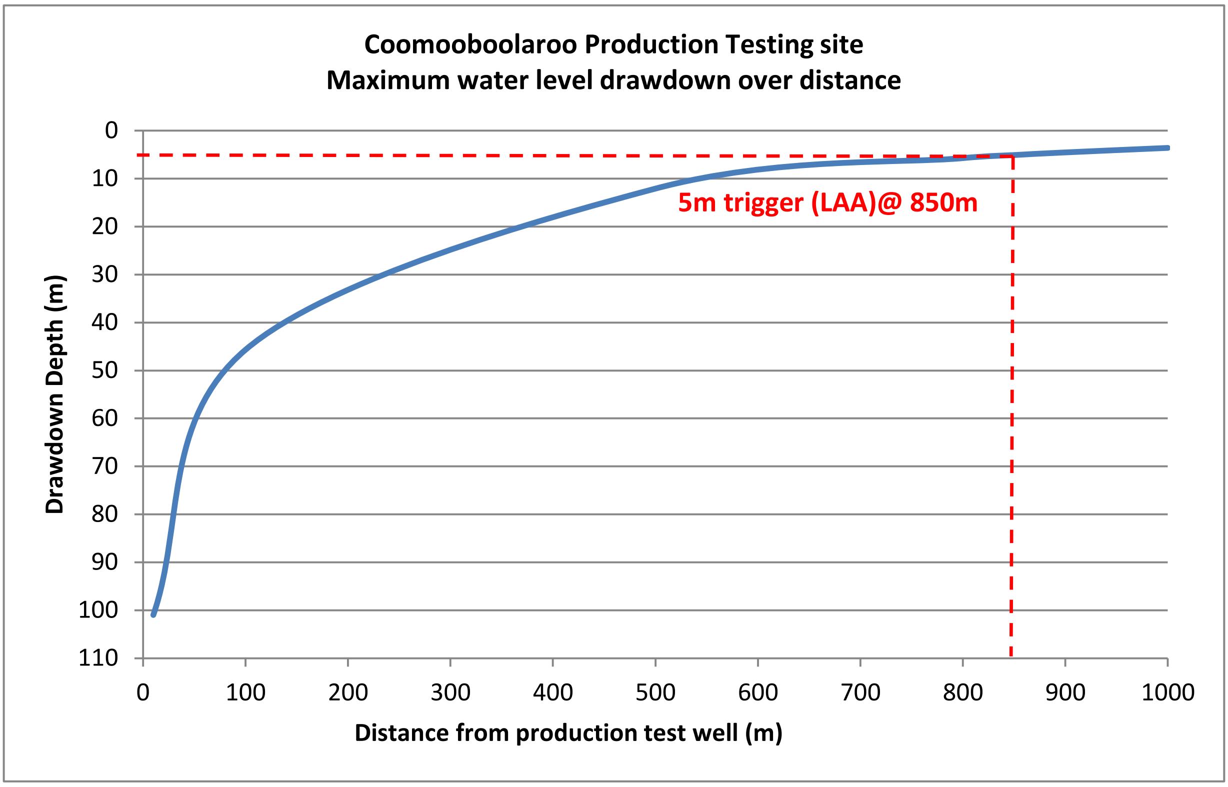

Figure 8: Water level drawdown over distance

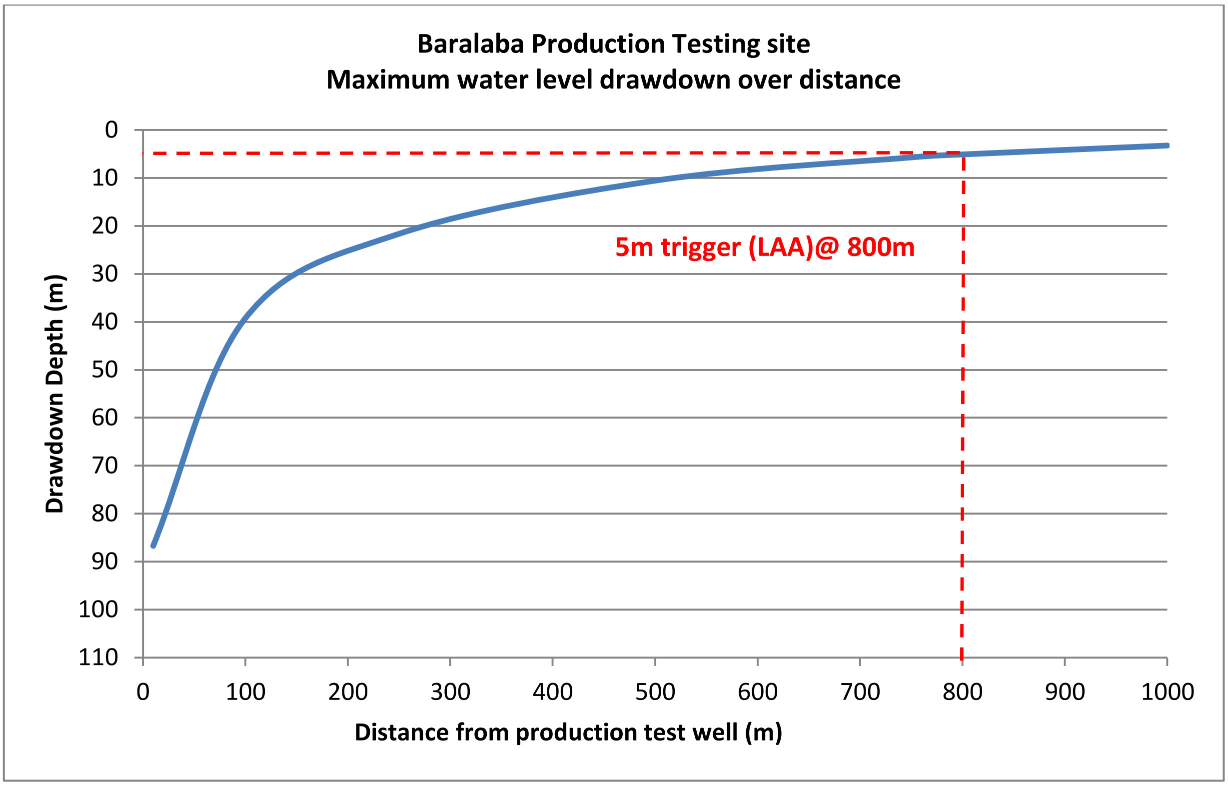

Figure 9: Water level drawdown over distance

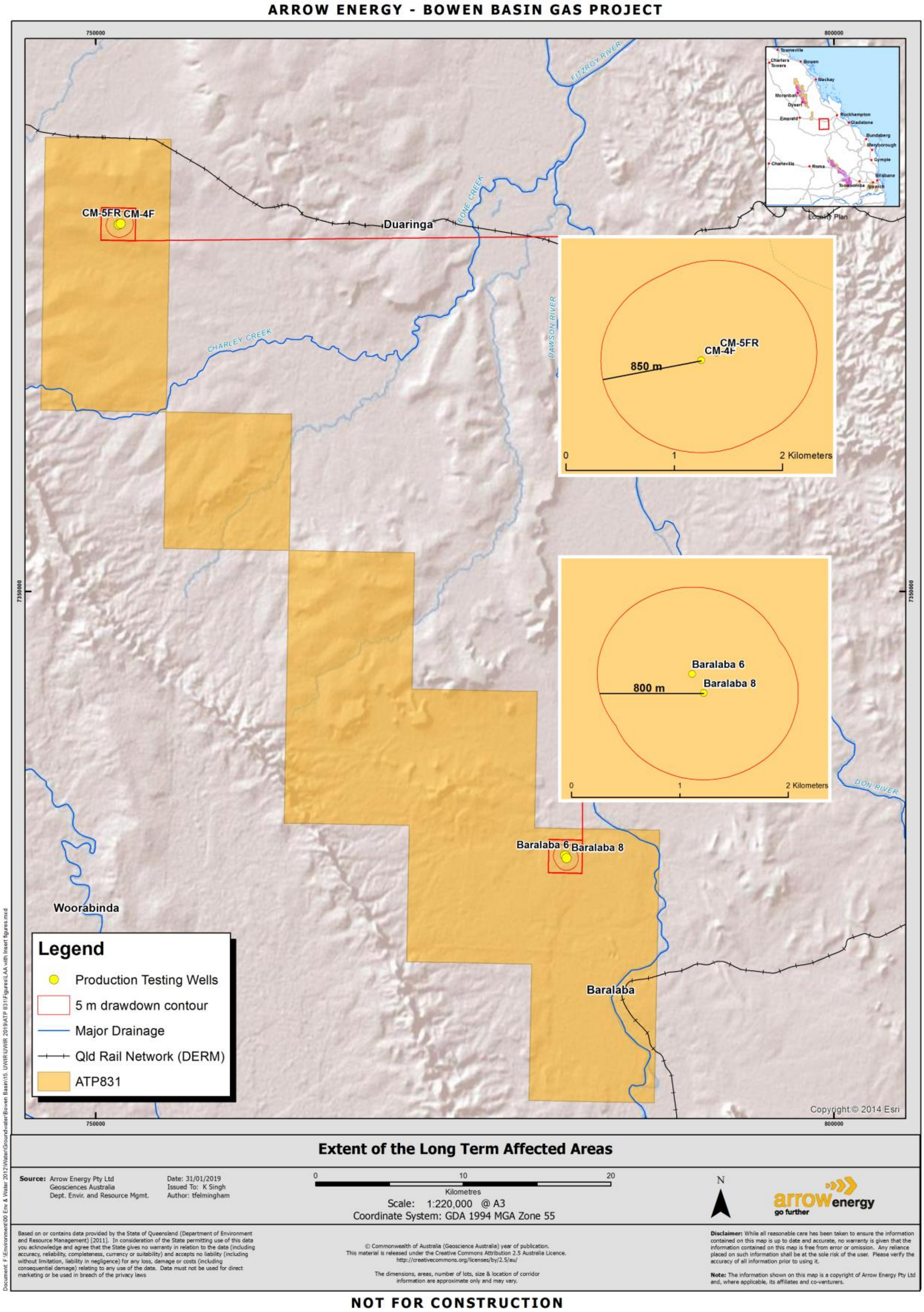

Figure 10: Extent of LAA at Production Testing Wells

7 SPRINGS

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

- 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 complex or watercourse springs. Spring vents are a single point in the landscape where groundwater is discharged at the surface. A spring complex is a group of spring vents located in close proximity to each other. A watercourse spring is a section of a watercourse where groundwater enters the stream from an aquifer through the stream bed. DES maintains an inventory of identified springs in the Queensland Springs Dataset

Based on this data, the springs (Palustrine springs) identified proximal to Arrow project tenure are found to the west and south-west of ATP 831 (illustrated in Figure 11), lying in the Mimosa Creek sub-catchments of the Dawson/Mackenzie River catchments. These springs are located greater than 20km south west of the northern Coomooboolaroo production testing wells

Arrow has undertaken limited production testing at four locations within ATP 831 tenure (at the Baralaba and Coomooboolaroo sites). Appraisal testing for the tenement ceased in 2017. Predicted impacts to the identified springs, as a result of the production testing within the ATP 831, are considered to be negligible. As such, impacts to these springs as a result of the production testing was not considered further in this UWIR and a Spring Impact Management Strategy was not be prepared as part of this UWIR.

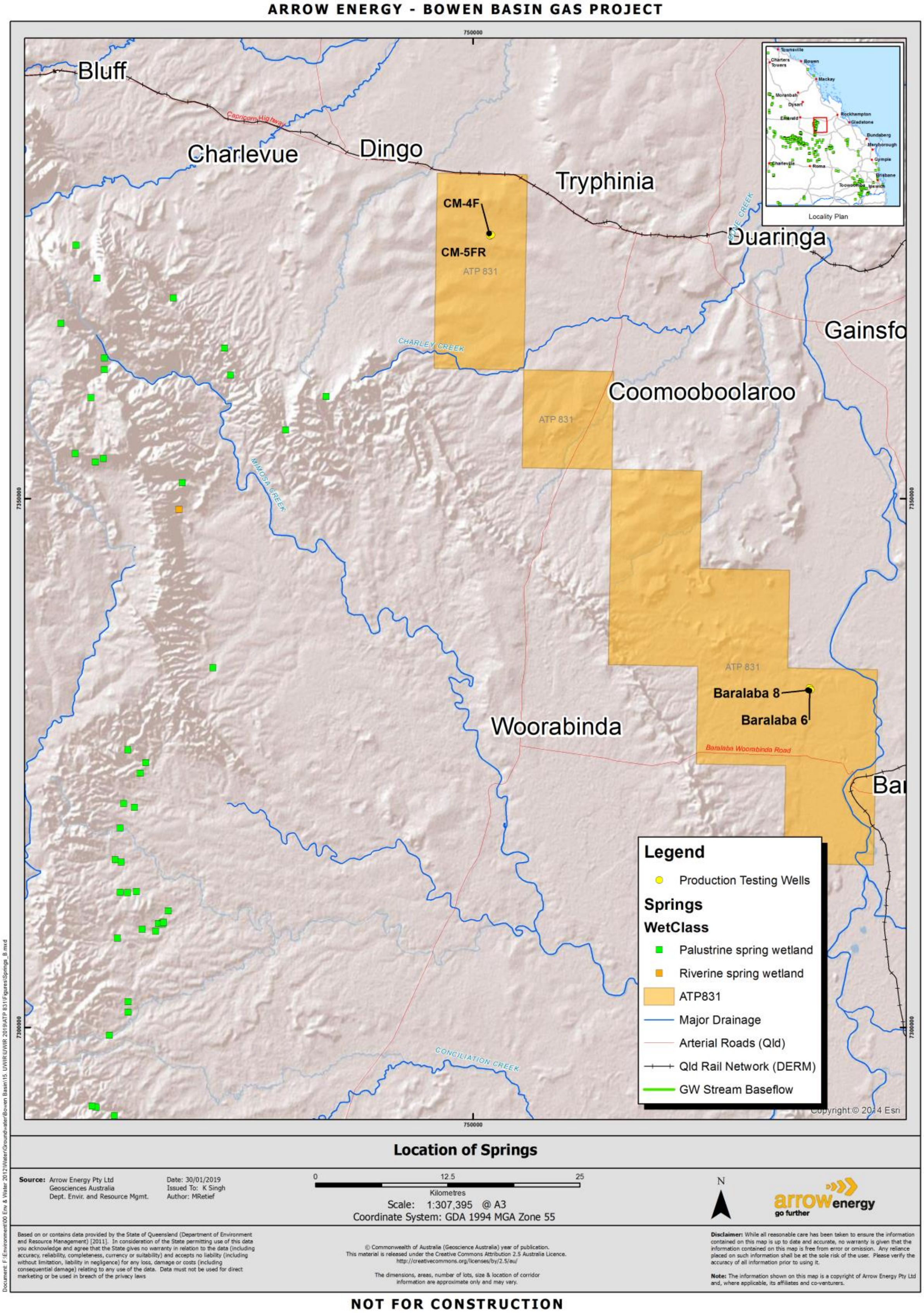

Figure 11: Location of Springs

8 SUMMARY AND CONCLUSION

The document serves as the final report for ATP 831 after relinquishment in October 2018 and addresses all matters as per s377 of the Water Act 2000.

No further production testing has taken place on ATP 831 since September 2017 as reported in the last Annual Review of the UWIR submitted and approved in 2018. The production testing wells in ATP 831 were plugged and abandoned in 2018.

The key findings for ATP 831 are:

- An IAA was predicted for production testing wells on ATP 831 in the 2016 Bowen UWIR.
- A review was carried out using the latest analytical model predictions of impacts and the Immediately Affected Area (IAA) was revised in accordance with the production testing water volumes and abstraction periods.
- The LAA's are highly localised around the production testing wells indicating minimal lateral impacts.
- No "make good" required due to the following:
    - The 5m LAA is located within the immediate vicinity of the production testing wells.
    - Groundwater levels have recovered back to levels prior to production testing at Coomooboolaroo and > 90% at Baralaba.
    - No water supply bores within 2km from the production testing wells

The finding indicates there are likely to be minimal impacts remaining from the production testing carried out on ATP 831

Glossary

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

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

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

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

Term	Meaning
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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