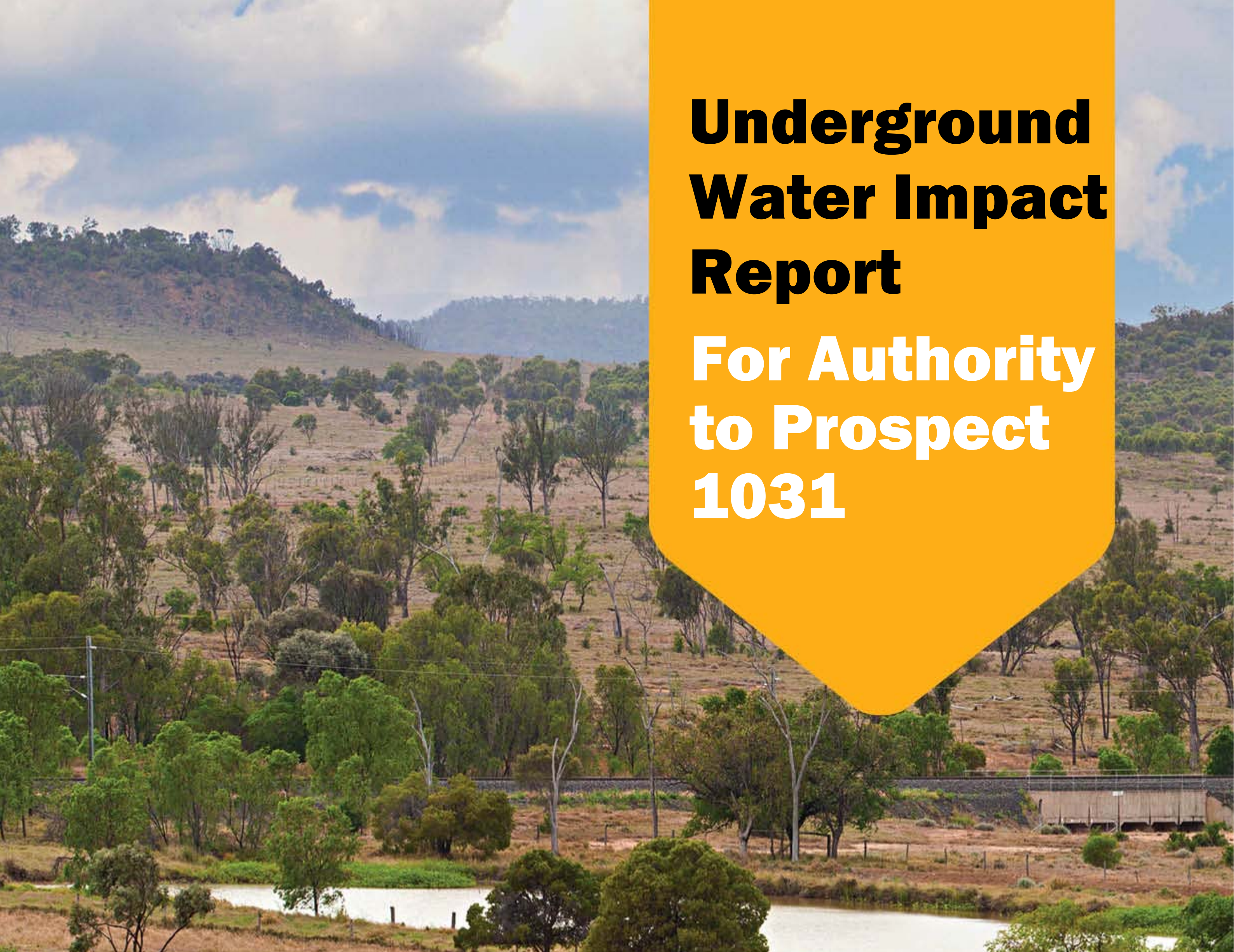

Underground Water Impact Report

For Authority to Prospect 1031

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February 2014

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EXECUTIVE SUMMARY

This report provides information on the potential decline in water levels in aquifers within Authority to Prospect (ATP) 1031 as a result of the taking of water during production testing by Bow CSG Pty Ltd.

The report 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;
- a description of aquifers potentially affected including how the aquifer interacts with other aquifers;
- the predicted water level decline as a result of the taking of water and a description of the methods and techniques used to make the prediction;
- information on water bores that may be impacted by a water level decline in excess of the bore trigger threshold; and
- a program for conducting an annual review of the predictions.

Production testing was undertaken on ATP1031 in wells PY030 and PY031. Limited volumes of water (~0.3ML) were taken during the production testing which was carried out between December 2012 and October 2013. It is concluded that there are no impacts to groundwater resulting from extraction of underground water during and after production testing within ATP1031. The following findings support this conclusion:

- Analytical modelling indicates an extremely limited radius of extent (7.5 m) and duration (~5 days) of water level decline in excess of the bore trigger threshold within the Rangal Coal Measures (RCM) for well PY030, following which water level decline is less than 5 m
- Analytical modelling indicates no water level decline by more than the bore trigger threshold (of 5m) for well PY031
- Shallower aquifers are separated from the perforated intervals of the production testing wells by intervening lower permeability formations which are up to 443 m thick. Based on this, there are no expected impacts as a result of production testing to the shallow aquifers.
- The nearest registered landholder bore is located ~2.8 km away from the production testing wells and will not be impacted by the production testing that has been undertaken at PY030 and PY031

It should be noted that baseline bore assessments have been completed at ATP1031 for pilot test wells PY030 and PY031. No landholder bores were found to exist with a 2km radius of the two pilot testing wells.

1 INTRODUCTION

This report provides information on the potential decline in water levels in aquifers within Authority to Prospect (ATP) 1031 because of the taking of water during production testing undertaken by Bow CSG Pty Ltd.

The registered holder of Authority to Prospect No. 1031 (**ATP1031**) is Bow CSG Pty Ltd ACN 117156742 (100%) (**Registered Holder**).

The subject ATP spans the area around the towns of Dysart and Middlemount in central Queensland.

The state government may declare cumulative management areas (CMAs) in areas of concentrated Coal Seam Gas (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. Bow's operations in the Bowen Basin falls outside of this CMA, and under the *Water Act 2000*, there is a requirement to prepare an Underground Water Impact Report (UWIR). This report forms the UWIR for Bow's CSG Operation contained within the bounds of the ATP1031.

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

a) For the area to which the report relates –

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

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

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

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

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

e) A program for –

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

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

h) A water monitoring strategy;

i) A spring impact management strategy;

j) Other information or matters prescribed under a regulation.

1.1 Legislation

The primary legislative requirements for the management and development of groundwater for the ATP1031 are summarised below.

1.1.1 *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. ATP1031 is permitted under the P&G Act (2004).

Under the P&G Act, the petroleum tenure holder may take or interfere with groundwater to the extent that it is necessary and unavoidable during the course of an activity authorised under the petroleum tenure.

P&G Act, 2004 and the Petroleum Act 1923 require tenure holders to comply with underground water obligations specified in the *Water Act 2000* Chapter 3.

1.1.2 *Water Act 2000*

The *Water Act 2000:*

- Provides a comprehensive regime for the planning and management of all water resources (including vesting to the State the rights over the use, flow and control of all surface water, groundwater, rivers and springs) in Queensland.
- Regulates water use and the obligations of coal seam gas producers in relation to groundwater monitoring, reporting, impact assessment and management of impacts on other water users.
- Provides a framework and conditions for preparing a Baseline Assessment Plan and outlines the requirements of bore owners to provide information the petroleum holder reasonably requires to undertake a baseline assessment of any bores.
- Sets out the process for applying for a Water Licence (where water is to be utilised outside of a Petroleum Lease or not on adjacent land owned by the same person).
- Sets out the process for assessing, reporting, monitoring and negotiating with other water users regarding the impact of coal seam gas production on aquifers.

The management of impacts on underground water caused by the exercise of underground water rights by petroleum tenure holders is achieved primarily by:

a) 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

b) giving the Office of Groundwater Impact Assessment (OGIA) 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 (IAA) will result from CSG activities. An IAA 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 Bow, addressed as appropriate and provided to the Department of Environment and Heritage Protection (DEHP). UWIRs are submitted for approval by DEHP. The OGIA may also advise DEHP about the adequacy of these reports.

The OGIA 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.

1.2 Summary of Methods

An assessment of impacts to groundwater from the production testing activities incorporates the following methodology:

- Desktop literature review and data gap analysis
- Hydrogeological assessment and conceptualisation
- Identification of potential impacts on groundwater
- Development of mitigation, management and monitoring plans

The literature review is based on publically available data and reports concerning the hydrogeology of the Bowen Basin. The data collated and the information sourced included:

- Extracts from the Department of Natural Resources and Mines (NRM) (formerly DERM) groundwater database of: bore registrations, aquifer descriptions, stratigraphy, casing details, facility, groundwater quality, and monitored groundwater levels (where available);
- Extracts from the NRM Water Entitlements Registration Database (WERD) and Water Management System[1] (WMS) including entitlement registration, status, issuance, nominal volume, works type and location by lot and plan for the bores and consumed water;
- Bowen Gas Project Environmental Impact Statement, Arrow Energy
- A number of reference documents and data sets as listed in the References section at the end of this report

A desktop review of this data was undertaken to provide input into the development of the conceptual hydrogeological model for the operations on the ATP1031 lease. The conceptual understanding of the groundwater occurrence and processes form the basis for the development of an analytical groundwater model. The model was developed in order to predict potential impacts to groundwater and underpin the development of management strategies.

A summary of the reporting requirements as stipulated in the *Water Act 2000* for this UWIR and relevant sections of this report in which they have been addressed is included in Table 1 below.

[1] The NRM management of groundwater and surface water entitlements is called the Water Entitlements System. The database that contains the entitlement records, such as client details, applications, licences, works, conditions etc., is called the Water Management System (WMS). The WMS replaced the Water Entitlements Registration Database (WERD) in 2009.

Table 1: *Water Act 2000* reporting requirements for this UWIR

UWIR reporting requirement	Report Section
a) For the area to which the report relates – i. The quantity of water produced or taken from the area because of the exercise of any previous relevant underground water rights; and	Section 2
ii. An estimate of the quantity of water to be produced or taken because of the exercise of the relevant underground water rights for a 3 year period starting on the consultation day for the report;	Section 2
b) For each aquifer affected, or likely to be affected, by the exercise of the relevant underground water rights– i. A description of the aquifer; and	Section 3
ii. An analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and	Section 3
iii. A description of the aquifer; and	Section 3
iv. An analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and	Section 3
v. An analysis of the trends in water level change for the aquifer because of the exercise of the rights mentioned in paragraph (a)(i); and	Section 5
vi. A map showing the area of the aquifer where the water level is predicted to decline, because of the taking of the quantities of water mentioned in paragraph (a), by more than the bore trigger threshold within 3 years after the consultation day for the report; and	Section 5
vii. A map showing the area of the aquifer where the water level is predicted to decline, because of the exercise of relevant underground water rights, by more than the bore trigger threshold at any time;	Section 5
c) A description of the methods and techniques used to obtain the information and predictions under paragraph (b);	Section 5
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;	Not applicable see Section 5
e) A program for – (a) Conducting an annual review of the accuracy of each map prepared under paragraph (b)(iv) and (v); and	Section 8
(b) Giving the chief executive a summary of the outcome of each review, including statement of whether there has been a material change in	Section 8

UWIR reporting requirement	Report Section
the information or predictions used to prepare the maps;	
f) A water monitoring strategy;	Not applicable – see Section 6
g) A spring impact management strategy;	Not applicable – see Section 7
h) If the responsible entity is the OGIA – i. A proposed responsible tenure holder for each report obligation mentioned in the report; and	Not applicable to ATP1031
ii. For each 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 ATP1031
i) Other information or matters prescribed under a regulation.	No matters identified
S378 1(a) (i) Water Monitoring Strategy	No IAA or LAA identified. See Section 6
i. Strategy for monitoring the quantity of water produced	
ii. Strategy for monitoring changes in water level	
(b) Rationale for the strategy	
(c) Timetable for implementing the strategy	
(d) Program for reporting the implementation of the strategy	
2 Strategy must include:	
(a) The parameters to be measured	
(b) Locations for taking the measurements	
(c) Frequency of the measurements	
3 A program for a baseline assessment for each bore that is:	
(a) Outside the tenure, within an IAA or Long Term Affected Area (LAA)	

2 BOWEN BASIN OPERATIONS

The spatial distribution of Bow's ATP1031 in the Bowen Basin is shown in **Figure 1**.

2.1 Project Area

ATP1031 is the subject of exploration activities for CSG. The project area for which this UWIR will be focussed on encompasses the entirety of the ATP1031 lease (referred to herein as the project area). Production testing for CSG on ATP1031 has been undertaken in two wells between December 2012 and October 2013 as summarised in **Table 2**. The locations of these wells are shown in **Figure 1**.

2.2 Water Production Schedule

Available historical water production data has been compiled for the production testing wells to provide an indication of the quantity of water taken for ATP1031 as is summarised in **Table 2**. This indicates an average of approximately 1.3 kL/day during testing and a cumulative total of approximately 300 kL of water. It should be noted that production testing in both of the wells was intermittent over the total time period. The greatest duration of continuous production testing for each of the wells was 24 days.

Progressive cavity pumps (PCPs) were used in the production test wells. A PCP pump includes a helical moving screw inside a matching cover.

The pumps are driven at surface via a hydraulic drive head powered by an electric motor. The manufacturers specifications provide each pump with a theoretical pump rate. The discharge is measured in the field to assess the actual pumping rate at a specified pump speed. Based upon this a pump efficiency number is calculated and entered into the pump monitoring system. The volume of water produced is then calculated from the actual pump speed and efficiency.

Table 2: Summary of Production Testing in ATP1031

Well Name	Date Start	Date End	Total days of water production	Average Flow kL/day	Cumulative Flow (kL)	Target Formation
PY030	20/12/2012	22/10/2013	38	1.631	205.531	Rangal Coal Measures
PY031	29/07/2013	22/10/2013	27	0.939	73.267	Rangal Coal Measures
Average Flow (kL/day)				1.285		
Cumulative Total (kL)					278.798	

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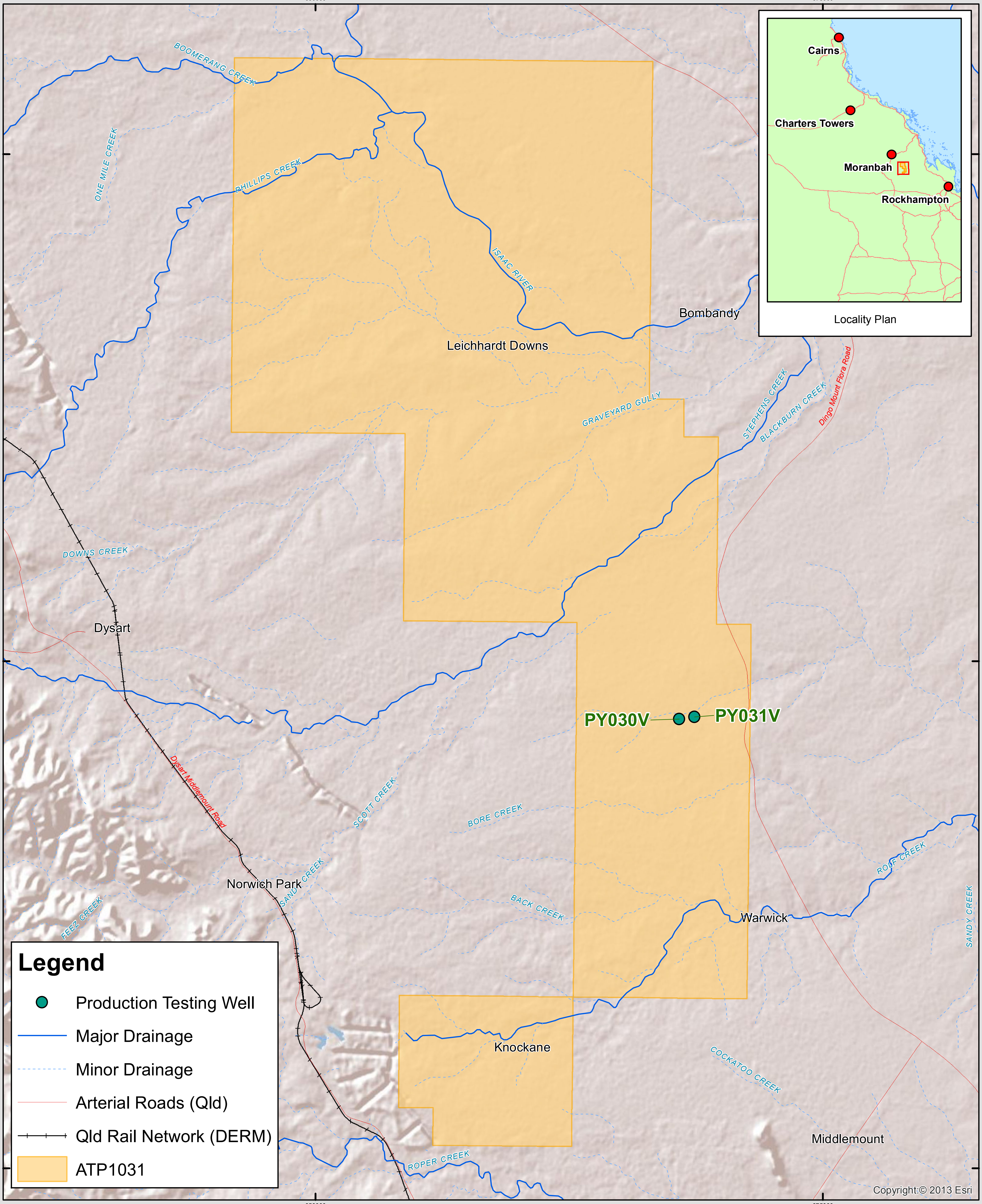

Figure 1- **Bow's ATP1031 Tenements in the Bowen Basin**

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

Date: 18/02/2014
Issued To: K Prasad
Author: tstringer

0 5 10
Kilometres

Coordinate System: GDA 1994 MGA Zone 55

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

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NOT FOR CONSTRUCTION

2.2.1 *Forecast 2013/2014 Appraisal Program*

Given that only pilot testing is planned for ATP1031, an estimate of the quantity of water to be produced or taken for a 3 year period starting on the consultation day for the report cannot be provided. A forecast of the 2013/2014 production testing program for ATP1031 can, however, be provided and is shown in the table below.

Table 3: Forecast 2013/2014 Appraisal Program

Type	Project Name	Wells
Pilot Testing	Picardy	PY(11-12), PY(30-31)
Pilot Testing	Vermont	VM (10-11)

3 EXISTING HYDROGEOLOGICAL REGIME

3.1 Geological Summary

Formed in three distinct phases, the Bowen Basin, (which includes the ATP1031) overlies the Early-Palaeozoic metamorphic and sedimentary strata of the Drummond Basin and Anakie Block. Figure 2 below provides an overview of the geological evolution of the Bowen Basin.

Commencing in the Early-Permian, a period of extension produced a series of isolated fault-bounded basins. In the case of the Bowen Basin, subsequent partial filling occurred in the form of volcanic (e.g. Lizzie Creek Formation) and sedimentary, Group I, (e.g. Reids Dome Beds) deposits. Secondly, after the period of rifting had ceased, thermal relaxation caused subsidence allowing for further deposition. This second phase, or Group II deposits, lasting until the Late-Permian, was dominated by a series of marine deposits including the Back Creek Group and Tiverton Formation. The final phase in the formation of the Bowen Basin was produced by the subsequent overtaking of the thermal relaxation by foreland loading. This transition occurred as progressive, Group III, deposits were laid down under conditions which varied from the marine-influenced deltaic environment of the German Creek Formation, to the dominantly fluvial flood plain environments of the Moranbah Coal Measures. A period of compression in the Middle to Late-Triassic terminated any further sedimentation within the basin.

Coal accumulations occur throughout the 3 phases and large volumes of CSG are known to be held within the Permian coals in the north of the basin.

Dominating the north of the Bowen Basin are two north-south trending depositional centres, the Denison Trough to the west and the Taroom Trough to the east.

The area is mantled by an irregular cover of poorly consolidated Tertiary sedimentary strata and basalt (fresh and weathered) of the Suttor Formation. The Tertiary cover overlies the sediments and main coal-bearing units of the Late Permian Blackwater Group (Table 4). The Blackwater Group is divided into three terrestrial units, namely the Rangal, Fort Cooper and Moranbah Coal Measures (RCM, FCCM and MCM).

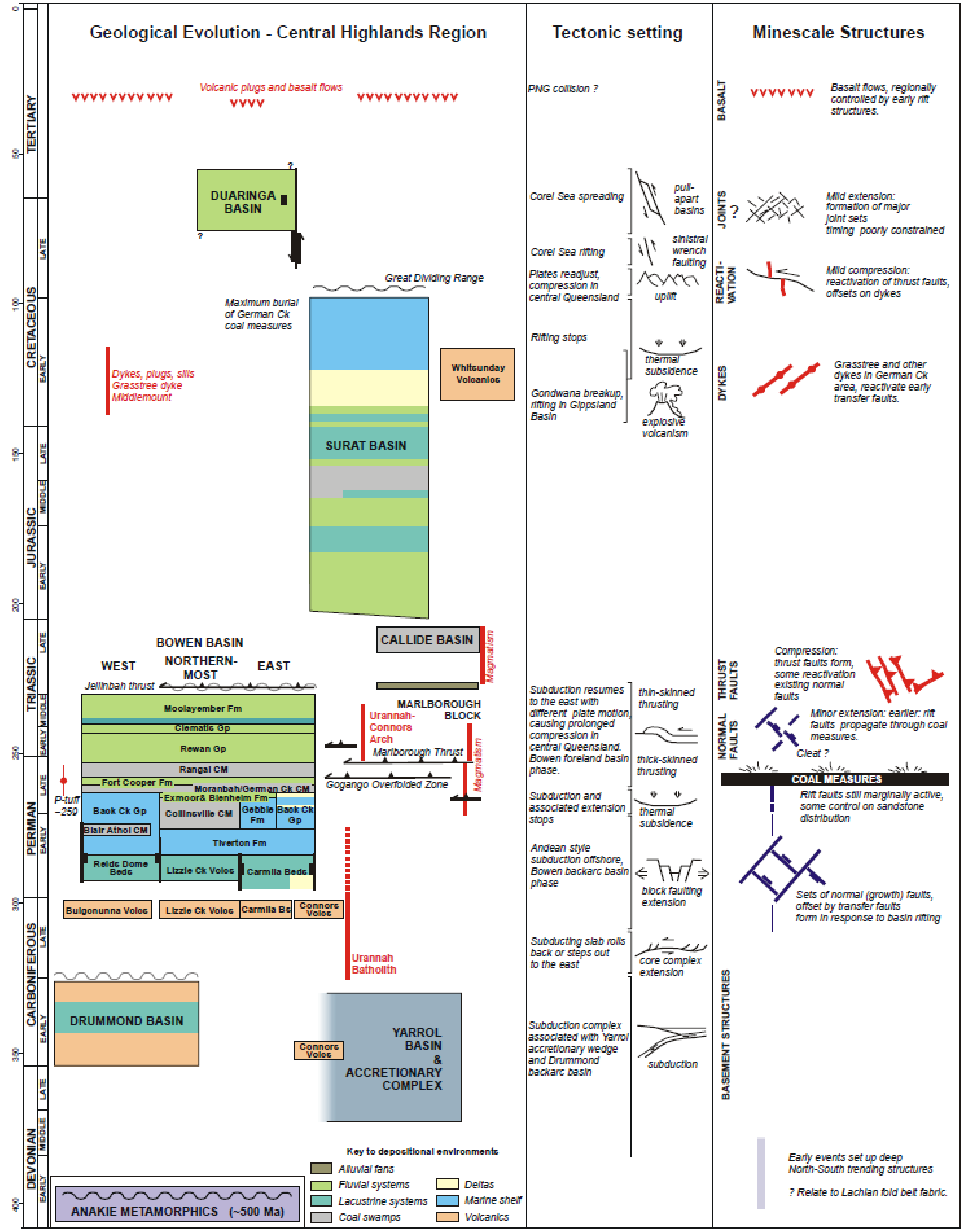

Figure 2 : Geological Evolution of the Bowen Basin

Table 4: Regional Stratigraphic Nomenclature of the Bowen Basin

Age	Formation	South	North
Triassic	Mimosa Group	Moolayember Formation	Moolayember Formation
		Clematis Sandstone	Clematis Sandstone
		Rewan Formation	Rewan Formation
Late Permian	Blackwater Group	Rangal Coal Measures	Rangal Coal Measures
		Burngrove Formation	Fort Cooper Coal Measures
		Fairhill Formation	
		MacMillan Formation	Moranbah Coal Measures
		German Creek Formation	
Middle Permian	Back Creek Group	Ingelara Formation	Blenheim Formation

The surface geology of the project area is shown in **Figure 3**.

3.1.1 *Target Geological Formations*

Coal seams with potential for gas generation and development in the basin are contained within the seams of the Late Permian Blackwater Group comprising stratigraphically from youngest to oldest:

- The Rangal Coal Measures;
- The Fort Cooper Coal Measures; and
- The Moranbah Coal Measures.

The exploration target for the production testing at ATP1031 is currently the RCM.

The Rewan Formation conformably overlies the RCM except in the northern portion of the project area, where the RCM outcrops. The RCM comprises both fractured and well-cleated coal seams. The target coal seams of the RCM are the Leichhardt and Vermont seams. The RCM are separated by light grey, cross bedded, fine to medium grained sandstone, grey siltstone, carbonaceous shale, and mudstone layers. These units have been observed to be competent and restrict vertical seepage between coal seams and from the adjacent over- and underlying stratigraphy. The RCM are generally estimated to be at least 100 m thick (approximately 150 m on average) and subcrop in the northern and southern areas of the Basin.

The RCM overlies the FCCM. The transition between the RCM and the FCCM is generally indicated by the Yarrabee Tuff, a basin-wide marker bed. The Yarrabee Tuff is a beige-brown tuffaceous claystone.

Figure 4 provides an overview of significant faults within the area. Based on the available data, ATP1031 is dominated by thrust faults as well as gently dipping and moderately dipping zones.

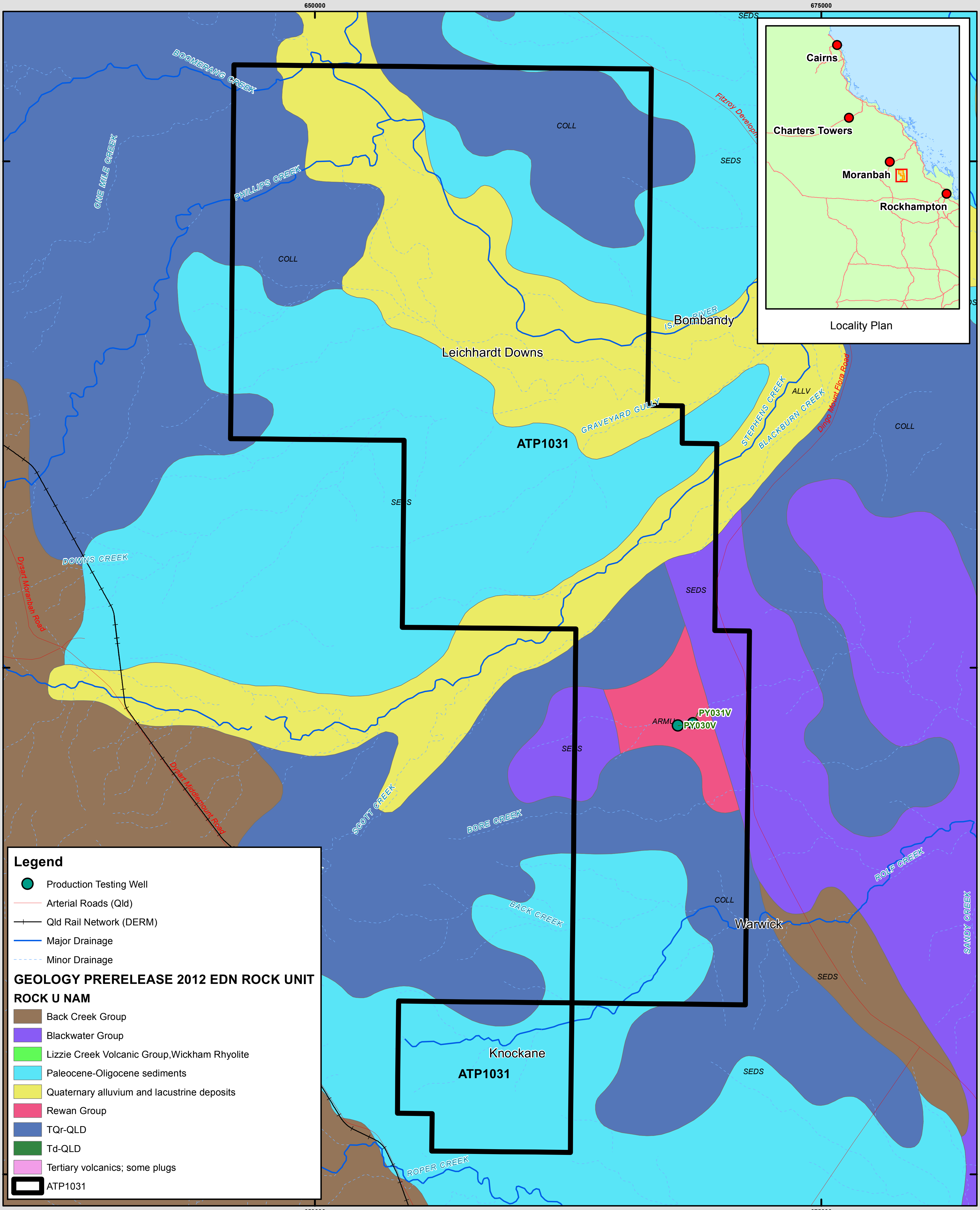

Figure 3 – Surface Geology of the ATP1031 Area

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

Date: 5/11/2013
Issued To: K Prasad
Author: tstringer

0 5 10
Kilometres

Coordinate System: GDA 1994 MGA Zone 55

N

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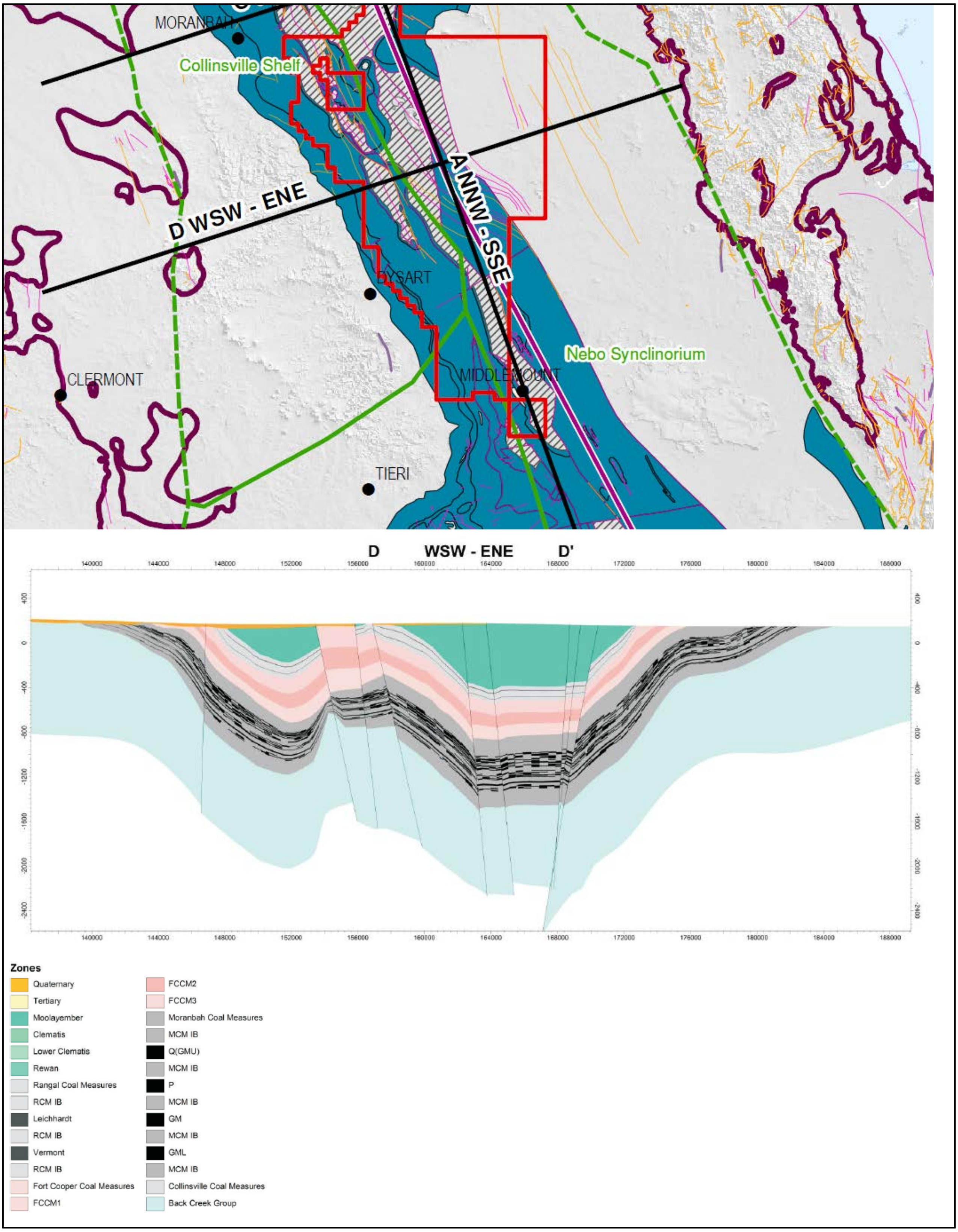

Figure 4 : Geological Structure of the project area

3.2 Aquifers

The description of aquifers has been undertaken based on the methodology outlined in Section 1.2 of this report.

3.2.1 *Overview*

Groundwater supply is not considered to be a major water source in the project area. Based on a review of available data, the beneficial use of groundwater in the Bowen Basin is considered to be low due to low sustainable yields and poor groundwater quality. Relevant aquifers consist of:

- Quaternary Alluvium Aquifers;
- Tertiary Sediment Aquifers;
- Tertiary Basalt Aquifers; and
- Permian – Triassic Strata Aquifers.

The occurrence and continuity of the above mentioned aquifers is highly dependent on the spatial distribution of the corresponding geological units in the Bowen Basin. In general, the occurrence of the Quaternary and Tertiary aquifers is not well defined in the Basin.

A cross section, through production testing bores PY030 and PY031, which provides an overview of the main aquifers in the project area, are depicted in the Figure below.

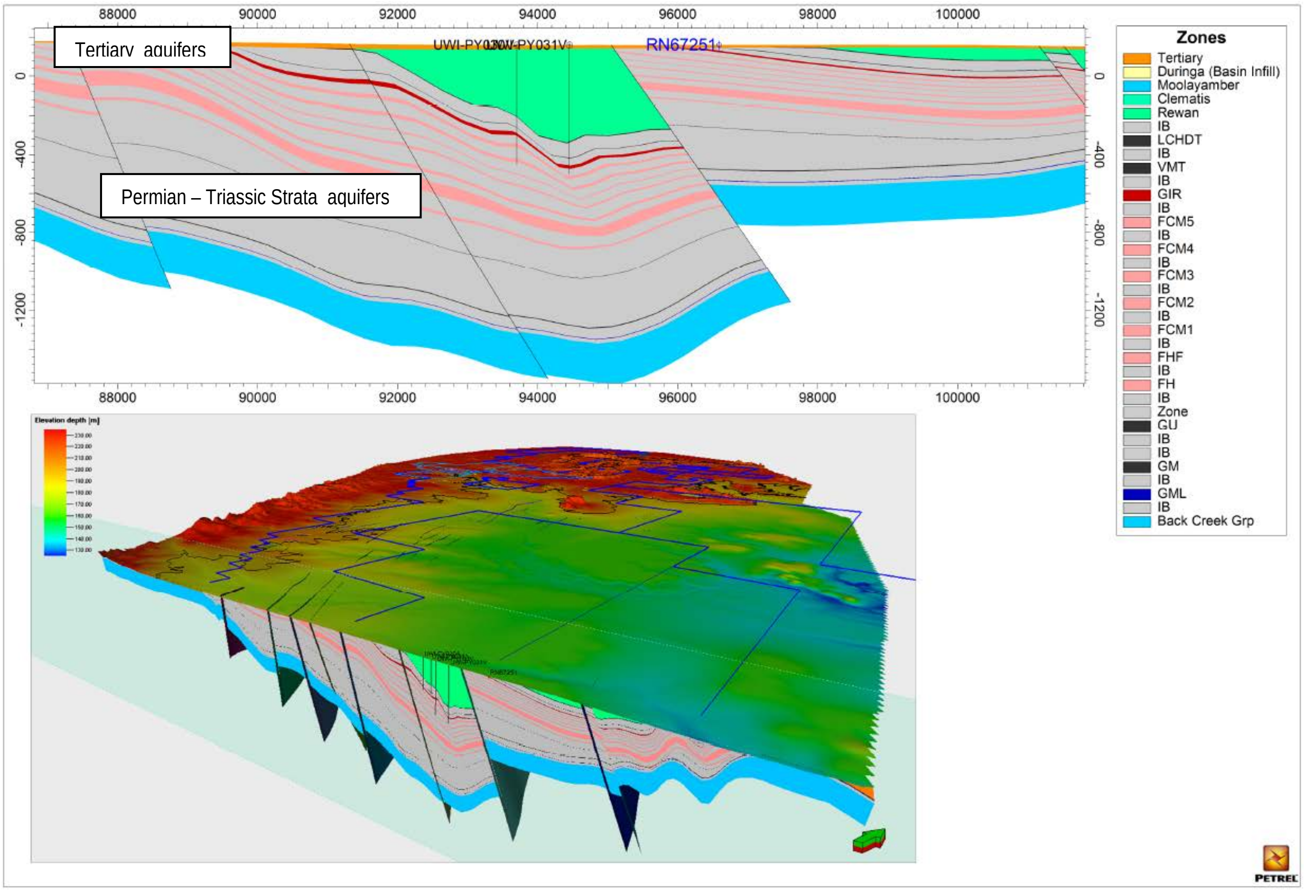

Figure 5: ATP1031 Cross Section through the two production testing wells.

These aquifers are summarised in more detail in the below sections.

3.2.1.1 Quaternary Alluvium Aquifers

Quaternary alluvium aquifers (alluvium aquifers) are extensive and typically are 1 to 10 km wide along the rivers and major creeks in the Isaac and Mackenzie River sub-catchments. The alluvium aquifers associated with the Isaac and Connors Rivers and their tributaries, form the most significant groundwater resource in the catchment and are considered to be strongly linked to surface water (SKM, 2009a). Data coverage across the alluvium aquifers is uneven with the greatest concentration of bores occurring in the alluvium of Fennel Creek, Nebo Creek, Denison Creek and the Connors River.

The alluvium in the Isaac Connors sub-catchment is associated with the Isaac River and its tributaries (SKM 2009a). River alluvium in the project area, occurs mainly along the Upper Isaac River and Stephens Creek, and available data indicates that the saturated alluvium is about 15 to 25 m thick (SKM 2009a); however, potable groundwater is not abundant in these areas.

The alluvium aquifer is unconfined to semi-confined aquifer with storage provided by its primary porosity. Potential for usable groundwater resources exists within the more permeable sand and gravel dominant sections of the alluvium, however, variations in saturated thickness and bedrock outcrops indicate that the alluvium is not one continuous aquifer.

The alluvium aquifers are considered to be strongly linked to surface water with recharge occurring during stream flow events (SKM 2009a). The majority of the surface water rivers and creeks within the study area are ephemeral and recharge of the alluvium is by:

- Recharge from surface water flow or flooding (losing stream); and
- Surface infiltration of direct rainfall and overland flow, where alluvium is exposed and no substantial clay barriers occur in the shallow sub-surface.

Available hydrologic data suggests that water infiltrates/drains to the base of the alluvium relatively quickly after rainfall events where more permeable units are at surface. This saturation is sporadic, producing semi-permanent, localised, thin, aquifers. A groundwater penetrating radar (GPR) survey was undertaken along the Isaac River, north of Moranbah, (JBT Consulting 2010) that indicated the Isaac River bed sands were dry or only damp in the base layer. This suggests that the groundwater occurrence is limited to deeper parts of the channel and may not be saturated all year round. Available drilling data indicates that the sediments adjacent to the Isaac River are generally dry to a depth below the base of the bed sands. This suggests that baseflow of groundwater to the Isaac River is not significant (JBT Consulting 2010). Alluvium groundwater resources are exploited along the Isaac River but the distribution of production bores is considered erratic (Pearce *et al.* 2006).

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 fresh groundwater only occurs in isolated areas (Section 4.6.3).

The regional pattern of lateral groundwater flow within the aquifer is expected to follow topography and drainage patterns. During periods of creek or river flow, the alluvium may discharge to sub-cropping coal seams or other underlying aquifers where they exist. Sub-vertical fault zones may also provide a vertical discharge pathway to deeper units, but only if these faults are (tangentially) permeable. Owing to a paucity of data for the Quaternary alluvium the spatial distribution of vertical groundwater leakage is difficult to quantify, however discharges to the surface are expected to be significant, including:

- Evapotranspiration from vegetation growing in the creek beds and along the banks;
- Short duration baseflow from the permeable sands and gravels within the alluvium material; and
- Infiltration and recharge to the underlying older formations where the creeks cross more permeable zones within these units.

The Quaternary alluvium aquifers are not well developed in most of the study area with the exception of the Braeside borefield located west of the project area. No significant groundwater extraction areas are recognised from the alluvium aquifers within the Bowen Basin.

3.2.1.2 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 in the project area are made up of the late Tertiary colluvial and residual deposits consisting of clay, silt, sand, gravel and soil, as well as Tertiary Paleocene-Oligocene sediments consisting of sandstone, mudstone and conglomerate. These 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. This aquifer is classed as a primary porosity aquifer where groundwater movement is via inter-granular flow and are expected to represent unconfined to confined aquifers depending on the location, degree of weathering, the nature of the overlying alluvium and clay content. Most of the clean sand and gravel lenses in the Tertiary sediments are permeable but are of limited lateral and vertical extent. Thus the volume of groundwater stored and the ability to transmit groundwater depends on the particle size of the material and the saturated thickness of the sediments. The thickness and extent of these Tertiary sediments are variable and for the most part, groundwater resources are very limited and typically have poor quality.

Tertiary basalt flows occur as small discontinuous remnants within the Tertiary sediment aquifers that act as thin sediment covers in some areas; thicker remnant flows have filled in former drainage systems/ palaeochannels and act as aquifers themselves in other areas.

Recharge processes in the Tertiary sediment aquifers are via:

- direct infiltration of rainfall and overland flow where Tertiary sediments outcrop and no substantial clay barriers exist in the subsurface; and
- seepage from overlying Quaternary alluvium aquifers.
- Primary discharge mechanisms in the Tertiary sediment aquifers are likely to be:
- through flow into adjacent or underlying aquifers (outcropping or sub-cropping coal seams);
- evapotranspiration; and
- groundwater extraction.

3.2.1.3 Tertiary Basalt Aquifers

Tertiary basalt aquifers have not been identified to occur within ATP1031 tenement. The spatial distribution of the Tertiary basalt is sporadic within the Bowen Basin. The largest mass occurs to the west of Dysart with several other masses occurring near Moranbah, west of Nebo and northeast of Middlemount (Pearce .B, Hansen .J, 2006a). The basalt is generally less than 50 m thick and almost completely weathered (Pearce .B, Hansen .J, 2006a). For the majority of exploration boreholes that intersected basalt, the basalt is logged as highly to extremely weathered, clayey and dry. The distribution of less-weathered, fractured and vesicular water-bearing basalt is variable

The Tertiary basalt aquifers are classed as a secondary porosity aquifer and are expected to represent unconfined to confined aquifers depending on location. Groundwater is principally stored and transmitted in the fractures, joints and other discontinuities within the rock mass. The nature of the Tertiary basalt, and hence its permeability and porosity, is highly variable, depending on the degree of weathering and the intensity and interconnectedness of jointing and/or fracturing. Fractured and weathered Tertiary-age basalts hold enough groundwater in some areas for stock watering and domestic use, however, bore yields are generally low and the water is often of low quality.

The depth of the basalt, and the generally clayey nature of the weathered upper basalt and the Tertiary sediments associated with the basalt, indicate that the recharge is low. Groundwater recharge in this aquifer occurs from:

- infiltration of rainfall in rock outcrop areas where no substantial clay barriers exist in the shallow subsurface; and
- vertical seepage or though flow from overlying or adjacent alluvium or tertiary sediment aquifers.

Primary discharge mechanisms in the Tertiary basalt aquifers are likely to be:

- downgradient Tertiary basalt outcrop areas;
- through flow into adjacent or underlying aquifers (outcropping or sub-cropping coal seams);
- evapotranspiration; and

- groundwater extraction.

3.2.1.4 Permian - Triassic Aquifers

The Permian – Triassic formations constitute the two dominant Permian formations which are the Blackwater Group and the Back Creek Group as well as the Triassic Rewan Formation, Clematis Sandstone and Moolayember Formation.

In the Bowen Basin, the distribution of the Clematis Sandstone and Moolayember Formation has mostly eroded but a few remnants occur as outcrops in the north. The Moolayember Formation consists of siltstone and sandstone and the Clematis Sandstone consists of sandstone, siltstone, mudstone and conglomerates. These two formations form part of the basal section of GAB recharge beds (Pearce .B, Hansen .J, 2006a), and do not occur within the ATP1031 tenement.

A small surface exposure of the Rewan Formation occurs in the ATP 1031 tenement and is comprised of mudstone, shale, siltstone and sandstone. The Rewan Formation is 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. This unit is generally considered to have low porosity and permeability (Worley Parsons 2010) and is extensive within the central Bowen Basin with a typical thickness of 0 to 800 m

As with the rest of the Bowen Basin, the coal seams are the more permeable units within the Permian sequences. The overburden and interburden rocks in several mines in the northern Bowen Basin (Broadlea Coal Mine, Burton Mine, and Ellensfield Coal Mine) have been described as essentially impervious to groundwater movement (AGE 2008); however, minor groundwater supplies are contained in porous sandstone layers of the interburden and overburden (Pearce .B, Hansen .J, 2006a). The coal seams; identified as continuous across the project area, constitute the most extensive aquifers. These seams have been extensively mined along the western margin of the Bowen Basin.

The coal seams of the Blackwater Group are confined from above by the Rewan Group (along the central axis of the Bowen Basin) and by interburden layers of low-permeability shale, mudstone and siltstone. The coal seams generally are dual-porosity material with primary-porosity provided by the matrix and a secondary porosity provided by fractures (joints and cleats). Natural fractures in the coal may be the dominant space for groundwater storage and the principal pathway for groundwater movement dependent on fracture interconnectivity.

Movement of groundwater through the aquifer (transmissivity) is likely to be through more permeable coal (cleats) rather than through the confining inter- and overburden units. The confining units are considered (based on piezometeric pressure differences in the coal seams) to have very low vertical hydraulic conductivity (leakage). This limits vertical movement as well as recharge to the coal seam aquifers.

Other sediments in the coal overburden and interburden sequence are relatively impermeable (either due to high clay content or significant cementing) and form aquitards. The Permian strata may, therefore, be categorised into the following hydrogeological units:

- Hydrogeologically ‘tight’ and hence very low yielding to essentially dry claystone, mudstone, sandstone, siltstone and shale that comprise the majority of the strata;
- Low to moderately permeable coal seams which are the prime water bearing strata within the Permian sequence; and
- Localised fracture or fault systems which are open and have not been infilled by clay/carbonate deposition.

Groundwater recharge in this aquifer occurs from:

- Infiltration of rainfall and overland flow in outcrop and subcrop areas;
- Downward seepage or though flow from overlying or adjacent alluvium or tertiary aquifers where no significant clay barriers exist; and
- Leakage between aquifers by faulting and other structural discontinuities in overburden and interburden sediments.

Primary discharge mechanisms in the Permian strata aquifers are likely to be:

- Down gradient Permian strata outcrop areas;
- Through flow into adjacent (outcropping or sub-cropping coal seams) or seepage into underlying aquifers (via structural discontinuities); and
- Groundwater extraction (CSG, incidental mine gas management, and mine dewatering activities).

Groundwater in the Back Creek Group is typically contained within porous sandstones at varying depths and also in fracture zones in shale and siltstone (Pearce .B, Hansen .J, 2006a). Shallow unconfined groundwater occurs in outcrops/subcrops of the Back Creek Group that are extensive along the east and west margins of the Bowen Basin. Back Creek Group aquifers within the central Bowen Basin are deep and confined with poor quality groundwater (SKM 2009a; Worley Parsons 2010). The Back Creek Group has been identified to outcrop to the west of the ATP1031 tenement. The unconfined aquifers exist within the porous sandstones of the Back Creek Group and yield reliable groundwater supplies. Water quality and yields in the Blackwater and Back Creek Group has however, been identified as commonly being very poor.

3.3 Groundwater Levels

The primary source of groundwater level data has been from the DNRM groundwater database. Within the ATP1031 tenement, groundwater level data is available for the Isaac River alluvium aquifer, Tertiary aquifers and the Permian aquifers.

Groundwater levels in the shallow Isaac River alluvium aquifer range from 0.5 to 14.78 mBGL. The groundwater bore yields recorded in this aquifer varies from 0.5 to 12 L/sec. This is indicative of low to moderate groundwater bore yields. This data is included in Table 5 below.

Table 5 : Isaac River Alluvium Aquifer Groundwater Level and Yield Data for ATP1031

RN	Easting	Northing	Water Level (mBGL)	Yield (L/sec)	Aquifer
67218	658629	7521429	0.5	0.8	Isaac River Alluvium
67219	659064	7519525	0.5	0.8	Isaac River Alluvium
97180	654694	7527196	12.19	0.76	Isaac River Alluvium
97181	656434	7523988	13.41	12	Isaac River Alluvium
97182	657151	7522448	14.78	0.51	Isaac River Alluvium
97183	657419	7522279	14.78	0.51	Isaac River Alluvium
97184	658710	7520443	13.79	2.6	Isaac River Alluvium
97185	658897	7519944	14.33	2.53	Isaac River Alluvium
67216	655364	7526286	1.8	0.5	Isaac River Alluvium

Generally, the bores have one reported water level measurement that was typically collected at the time of installation. One long-term (transient) groundwater level data is reported from RN13040180 which is situated just outside of ATP1031 near the Isaac River. The 1971 to 2011 hydrograph for bore RN13040180, is shown in the figure below with the Moranbah rainfall residual mass curve (RRMC) and Isaac River stream flows for the same time period. Between 1990 and 2007 there was a decline in groundwater due to below-average rainfall (and possible groundwater consumption) and then recovery during above-average rainfall between 2000 – 2002 and 2010 – 2011. These major shifts in average rainfall are coupled to *el Nino* (dry/drought) and *la Nina* (wet/flood) rainfall conditions over eastern Australia.

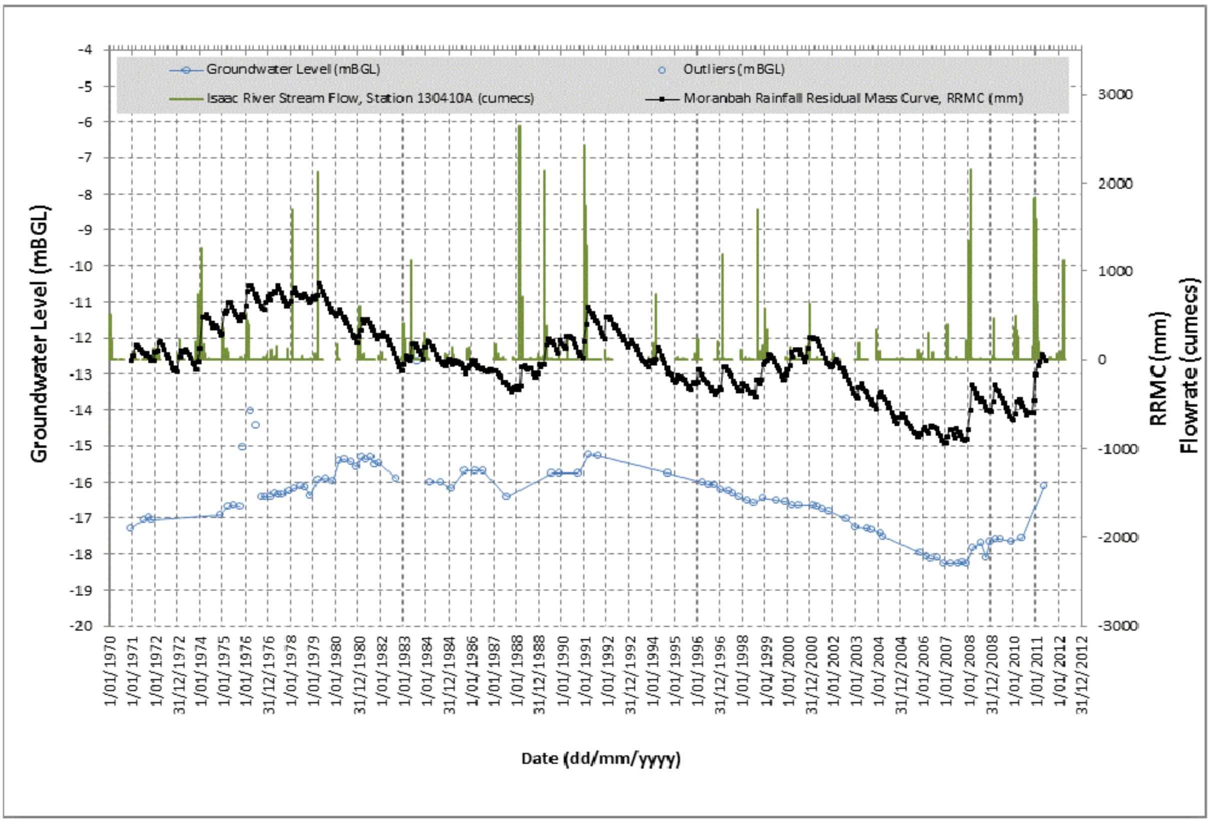

Figure 6 : Groundwater Hydrograph for Bore RN 13040180 Located in Isaac River Alluvium near ATP1031

Available groundwater level and yield data for Tertiary aquifers within ATP1031 is shown in Table 6 below. The general depth to groundwater ranged from 17 to 24 mBGL. Available groundwater yield data for this aquifer is generally variable however the recorded yields for the below groundwater bores ranged from 1 to 2.27 L/sec.

Table 6: Tertiary Aquifers Groundwater Level and Yield Data for ATP1031

RN	Easting	Northing	Water Level (mBGL)	Yield (L/sec)	Aquifer
88527	665212	7516134	17	1	Tertiary – Undefined
88528	664087	7516922	24	1.2	Tertiary – Undefined
97043	665148	7516578	-	2.27	Duaringa Formation

Whilst no DNRM bores in ATP1031 are identified to existing with the Triassic aquifers, there is some data available for the groundwater bores in the Triassic aquifers in the neighbouring ATP1103 tenement. Available data in this tenement suggests that groundwater levels range from 7 to 19 mBGL (Table 7). Groundwater yield data is only available for one of the bores within the neighbouring ATP1103 tenement. This bore shows that the groundwater bore yield is approximately 0.25L/sec. However generally yield ranges within the region are between 3 to 6 L/sec.

Table 7: Triassic Aquifers Groundwater Level and Yield Data for neighbouring ATP1103

RN	Easting	Northing	Water Level (mBGL)	Yield (L/sec)	Aquifer
46848	630826	7621419	7.6	-	Rewan Fm
81908	619562	7588213	19	0.25	Rewan Fm

Available groundwater level and yield data for the Permian aquifers are shown in Table 8. Groundwater levels for the Permian aquifers range from 11.3 to 45.7 mBGL. Based on the database records, the majority of these bores are located within the shallower parts of the Blackwater Group and Back Creek Group (< 100 m total depth). Available data for groundwater bore yields indicate that yields range from 0.01 to 6.3 L/sec. In general, groundwater bore yields for bores installed in this aquifer are low.

Table 8: Permian aquifers Groundwater level and Yield Data for ATP1031

RN	Easting	Northing	Water Level (mBGL)	Yield (L/sec)	Aquifer
43064	663042	7484421	24.4	0.5	BACK CREEK GROUP
43305	647075	7516837	45.7	0.39	BLACKWATER GROUP
43603	667263	7484901	-	0.5	BACK CREEK GROUP
47037	666315	7484118	15.1	0.39	BACK CREEK GROUP
47038	667707	7485630	-	-	BACK CREEK GROUP
47054	668598	7506572	-	1.52	BLACKWATER GROUP
47055	665959	7505721	-	-	BLACKWATER GROUP
47056	664011	7504465	-	1.2	BLACKWATER GROUP
47189	667724	7507896	-	6.3	BLACKWATER GROUP
67249	670825	7498141	11.3	0.59	BLACKWATER GROUP
67251	670780	7497623	17	0.59	BLACKWATER GROUP
67252	671239	7498096	-	0.79	BLACKWATER GROUP
89454	653338	7513734	45.7	1.3	BLACKWATER GROUP
84141	666299	7506066	-	0.76	BLACKWATER GROUP
90264	662740	7485824	-	-	PERMIAN COAL MEASURE
90471	656361	7511724	-	-	BLACKWATER GROUP
90472	653417	7512498	-	0.01	BLACKWATER GROUP
90473	651871	7512131	-	0.01	BLACKWATER GROUP
90480	652589	7519704	39.6	0.75	FAIR HILL FORMATION
13040291	671257	7499371	19	-	BACK CREEK GROUP

Long term (transient) groundwater level data for the confined Permian aquifers are illustrated in the figure below. Bore RN13040294 is situated ~40 km east of ATP1031, RN13040283 is situated ~18 km west of ATP1031 and RN13010005 is situated ~35 km south east of ATP1031. These bores show only minor variations and no discernible rainfall response. These hydrographs are consistent with previous reports that the fractured rock aquifers of the Blackwater Group groundwater levels have little or no response to rainfall patterns (cited in Worley Parsons 2010).

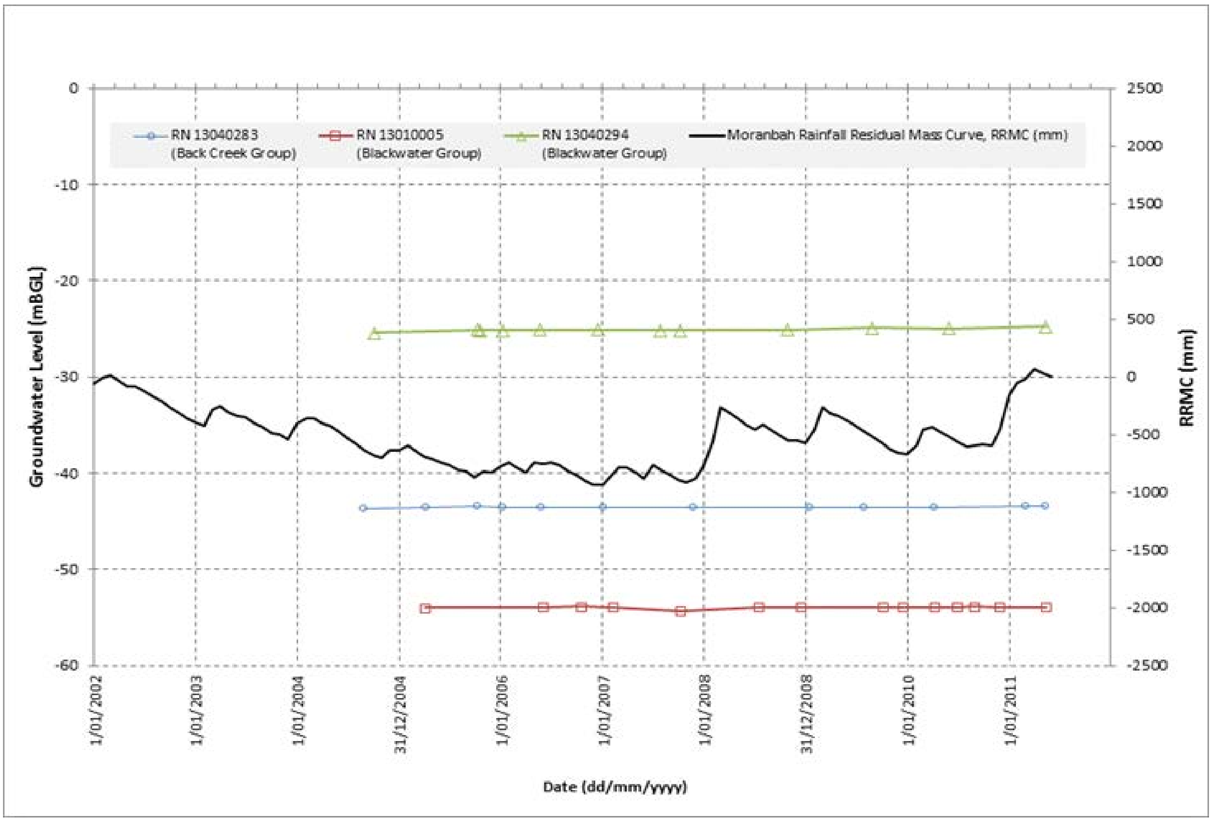

Figure 7 : Groundwater Hydrograph for three bores located in confined Permian aquifers outside of ATP1031

3.4 Groundwater Flow

Based on the available data, it can be inferred that the regional water table generally mimics surface topography albeit smoother and more 'subdued' (Toth 1963; Haitjema *et al.* 2005). Groundwater in the alluvium aquifers generally flows down valley in the same direction as stream flow. Given the heterogeneous nature of the alluvium aquifer sediments and the variability in annual and seasonal recharge, the rate of this down valley flow is expected to be spatially and temporally non-uniform. Flows are likely to be constrained to higher permeability pathways where sands and gravels are present, rather than the entire cross sectional area of alluvium. The inferred groundwater level contours and flow directions in the surficial aquifer (Quaternary and Tertiary) is shown in the figure below, as was depicted in the Bowen Gas Project EIS. For the area representing ATP1031, the groundwater flow direction is to the east. The potential for downward seepage loss is limited by the extensive coverage of the Rewan Formation across the central Bowen Basin. There is limited data and information on the interactions of groundwater between the alluvium aquifers and adjacent and underlying aquifers.

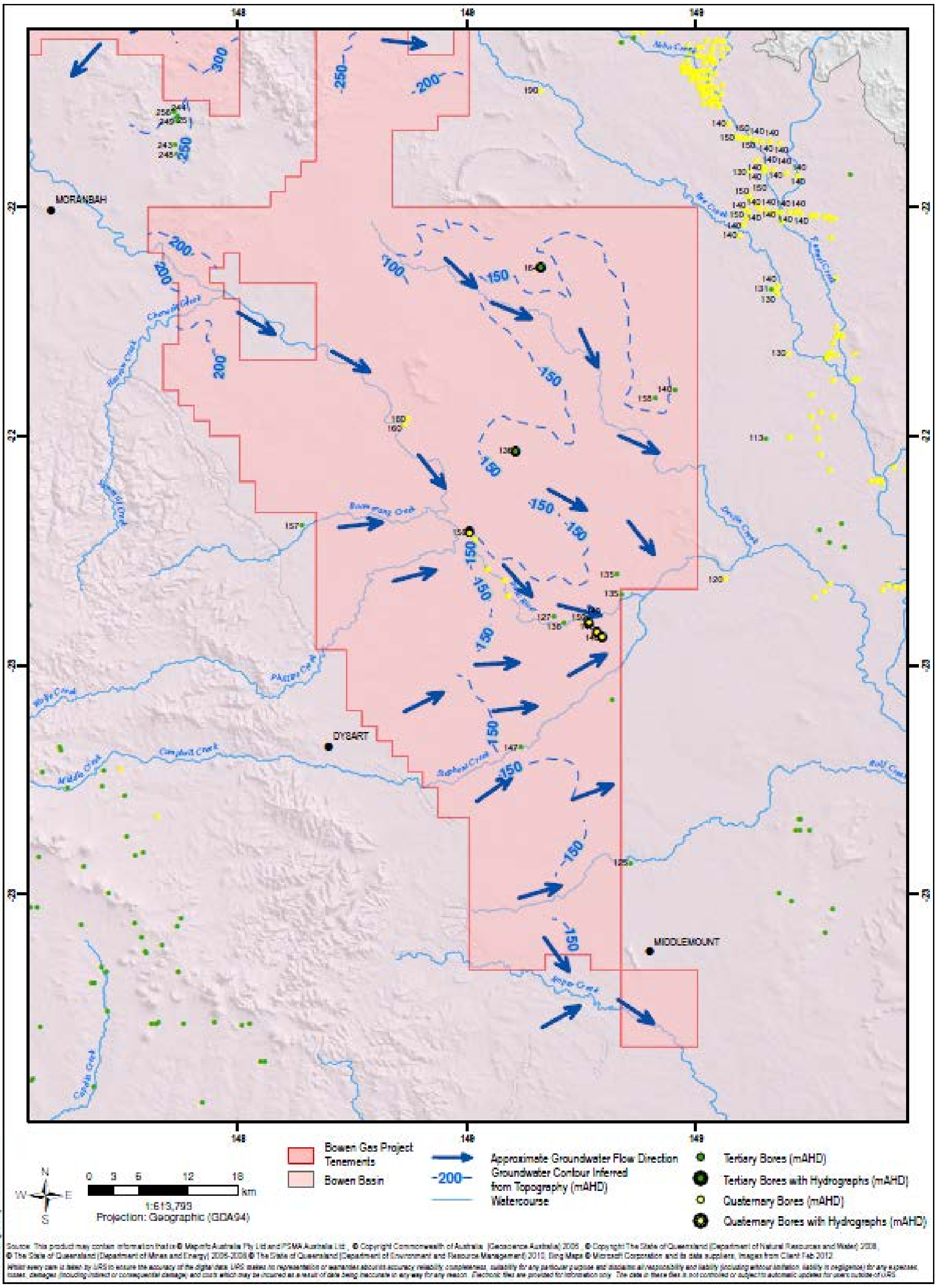

Figure 8 : Inferred Groundwater level and contours and flow directions in the surficial (Quaternary and Tertiary) aquifers (Source: Arrow Energy Bowen Gas Project EIS, URS 2012)

The characterisation of groundwater flow in the Blackwater Group is based on the basin wide assessment undertaken for the Arrow Energy Bowen Gas Project EIS (URS, 2012). The average groundwater level contours suggest the regional groundwater flow direction within the Blackwater Group bores is variable across the Basin as is shown in the Figure below. Flow patterns are generally from the east and west margins of the Basin, towards the central axis of the basin and then to the southeast and the north.

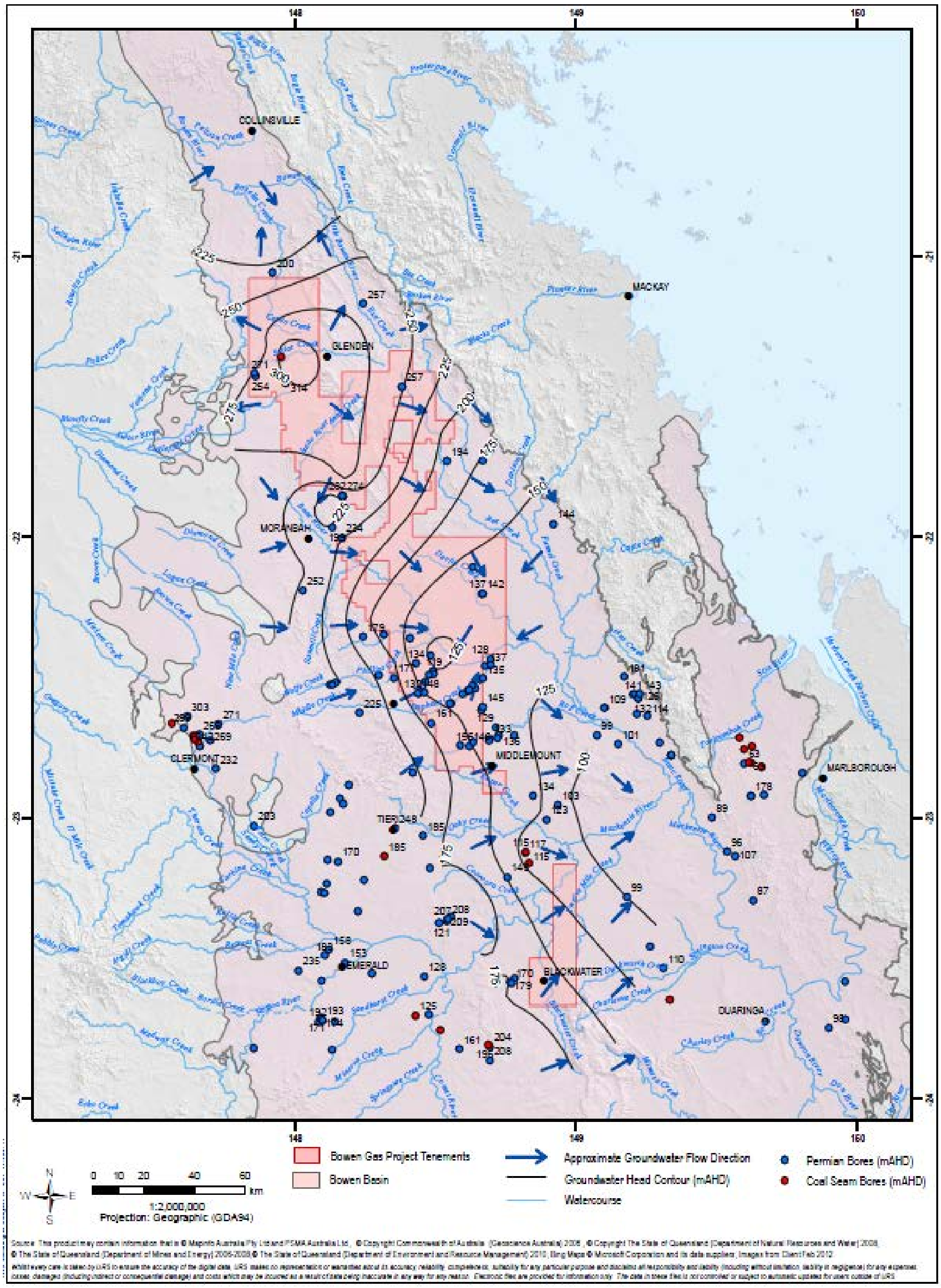

Figure 9 : Average recorded groundwater levels in the Blackwater Group aquifers and approximate groundwater head contours and flow direction (Source: Arrow Energy Bowen Gas Project EIS, URS 2012)

Based on the current and previous reviews (Worley Parsons 2010) the Rewan Formation is an aquitard and limits the vertical movement of groundwater between the Blackwater Group and surficial aquifers. In this respect inter-aquifer flow within the central Bowen Basin is interpreted to be limited under natural conditions where the Rewan Formation is present. The low permeability of the shale, mudstone, and siltstone inter-burden of the Blackwater Group also limits vertical (inter-aquifer) flow between the coal measures, and between the coal measures and the surficial aquifers.

3.5 Groundwater Quality

A review of the DNRM groundwater database was undertaken to provide an indication of available field quality data for the aquifers within the ATP1031 tenement. These are shown in Table 9, Table 10 and Table 11 for the alluvium aquifer, Tertiary aquifer and Permian aquifer respectively.

Available groundwater quality data for bores in alluvium aquifers in ATP1031 are limited to quality observations which indicate reasonable to good quality groundwater in the Isaac River alluvium aquifer.

Table 9: Groundwater Quality data (field parameters) in the alluvium aquifer for ATP1031

RN	Conductivity µS/cm	Quality Observations*	Formation Description
67219	-	Reasonable	Isaac River Alluvium
97180	-	Good	Isaac River Alluvium
97181	-	Good	Isaac River Alluvium
97182	-	Good	Isaac River Alluvium
97183	-	Good	Isaac River Alluvium
97184	-	Good	Isaac River Alluvium
97185	-	Good	Isaac River Alluvium
67216	-	Good	Isaac River Alluvium

*Represents comments made in the field regarding the quality of the water

There are only three groundwater bores in the Tertiary aquifer in ATP1031 with available groundwater quality data. This data suggests that groundwater quality in the Tertiary aquifer is brackish in nature.

Table 10: Groundwater Quality data (field parameters) in the Tertiary aquifer for ATP1031

RN	Conductivity µS/cm	Quality Observations	Formation Description
88527	-	Brackish	Tertiary - Undefined
88528	-	Brackish	Tertiary – Undefined
97043	12400	-	Duaringa Formation

Groundwater quality data for bores in the Permian aquifers in ATP1031 is shown in the table below. Electrical Conductivity ranges from 690 to 16000 µS/cm. Groundwater quality observations range from very good to salty. This suggests highly variable existing groundwater quality conditions in this aquifer. However, there is insufficient data to characterise the water quality of the unit.

Table 11: Groundwater Quality data (field parameters) in the Permian aquifers for ATP1031

RN	Conductivity µS/cm	Quality Observations	Formation Description
43064	8500	-	Back Creek Group
43305	-	Very Good	Blackwater Group
43603	-	Fair	Back Creek Group
47037	8850	-	Back Creek Group
47038	-	Salty	Back Creek Group
47189	690	-	Blackwater Group
67249	3800	-	Blackwater Group
67251	3000	-	Blackwater Group
67252	4000	-	Blackwater Group
89454	16000	-	Blackwater Group
90471	-	Salty	Blackwater Group
90473	-	Brackish	Blackwater Group
90480	-	Good	Blackwater Group
13040291	4450	-	Back Creek Group

3.6 Groundwater Use

A review of the DNRM groundwater database was undertaken to identify registered groundwater bores within the project area. **Table 12** below provides a summary of the number of registered groundwater bores that are located within the Bow tenement.

Table 12: DNRM registered groundwater bores within ATP1031

Number of Groundwater Bores	Facility Type	Number	Facility Status	Number
40	Subartesian Facility	39	Abandoned and Destroyed	7
			Abandoned but still useable	5
			Existing	27
	Artesian Bore, Condition Unknown	1	Existing	1

Figure 10 shows the locations of registered groundwater bores within a 5 km radius of the two production testing wells at ATP1031. There are four existing registered bores, the details of which are shown in the table below. It should be noted that there are no registered groundwater bores within a 2 km radius of the two production testing wells at ATP1031.

Table 13: DNRM registered groundwater bores within 5 km of the production testing wells at ATP1031

RN	Facility Type	Facility Status	Formation Description	TD
67251	Subartesian Facility	Existing	Blackwater Group	23
67252	Subartesian Facility	Existing	Blackwater Group	21
67249	Subartesian Facility	Existing	Blackwater Group	31
13040291	Artesian Bore, Condition Unknown	Existing	Back Creek Group	26
43902	Subartesian Facility	Existing	Blackwater Group	118

A search was undertaken of the DNRM Water Management System (WMS) to identify the types of groundwater uses and entitlements associated with licensed bores within the project area. Based on the available data, there are no existing groundwater entitlements associated with existing bores within the project area. Figure 11 shows the locations of the nearest bores listed in the DNRM WMS database. The nearest registered bore is a stock bore (RN43403) which is approximately 30km away from the pilot testing bores.

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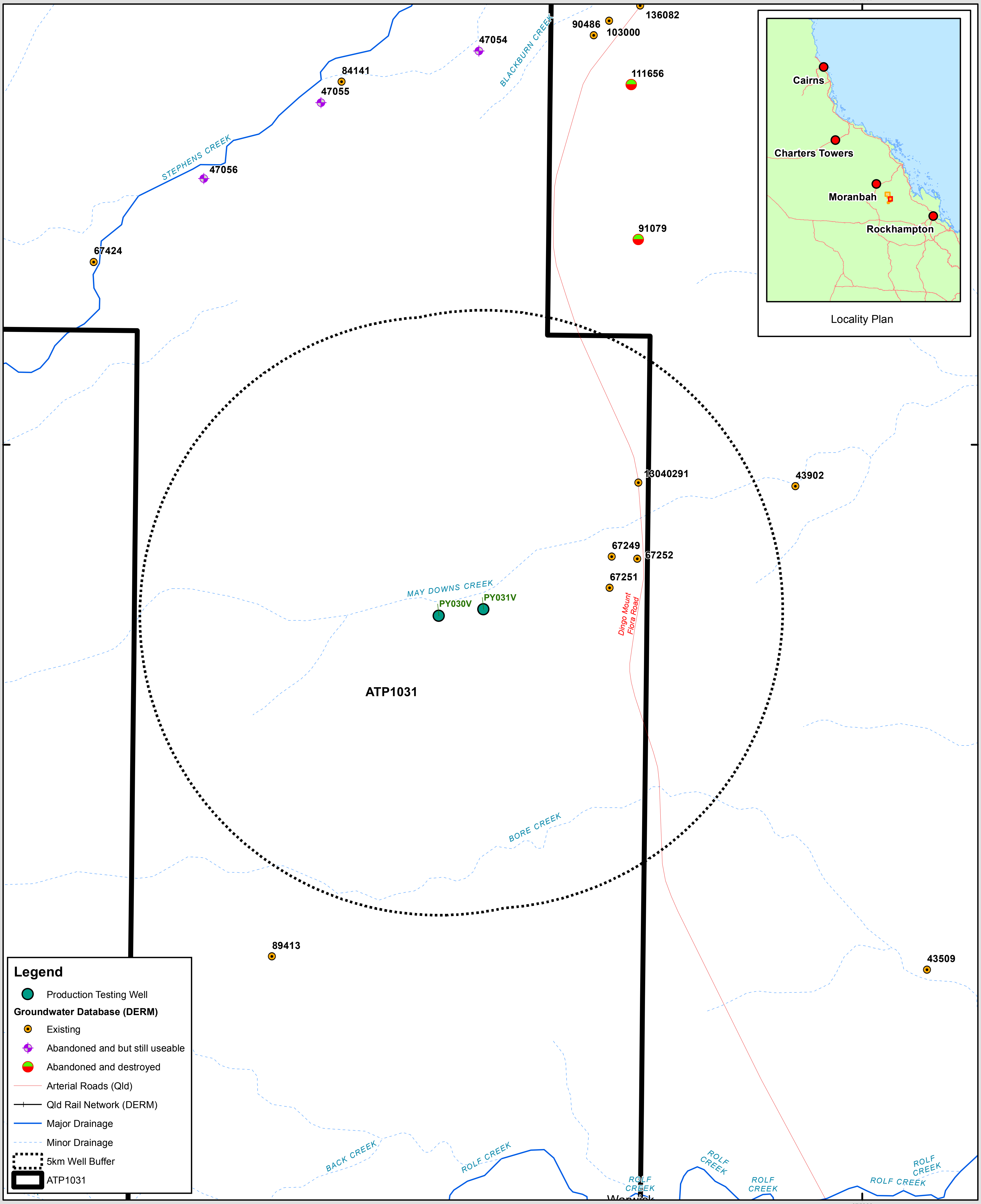

Figure 10 – Locations of DNRM registered groundwater bores

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

Date: 14/11/2013
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Author: tstringer

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Coordinate System: GDA 1994 MGA Zone 55

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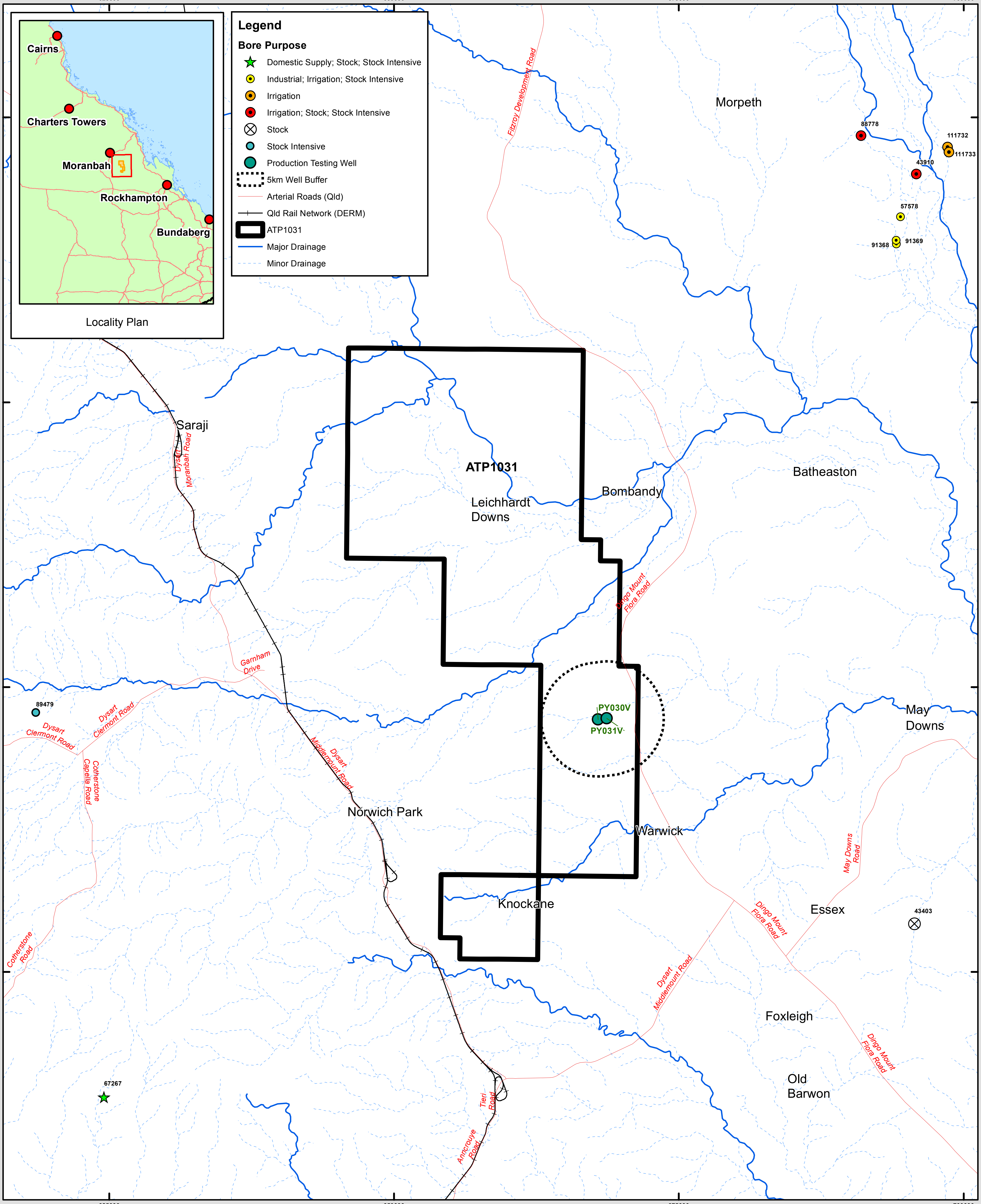

Figure 11 – Groundwater Use data for ATP1031

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

Date: 19/11/2013
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Author: tstringer

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3.7 Springs

A review has been undertaken of the springs dataset prepared by OGIA using the Herbarium datasets. Based on this data, no springs have been identified to exist within the proximity of ATP1031. This is illustrated in Figure 12 below. Based on this, impacts to springs as a result of the production testing at ATP1031 will not be considered further in this UWIR.

3.7.1 *Groundwater Dependent Ecosystems (GDEs).*

A desktop review of available data with respect to Groundwater Dependent Ecosystems (GDEs) within the project area has been undertaken. Groundwater Dependent Ecosystems are ecosystems that need groundwater to support any aspect of their growth or function. Six broad functional groups of GDEs have been classified: terrestrial vegetation, river base flow systems, estuarine and near shore marine, aquifer and cave systems and wetlands (Clifton and Evans, 2001) (Hatton and Evans, 1998). Groundwater dependant ecosystems function (i.e. health) is generally defined by four groundwater parameters: flux, level, pressure and quality, with dependence being a function of one or all of these factors.

According to SKM (2009b), there is no long-term historical data or detailed field assessments to describe the groundwater dependence or response functions of GDEs in the Isaac Connors catchment. The Isaac Connors Groundwater Project undertaken by SKM (2009b) provided a conceptual model for the likely relationships between ecosystems and groundwater in the Isaac Connors alluvium. In the Isaac Connors alluvium area, which encompasses a large area of interest, groundwater is considered to support riparian vegetation, in-stream pools, riverine wetlands, hyperheic zones and in some areas, baseflow ecosystems.

Within the project area, the Isaac River is ephemeral and ceases to flow for extended periods. Flows are seasonal and linked to regional rainfall patterns. Available drilling data indicates that the sediments adjacent to the river are generally dry to a depth below the base of the bed sands. This suggests that baseflow of groundwater to the Isaac River is not significant (JBT Consulting, 2010). Nonetheless, it is considered that during periods of river flow (wet season, storm events etc.), the alluvium may become fully saturated and discharge to sub-cropping coal seams as is supported by URS (2009).

A review of the DEHP Regional Ecosystems mapping and Referable Wetlands data show that a Wetland Protection Area of high ecological significance exists along the Isaac River. The majority of the area along the Isaac River consists of Regional Ecosystems with a Biodiversity Status that is deemed to be 'Of Concern (dominant)' to 'Endangered (sub-dominant). Terrestrial vegetation GDEs typically access groundwater via root uptake from the water table or overlying saturated zone (capillary fringe). Riparian vegetation GDEs are observed to occur within about 10m to 300m from streams and wetlands (SKM, 2009b).

In the project area, it is considered that the level of groundwater dependency by terrestrial vegetation is likely to be relatively low. Give the local climatic conditions and drainage characteristics of these areas, surface water runoff and infiltrated rainfall is likely to represent the primary source of flux required to satisfy plant water requirements. Established vegetation may potentially utilise groundwater opportunistically during dry periods.

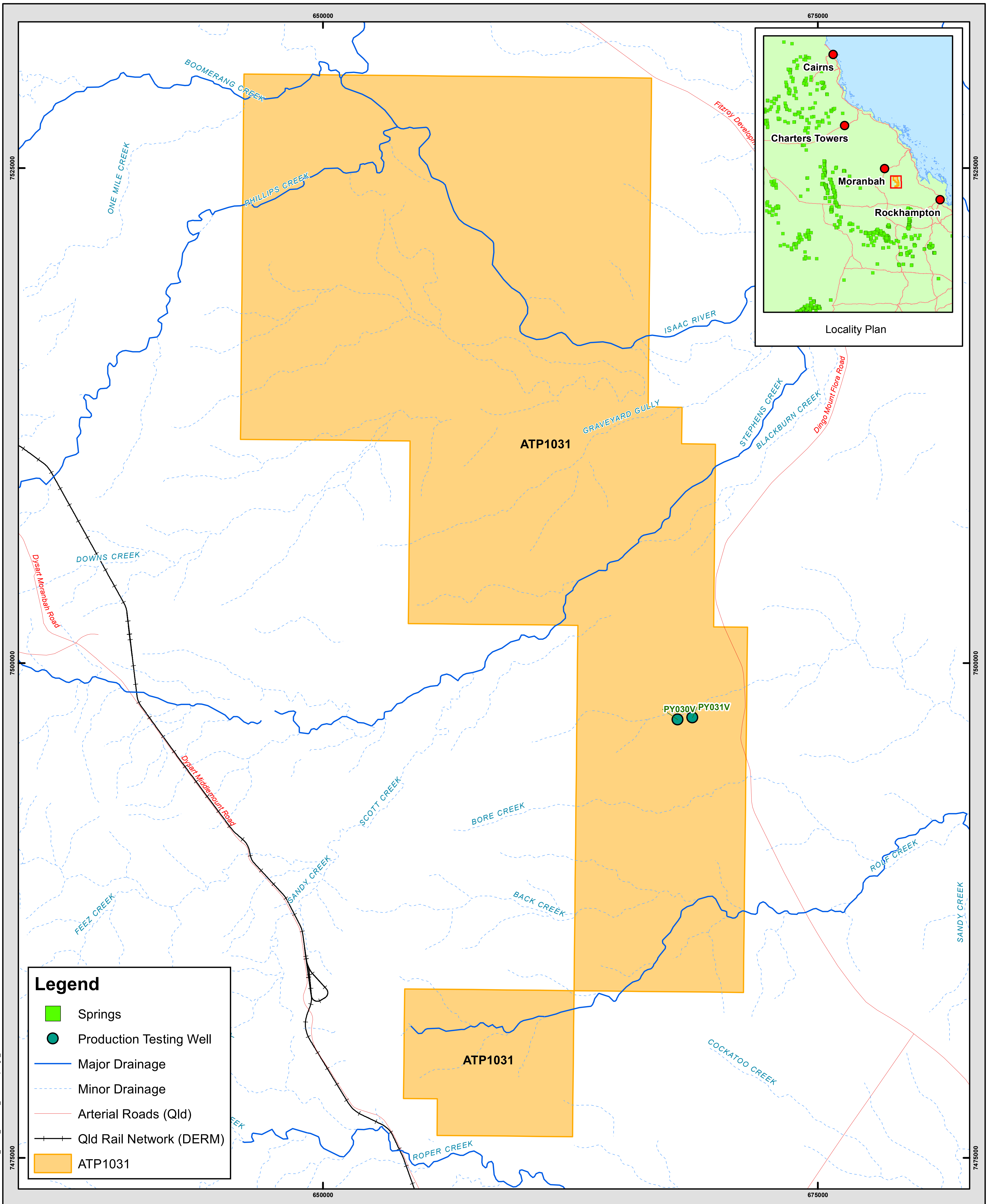

Figure 12 – Location of Springs

Source: Arrow Energy Pty Ltd
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Author: tstringer

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4 CONCEPTUAL HYDROGEOLOGICAL MODEL

A conceptual hydrogeological model has been formulated for the anticipated hydrogeological conditions within the study area. This is based on a summary of all the data presented in Sections 1, 2 and 3 of this report. There is some level of uncertainty associated with the conceptual framework as a result of data limitations.

The conceptual model does not provide detailed information at the local scale as this would require site-specific field investigations. A schematic representation of the regional conceptual model is shown in Figure 13.

Within the ATP1031 tenement, the aquifer systems are made up of the:

- Back Creek Group aquifer
- Blackwater Group coal seam aquifers
- Tertiary sediment aquifer
- Quaternary alluvium aquifer associated with Stephens Creek and Isaac River

The shallow aquifers include the Quaternary alluvium and the Tertiary sediment aquifer. The alluvium is dominantly associated with Stephens Creek and the Isaac River which cross the ATP1031 tenement. The Tertiary aquifer underlies the alluvium and outcrops over a large area of the ATP1031 tenement. The alluvium and Tertiary aquifers are classified as a porous media aquifer where groundwater occurs within the voids between individual grain particles. These aquifer systems are considered to be unconfined and semi-confined in nature. In some cases the Tertiary aquifers may be confined aquifers depending on the location, degree of weathering, the nature of the overlying alluvium and clay content. Groundwater in the alluvium aquifers have been identified to be hydraulically connected to the surface water systems within the basin with recharge occurring during stream flow events. The Isaac River and Stephens Creek in this area are ephemeral and recharge of the alluvium as well as the Tertiary aquifer is generally by surface infiltration of direct rainfall and overland flow where the alluvium is exposed and no substantial clay barriers occur in the shallow sub-surface. Recharge process in the Tertiary sedimentary aquifer may also occur via seepage from any overlying Quaternary alluvium aquifers, particularly near Stephens Creek and Isaac River. The primary discharge mechanisms for the Quaternary and Tertiary aquifers are likely to be through flow into adjacent outcropping formations, evapotranspiration or groundwater extraction. Most of the clean sand and gravel lenses in the Quaternary and Tertiary sediments are permeable but are of limited lateral and vertical extent. Thus the volume of groundwater stored and the ability to transmit groundwater depends on the particle size of the material and the saturated thickness of the sediments.

The Triassic Rewan Formation underlies the Tertiary aquifers and acts as a regional aquitard in the area. A small surface exposure of the Rewan Formation occurs in the ATP 1031 tenement. This unit is generally considered to have low porosity and permeability. In the project area, the Rewan Formation has been identified as being around 400 m thick and this is in line with the lithological logs for the wells on the ATP1031 tenement.

The coal seam aquifers of the Blackwater Group are confined from above by the Rewan Formation. The coal seams generally are dual-porosity material with primary-porosity provided by the matrix and a secondary porosity provided by fractures (joints and cleats). Natural fractures in the coal may be the dominant space for groundwater storage and the principal pathway for groundwater movement dependent on fracture interconnectivity. Groundwater recharge to the Blackwater Group aquifers occurs from infiltration of rainfall in rock outcrop areas. The Blackwater group has been identified to outcrop in some areas of the tenement and may receive throughflow from overlying or adjacent alluvium and/or Tertiary Aquifers. Groundwater is expected to discharge from the Blackwater Group aquifers down gradient and it is anticipated that groundwater flows towards the south-east and in general towards the basin axis. Groundwater discharge in some areas can also occur to adjacent alluvium or tertiary aquifers. This is evidence that the Permian formations are heterogeneous, having discrete zones of higher permeability over short distances and the very low hydraulic conductivity in the majority of the inter-burden and overburden isolate more conductive parts associated with the fracture/fault systems. The Back Creek Group underlies the Blackwater Group and is considered to be a confining unit.

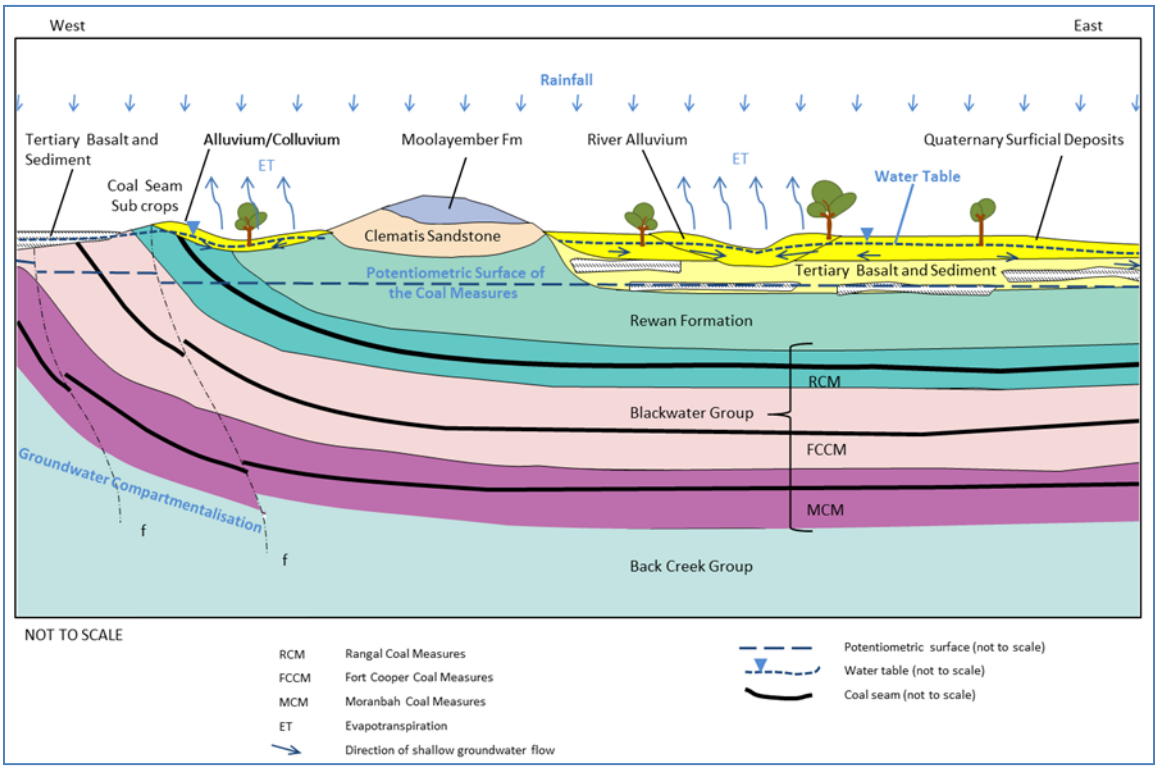

Figure 13: Regional Conceptual Hydrogeological Model

5 ANALYTICAL GROUNDWATER MODELLING

An analytical groundwater model has been used to provide estimates of decline in water level in response to the abstraction of groundwater associated with CSG activities at pilot wells PY030 and PY031 in ATP1031. The details of this are described in the following sections.

5.1 Analytical Model Set up

A two dimensional analytical solution has been used to assess the potential impacts of groundwater extraction as a result of production testing undertaken in two wells at ATP1031. 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 unique 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.

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. The vertical hydraulic conductivity (Kv) ranges from 0.00001 – 0.001 m/day for the Rewan Formation and, 0.00001 – 0.005 m/day for the Rangal Coal Measures. The storage values range from 0.000005 to 0.0005 for the Rewan Formation and the Rangal Coal Measures. The values used for the analytical model are shown in the below table and represent the “high values” (worst case) in order to undertake a conservative assessment of impacts.

Table 14: Layers and parameters used for the analytical model set up

Aquifer/Aquitard	Thickness (m)	Kv (m/day)	Storage
Rewan Formation	399 to 443	0.001	0.0005
Rangal Coal Measures	167 to 260	0.005	0.0005

The pumping regime was inputted into the model and calculations made for drawdown over time. The production testing schedule is discussed in more detail in the below section.

5.1.1 *Production Testing Schedule*

Production testing at ATP1031 has been undertaken in two wells, PY030 and PY031. A summary of production testing for both of these wells at ATP1031 is shown in the table below. It should be noted that production testing in these wells have been intermittent as can been seen by the dates in the below table. Well PY030 was pumped over the following dates:

- 21/12/2013 to 23/12/2013
- 27/12/2013 to 30/12/2013
- 15/01/2013
- 16/02/2013 to 17/02/2013
- 20/02/2013
- 30/07/2013
- 31/08/2013 to 01/09/2013

- 29/09/2013 to 22/10/2013

Well PY031 was pumped over the following dates:

- 30/07/2013
- 31/08/2013 to 01/09/2013
- 29/09/2013 to 22/10/2013

The days that fall outside of the above mentioned pumping dates for PY030 and PY031 represent days that there was no production testing, hence no production of water. The production testing regime in the analytical model has adopted the maximum consecutive amount of production testing over time which is from the 29th September 2013 to 22nd October 2013 for both of the wells.

Table 15: Production Testing Schedule ATP1031

PY030		PY031	
Date	Water Production (L/day)	Date	Water Production (L/day)
21/12/2012	7257.6	*30/07/2013*	43.2
22/12/2012	15624.0	*31/08/2013*	950.4
23/12/2012	7862.4	*1/09/2013*	259.2
27/12/2012	7257.6	*29/09/2013*	777.6
28/12/2012	20764.8	*30/09/2013*	1555.2
29/12/2012	25200.0	*1/10/2013*	1900.8
30/12/2012	19656.0	*2/10/2013*	2246.4
15/01/2013	100.8	*3/10/2013*	2764.8
16/02/2013	7862.4	*4/10/2013*	3067.2
17/02/2013	1915.2	*5/10/2013*	3326.4
20/02/2013	403.2	*6/10/2013*	3499.2
30/07/2013	100.8	*7/10/2013*	3672.0
31/08/2013	2016.0	*8/10/2013*	4017.6
1/09/2013	302.4	*9/10/2013*	4536.0
29/09/2013	1310.4	*10/10/2013*	4665.6
30/09/2013	2116.8	*11/10/2013*	4406.4
1/10/2013	2419.2	*12/10/2013*	3628.8
2/10/2013	2620.8	*13/10/2013*	4363.2
3/10/2013	3124.8	*14/10/2013*	3283.2
4/10/2013	3830.4	*15/10/2013*	2937.6
5/10/2013	4838.4	*16/10/2013*	2419.2
6/10/2013	5342.4	*17/10/2013*	3196.8
7/10/2013	6249.6	*18/10/2013*	2419.2
8/10/2013	6753.6	*19/10/2013*	2376.0
9/10/2013	8769.6	*20/10/2013*	2376.0
10/10/2013	9475.2	*21/10/2013*	2203.2
11/10/2013	6652.8	*22/10/2013*	2376.0

PY030		PY031	
Date	Water Production (L/day)	Date	Water Production (L/day)
12/10/2013	3628.8	-	-
13/10/2013	1713.6	-	-
14/10/2013	2116.8	-	-
15/10/2013	2620.8	-	-
16/10/2013	1310.4	-	-
17/10/2013	2721.6	-	-
18/10/2013	2822.4	-	-
19/10/2013	2016.0	-	-
20/10/2013	2016.0	-	-
21/10/2013	2217.6	-	-
22/10/2013	2520.0	-	-

5.2 Analytical Model Predictions

At the completion of production testing (22/10/2013) for PY030 and PY031, the water level decline is less than the bore trigger threshold of 5 m (for a confined aquifer) in the Rangal Coal Measures.

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*. They are 5 m for consolidated aquifers (such as sandstone) and 2 m for unconsolidated aquifers (such as sands).

Water level decline greater than the bore trigger threshold of 5 m (for a confined aquifer) in the Rangal Coal Measures was only observed for a limited duration between days 8 to 12 of production testing for PY030. The extent of the 5m drawdown contour for day 12 of production testing at PY030 reached a maximum of approximately 7.5 m from the well. Based on this, there was an IAA that extended a maximum of 7.5 m from PY030 only for a limited duration; however following the completion of the pilot testing, there is no longer an IAA.

Drawdown observations from 1 m and 7.5 m away from pumping well PY030 are shown in the figure below:

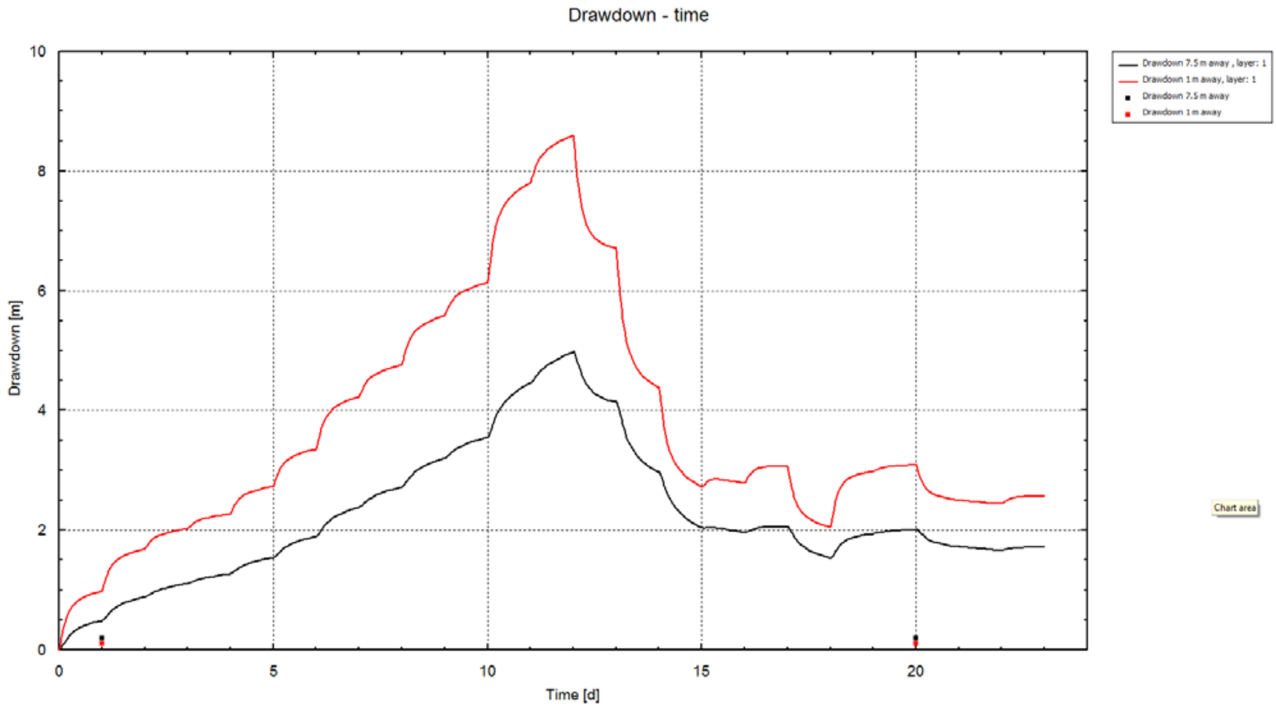

Figure 14: Drawdown observations 1m and 7.5m away from pumping well PY030

Water level decline greater than the bore trigger threshold of 5 m (for a confined aquifer) in the Rangal Coal Measures in not predicted to occur at anytime over the production testing period at PY031. Drawdown observed 1 m away from pumping well PY031 is shown in the figure below:

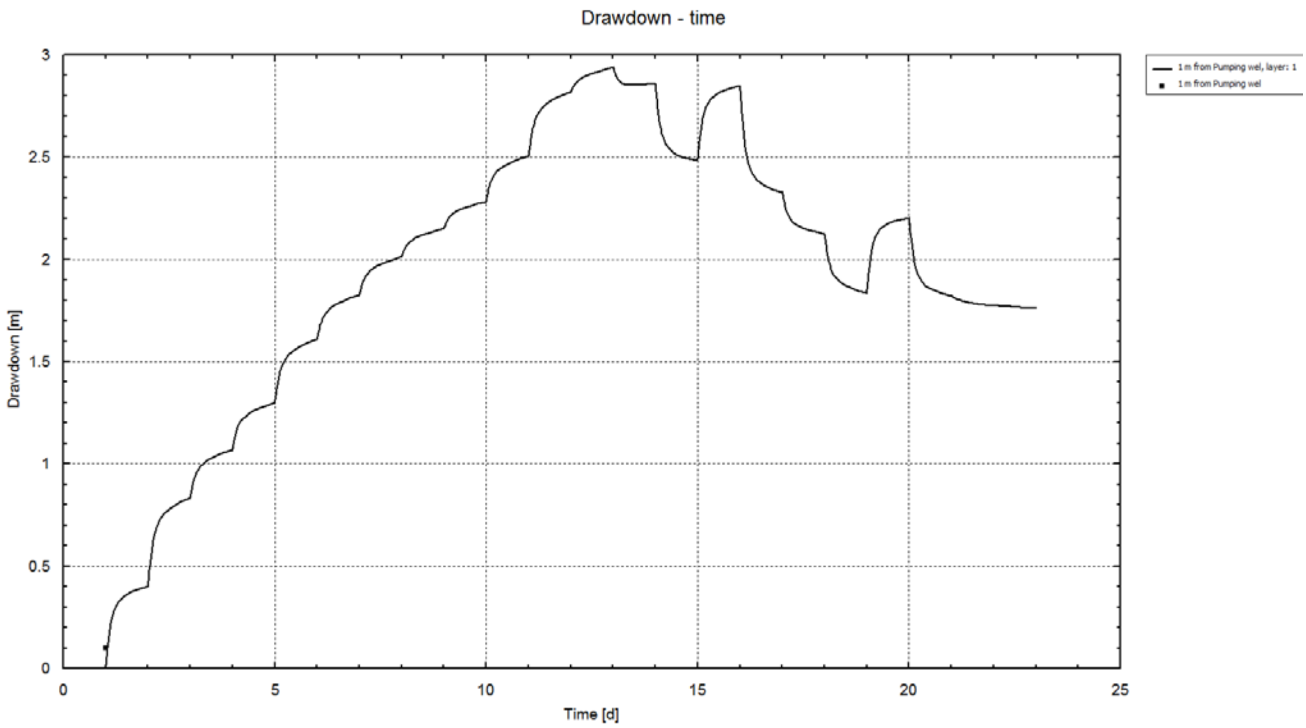

Figure 15: Drawdown observations 1m away from pumping well PY031

No maps have been produced due to the limited duration and extent of drawdown. This is effectively illustrated in the graphs above.

It is expected that any impacts to groundwater will be contained within the Rangal Coal Measures and no impacts will occur to the shallow tertiary or alluvium aquifers given that:

- Production testing occurs over a limited time for each bore and abstracts a limited amount of water. The amount of water produced from the pilot testing wells is low (cumulative total of ~0.3 ML);
- The thickness of the RCM at the well sites range from 167 m to 260 m;
- The thickness of the overlying Rewan Formation aquitard at the well sites range from 399 m to 443 m and separates the RCM from the shallow Tertiary and Quaternary aquifers. The Rewan Formation forms and effective barrier for inter-aquifer flow ; and
- The production test wells are fully cased and cemented between different hydrogeological units.

The location of the nearest registered bore is ~2.8 km (RN67251) and is identified as being screened in the Blackwater Group with a total depth of 23 m. The production testing bores target the coal measures at depths greater than 400 m. The maximum extent of the 5 m drawdown contour resulting from production testing at PY030 only extends 7.5 m away from the production testing well. Based on this, no impacts are expected to occur for the nearest registered bore RN67251. Therefore, a summary of information about water bores including the number of bores, location, authorised use or purpose of each bore is not applicable or required.

Based on this, no IAA or LAA is predicted for production testing completed at wells PY030 and PY031.

6 WATER MONITORING STRATEGY

It is concluded that there are no impacts to groundwater resulting from extraction of underground water during and after production testing within ATP1031. The following supports this conclusion:

- limited volumes of water (~0.3 ML) were taken during production testing carried out between December 2012 and October 2013;
- shallower aquifers are separated from the perforated intervals of the production testing wells by intervening lower permeability formations;
- production testing wells are fully cased and cemented;
- Analytical modelling indicates a limited extent (7.5 m) and duration (~5 days) of water level decline in excess of the bore trigger threshold within the RCM for well PY030, following which water level decline is less than 5m
- No expected impacts resulting in water level decline to the shallow aquifers
- Baseline Assessments have been completed for the pilot testing on ATP1031. No landholder bores were found to exist with a 2km radius of the two pilot testing wells PY030 and PY031.
- The nearest registered landholder bore is located ~2.8 km away from the production testing wells and will not be impacted by the production testing that has been undertaken at PY030 and PY031

Based on this, a Water Monitoring Strategy is not proposed, given that there is no material impact.

Should further production testing take place at any time in the future, then the proposed water monitoring strategy includes:

- The quantity of water produced will be recorded in accordance with the *Water Act 2000*
- The baseline assessment plan for ATP 1031 will be updated. A baseline assessment of identified bores within a 2 km radius of the proposed production test will be undertaken.
- The pilot bores will be monitored to assess the change in water level in the affected aquifer
- The UWIR will be updated at the three year review date to include the impacts of new production testing in the predictions only if material changes are likely.

7 SPRING IMPACT MANAGEMENT STRATEGY

No springs have been identified to exist within proximity of PY030 and PY031 or ATP1031. Therefore, based on available data, impacts to springs as a result of the project area activities will not occur. In addition to this, it is expected that there will be no impacts to Quaternary alluvium aquifer from production testing at ATP1031. Based on this a spring impact management strategy is not required to be prepared.

8 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 has been undertaken or is planned; and
- whether the predictions made in Section 5 have materially changed.

The implementation of the water monitoring strategy will be reported to the commission on an annual basis in conjunction with the annual UWIR review.

The proposed schedule for the review will comprise public consultation on the three year anniversary date and subsequent DEHP review and report dissemination as required by the Water Act (2000).

Glossary

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.
Anisotropy	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.

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

Fresh Water	Water containing low salt concentrations, typically less than 1,000 mg/L. (Compare Brackish, Saline and Brine).
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 recrystallisation due to heat, pressure or chemical precipitation.
Infiltration	Rainfall penetration into the soil profile or sub-surface. Infiltrated water that accesses the watertable is one component of groundwater recharge.
Jumpups	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.
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 watertable 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.
Watertable	The top of the saturated zone in an unconfined aquifer.
Well	A hole drilled into a groundwater resource (aquifer), oil or gas resource reservoir) and constructed with a casing and screen or similar. In Australia also commonly referred to as a 'bore'.
Well Field	A group of boreholes in a particular area having a common use, such as for groundwater, oil or gas extraction.
Well Yield	The flow rate obtainable from an extraction well or bore.

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