14

GROUNDWATER

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14 Groundwater

14.1 Introduction

The groundwater section includes a description of recognised groundwater environmental values within and adjacent to the Project area tenements and an assessment of potential impacts on these values. Potential impacts as a result, direct or indirect, from the construction, operation and decommissioning of the Project. Groundwater impacts may extend beyond tenement boundaries; therefore, the groundwater impact assessment has considered the regional groundwater system of central Queensland's Bowen Basin in terms of baseline data collation, hydrogeological interpretation, and impact assessment.

This section also describes groundwater environmental protection commitments, including objectives, mitigation, monitoring, and management measures developed to protect the recognised groundwater environmental values. The *significance assessment method* was adopted for this process and is described in the Impact Assessment Method chapter (Section 6) of this EIS. The *significance assessment method* provides a 'framework' that allows for the consideration and inclusion of new information that is obtained during the design, construction and operation phases of the Project.

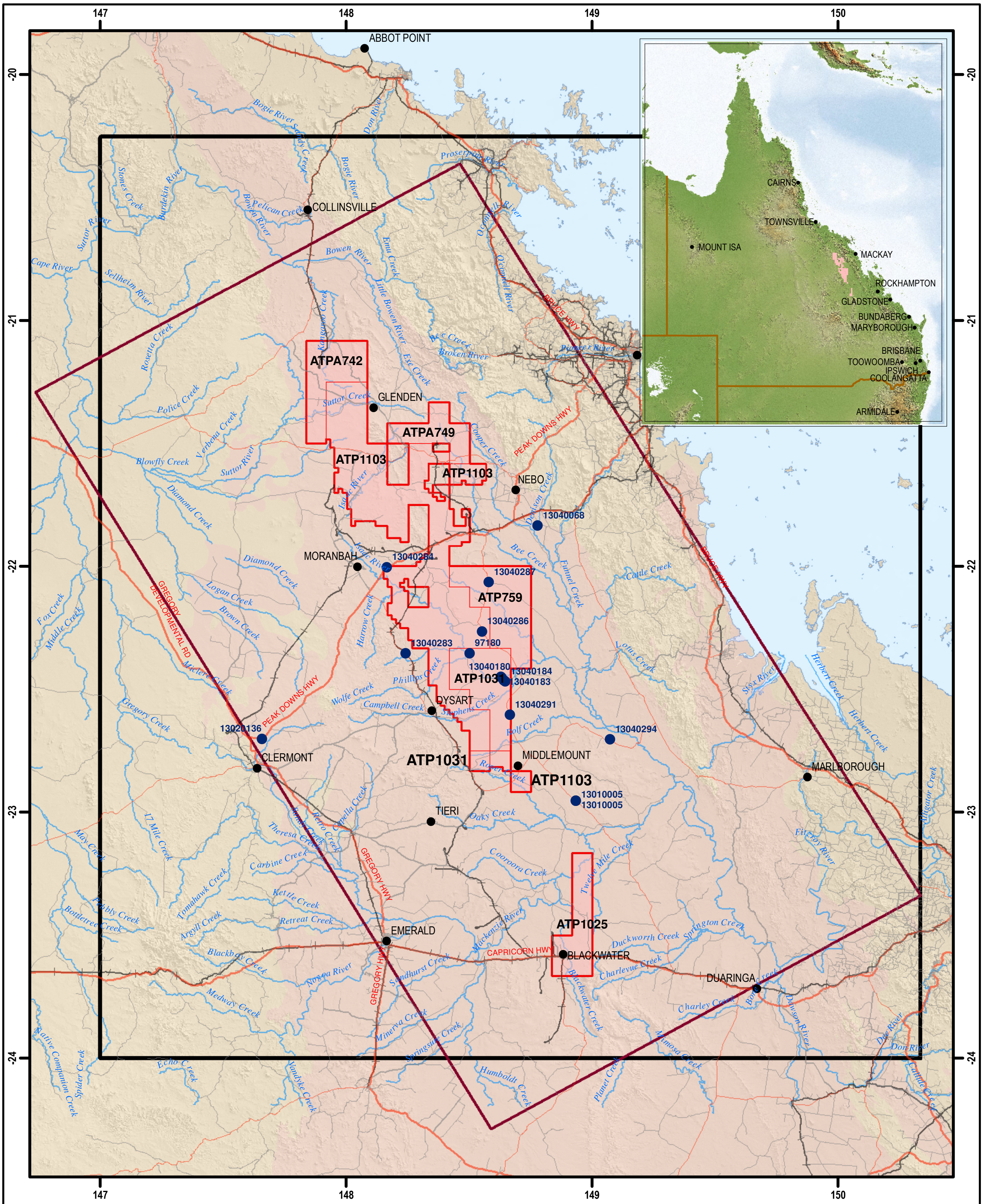
The hydrogeological study area includes the Project area tenements and the outer geological (and hydrogeological) boundary of the Bowen Basin (Figure 14-1) in line with the numerical groundwater model domain. A description of the Project area and study area is provided in other relevant sections of this EIS.

For further technical details refer to the following two reports:

1. Groundwater and Geology Technical Report (Appendix L); and
2. Groundwater Model Technical Report (Appendix M) of this EIS.

The first report provides an assessment of the groundwater aspects of the proposed development, including recognised environmental values, potential impacts, and mitigation measures. The second report describes a numerical groundwater model that was developed for this EIS, specifically to provide groundwater drawdown predictions associated with the proposed CSG production.

A cross reference to the locations where each of the requirements of the ToR has been addressed is given in Appendix B which references both the study chapters (Sections 1 through 34) and/or the Appendices (A through EE).



Project Area	Primary Road
Bowen Basin	Other Road
Study Area	Railway
Rotated Model Domain	Watercourse
Referenced Bore	

N / W / E / S

0 10 20 40 60 km

1:2,400,000

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BOWEN GAS PROJECT EIS

GROUNDWATER STUDY AREA

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GROUNDWATER

Figure: **14-1**

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14.2 Legislative Requirements

The primary legislative requirements that guide the management and development of groundwater components for the Project are listed below and summarised in Table 14–1:

- *Environmental Protection Act 1994* (EP Act);
- *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act);
- *Water Act 2000* (Qld) (Water Act);
- *Petroleum and Gas (Production and Safety) Act 2004* (P&G Act);
- *Water Resources (Great Artesian Basin) Plan 2006;*
- *Great Artesian Basin Resource Operations Plan 2007*;
- *Water Supply (Safety and Reliability) Act 2008*;
- *Environmental Protection (Water) Policy 2009* (EPP (Water));
- *Sustainable Planning Act 2009*;
- *Queensland Coal Seam Gas Water Management Policy 2010*[1]*;*
- *Fitzroy Basin Water Resource Plan 2011* (Fitzroy Basin WRP); and
- *Water Resource (Burdekin Basin) Plan 2007* (Burdekin Basin WRP).

The ToR also requires a description of the existing environmental values of groundwater identified in the EPP (Water) and an evaluation of the quality, quantity, and significance of artesian and non-artesian groundwater resources in the Project area. The groundwater environmental values are discussed in Section 14.6.

Table 14-1 Summary of Relevant Policies, Guidelines and Legislation to the Project Area

Policy, Guidelines or Legislation	Description	Relevance to Project – Groundwater Impact Assessment
EP Act (reprinted as in force 14 August 2012)	The objective of the EP Act is to protect the Queensland environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (Queensland Government, 2012). Subordinate to this Act is the Environmental Protection Regulation 2008, which provides for the effective administration and enforcement of the objectives and provisions of the EP Act.	All persons must not carry out any activity that causes, or is likely to cause, environmental harm unless the person takes all reasonable and practical measures to prevent or minimise the harm (Section 319 of the EP Act). This general duty to the environment requires the implementation of proactive measures to prevent environmental degradation and act in accordance with the precautionary principle. This requirement is underpinned by the impact assessment and mitigation process in this study.

[1] The DERM Coal Seam Gas Water Management Policy 2010 was superseded by the DEHP Coal Seam Gas Water Management Policy 2012 on 21/12/2012, subsequent to the compilation of the Draft Bowen Gas Project EIS. Arrow are reviewing the updated policy at the time of the Bowen Gas Project EIS being published, and may undertake further amendments to the Arrow CSG Water and Salt Management Strategy (Appendix AA) in keeping with the updated DEHP policy, as part of a supplementary report to the EIS

<table>
<tr><th>Policy, Guidelines or Legislation</th><th>Description</th><th>Relevance to Project – Groundwater Impact Assessment</th></tr>
<tr><td>EPBC Act</td><td>The purpose of the Act is to provide for the protection of matters of national environmental significance (MNES), including groundwater dependant ecosystems (GDEs) and MNES species that rely on springs.</td><td>The Project is considered under the EPBC Act, as the EPBC Act is triggered for assessment of MNES. For groundwater this would be for assessment of impacts to mound springs or significant species habitat from drawdown.</td></tr>
<tr><td>Water Act</td><td>The purpose of the Water Act is to provide for the sustainable management and efficient use of water and other resources, a regulatory framework for providing water services and the establishment and operation of water authorities.
Water resource plans have been developed to define the availability and allocation of water and to ensure the sustainable management of water in Queensland. The objectives of the water resource plans are to balance the needs of humans and the environment in a sustainable manner.
The Water Act defines the responsibilities and requirements of petroleum tenure holders within a Cumulative Management Area (CMA) and the role of the chief executive (Queensland Water Commission (QWC)) over a CMA.</td><td>Water use and the obligations, processes, and framework for CSG producers and petroleum tenure holders in relation to groundwater monitoring, reporting, impact assessment and management of impacts on other water users including ‘make good’ agreements is regulated under the Act.
The most southerly Project tenement, Authority to Prospect (ATP) 1025 around Blackwater, is located within the Surat CMA (refer Appendix A of the Groundwater and Geology Technical Report (Appendix L) of this EIS).</td></tr>
<tr><td colspan="3">The Water Act includes the following provisions:
• To protect landholders’ existing and new water supply bores from the impact of petroleum tenure holders extracting groundwater, by establishing trigger thresholds and make good obligations for tenure holders, including the requirement for bore assessments;
• For petroleum tenure holders to undertake baseline assessments of water bores;
• For tenure holders to manage their impact on natural springs through the development of a spring impact management strategy;
• The management of cumulative impacts of groundwater extraction by petroleum tenure holders by providing for the declaration of CMA;
• For Underground Water Impact Reports;
• To appoint the QWC as an independent management body to oversee the groundwater impacts of the petroleum industry; and
• For a dispute resolution process for the negotiation of make good agreements.
The Queensland Government has set trigger thresholds for impacts to water bores and springs under the Water Act. The trigger thresholds are used to investigate an individual operators’ impact that may cause a decline in water levels and potentially reduce the ability of a water bore to supply water to the bore owner for its intended use. Trigger thresholds are defined below.

<u>Bores:</u>
Bore Trigger Threshold - for an aquifer, means a decline in the water level in the aquifer that is:
a) If a regulation prescribes the bore trigger threshold for an area in which the aquifer is situated the prescribed threshold for the area; or
b) Otherwise:
— For a consolidated aquifer – 5 m; or
— For an unconsolidated aquifer – 2 m.</td></tr>
</table>

Policy, Guidelines or Legislation	Description	Relevance to Project – Groundwater Impact Assessment
Springs: Although springs are not recorded to occur in the potential impact area for the Project, the thresholds for springs are described below for reference. The spring trigger threshold, for an aquifer, means a decline in the water level of the aquifer that is: a) If a regulation prescribes the threshold for a particular area the prescribed threshold for the area; or b) Otherwise 0.2 m. Other Users: CSG producers have an obligation to manage the impacts of their water extraction on other water users and on springs in accordance with the requirements of the Water Act. The aims of the trigger levels are considered to include the following: a) To set trigger levels which are distinguishable from natural variation; and b) Set trigger levels that focus monitoring, assessment and make good efforts on genuinely affected bores. If numerical groundwater modelling indicates that an aquifer has the potential to exceed the trigger levels within three years, bores within that area are identified as being within an 'immediately affected area' and the petroleum tenure holder is obliged to undertake a bore assessment (if no baseline assessment has been undertaken) and negotiate a make good agreement with the bore owner. The make good agreement will identify the make good measures to be undertaken by the responsible tenure holder if a bore has an impaired capacity due to CSG activities. Where there may be cumulative impacts due to overlapping tenures, the government will declare a CMA. The QWC has an expanded role under the new arrangement which is to oversee the management of regional cumulative groundwater impacts in a CMA and be responsible for managing activities including: • Preparing an underground water impact report for the CMA; • Modelling impacts on groundwater; • Predicting impacts as a result of water extraction by petroleum tenure holders and designating the responsible tenure holder for specific areas within the CMA; • Maintaining systems to store data; and • Providing independent advice to the chief executive of the EHP.		
P&G Act	The purpose of the P&G Act is to facilitate and regulate the carrying out of responsible petroleum activities and the development of a safe, efficient and viable petroleum and fuel gas industry. Requirements of underground water obligations for associated water (i.e. monitoring) is also identified in the Act.	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.
Water Resources (Great Artesian Basin) Plan 2006	The Water Resources (Great Artesian Basin) Plan 2006 is the primary legislation for groundwater management of the Great Artesian Basin (GAB) in Queensland.	The most southerly tenement of the proposed Project (ATP 1025) includes a portion of the GAB recharge area.

Policy, Guidelines or Legislation	Description	Relevance to Project – Groundwater Impact Assessment
Great Artesian Basin Resource Operations Plan 2007	The Plan identified 25 'groundwater management areas' and associated 'groundwater management units'. A groundwater management unit corresponds to a group of formations and a specified upper annual allocation of groundwater.	The Mimosa Management Area (Number 22) is located within the Project area and includes the southeast corner of ATP 1025 and overlaps in three sections (Figure 14-2). Due to the limited overlap with the Mimosa Management Area, the above mentioned GAB plans are not of significant relevance to the current Project.
The Water Supply (Safety and Reliability) Act 2008	The purpose of the Act is to provide for the safety and reliability of water supply in Queensland. The Act sets out requirements for Environmental Management Plans and obligations in relation to the potential to impact on drinking water supplies.	The Project is automatically captured by this process for injection, direct supply or discharge of water, however; an exemption can be applied for.
EPP (Water)	The purpose of the Policy is to achieve the objectives of the EP Act in relation to Queensland waters while allowing for ecologically sustainable development.	The environmental values are to be enhanced or protected (Section 6 of the Act). The relevant environmental values vary depending on the ecological value of the water, level of disturbance and intended use of the water. The management controls / mitigation measures in this study were prepared to meet the requirements of this policy.
Sustainable Planning Act 2009	The purpose of the Act is to regulate the development of infrastructure outside petroleum tenures.	The Project is within the Isaac Connors Groundwater Management Area (GMA) where any works for taking or interfering with water for purposes other than stock or domestic use (other than small diameter groundwater monitoring bores) are assessable activities and require a development permit.
Queensland Coal Seam Gas Water Management Policy 2010[2]	The purpose of the Policy is to ensure that salt produced through the generation of CSG water does not adversely impact the environment, and to maximise the opportunities for beneficial use of the water.	The policy requires the preparation of a CSG water management plan describing the options for management and disposal of CSG water and salt.
Fitzroy Basin Water Resource Plan 2011	The WRP provides for the allocation and management of water in the Fitzroy Basin and the subordinate legislation under the Water Act.	Tenements in the northern portion of the Project area are located within the declared Isaac Connors GMA, as defined under Chapter 2, Section 7, Schedule 3, Schedule 4, and Schedule 7 of the Fitzroy Basin WRP. Any long-term water take or interference from groundwater sources requires authorisation by way of a licence.

[2] The DERM Coal Seam Gas Water Management Policy 2010 was superseded by the DEHP Coal Seam Gas Water Management Policy 2012 on 21/12/2012, subsequent to the compilation of the Draft Bowen Gas Project EIS. Arrow are reviewing the updated policy at the time of the Bowen Gas Project EIS being published, and may undertake further amendments to the Arrow CSG Water and Salt Management Strategy (Appendix AA) in keeping with the updated DEHP policy, as part of a supplementary report to the EIS.

Policy, Guidelines or Legislation	Description	Relevance to Project – Groundwater Impact Assessment
Burdekin Basin Water Resource Plan2007	The WRP provides a framework for sustainably managing water and the taking of water within the plan area.	The Project location is a long distance upstream from the closest Burdekin WRP environmental flow objectives (EFO) node (refer to the Surface Water Technical Report (Appendix N) of this EIS) and the Project area is a very small portion of the total catchment to the closest EFO location; the Project will not materially impact on the State's ability to achieve statutory EFO prescribed in the Burdekin WRP.

14.3 Groundwater Management Areas

Authorisation from the Department of Natural Resources and Mines (NRM) is required to take groundwater in sub-artesian areas declared under the Water Act, Water Resource Plans, and the Water Regulation 2002. The majority of the Bowen Basin, south of Nebo (-21.68°S), is within the Highlands Sub-Artesian Area. The Highlands Sub-Artesian Area is a declared groundwater management area (GMA) (Figure 14-2). Stock and domestic bores within the Highlands Sub-Artesian Area do not require an NRM water licence whilst other applications, including irrigation, industrial, mining, commercial etc. do require licenses.

The *Water Resource (Great Artesian Basin) Plan 2006* and the *Great Artesian Basin Resource Operations Plan* define 25 management areas for the GAB. Of these, only the Mimosa Management Area (No. 22) is located near the Project area where it overlaps the edge of ATP 1025 in three small areas (Figure 14-2).

14.4 Hydrogeological Overview

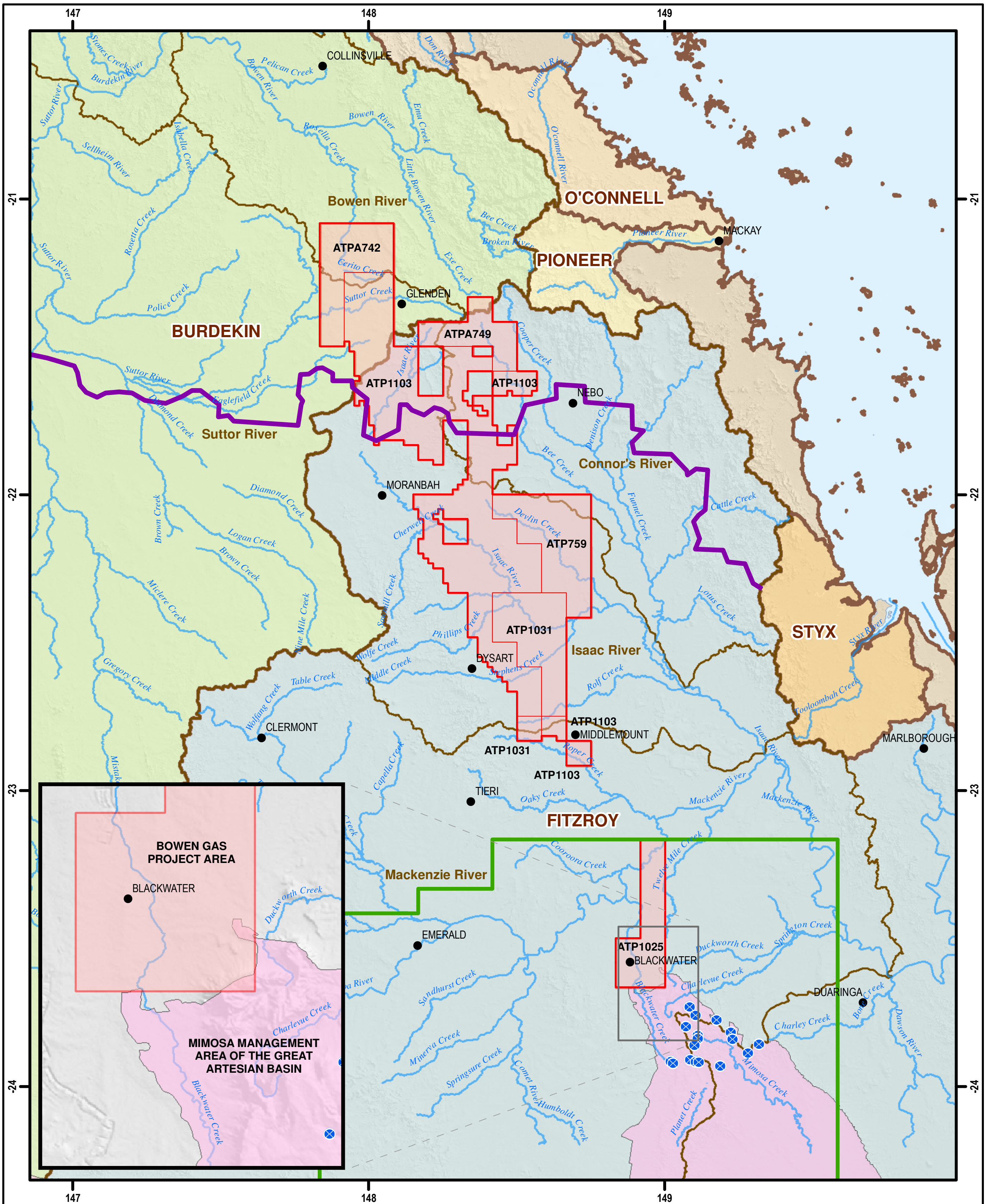
14.4.1 Hydrostratigraphy

The Project area is situated on the interior plains of the Bowen Basin and oriented north-south and parallel with the ancient drainage pattern and greatest thickness of sediment successions, as described in the Geology chapter (Section 13) of this EIS. The sediment successions that are relevant to the Project area are classified in Table 14-2 in terms of hydrostratigraphy.

The Back Creek Group comprises sandstone, siltstone, shale and minor coal and is considered a semi-pervious lower boundary for groundwater flow to the overlying Blackwater Group coal measures. The Blackwater Group is overlain by the Mimosa Group, of which only the Rewan Formation occurs extensively in the middle of the basin (Figure 14-3). Thickness of the Rewan Formation ranges across the Bowen Basin up to 800 m thick (in the depocentre of the basin) with a typical thickness of approximately 300 m in the Project area. The Rewan Formation is a semi-pervious barrier to vertical groundwater flow that acts as a confining unit across the Project area and is a basal confining layer of the GAB (Habermehl, 1980; Habermehl and Lau, 1997; Habermehl, 1998).

The Clematis Sandstone (a major GAB aquifer) and the Moolayember Formation (a GAB confining unit) occur as elevated outcrops in the Project area southeast of Glenden, and near the Project area southeast of Blackwater.

The Triassic and Permian sedimentary successions are overlain by isolated basaltic lava (Tertiary) outcrops, areas of Suttor Formation (Tertiary), and areas of Duaringa Formation (Tertiary). Extensive alluvial deposits (Quaternary) also occur along rivers, creeks and floodplains within the Project area.



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Bowen Gas Project Tenements	Mimosa Management Area of the Great Artesian Basin Highlands Sub-Artesian Area
Drainage Basin Boundary	Northern Boundary of Surat Catchment Management Area
River Catchment Boundary	Spring
	Watercourse
	Northern Boundary of the Highlands Sub-Artesian Area

N / E / S / W

0 10 20 40 60 km

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Projection: Geographic (GDA94)

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BOWEN GAS PROJECT EIS

SURFACE CATCHMENTS AND GROUNDWATER MANAGEMENT AREAS OF THE STUDY AREA

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Figure: 14-2

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Table 14-2 Hydrostratigraphy of the Project Area

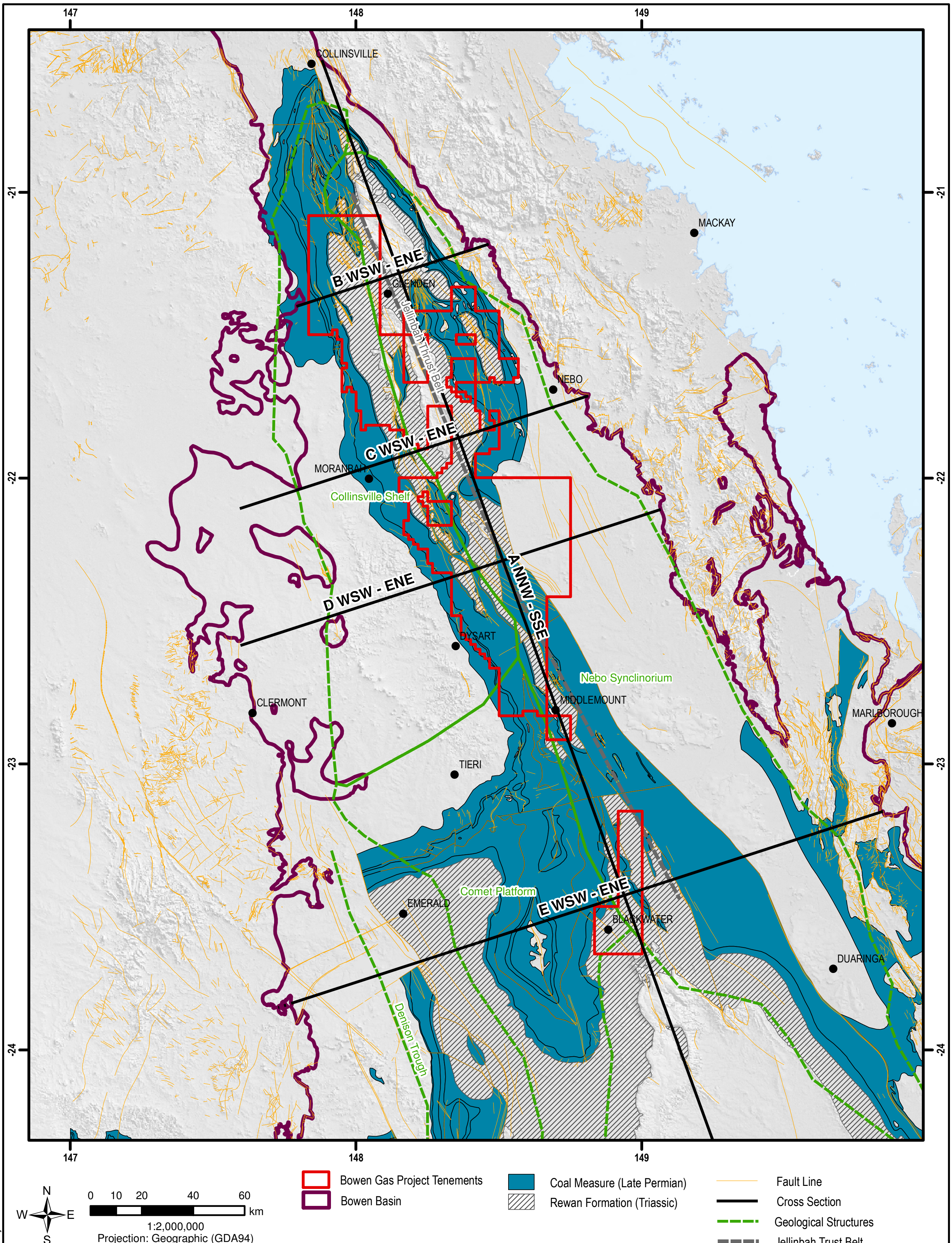
Age	Stratigraphic Unit		Lithology	Typical Thickness (m)	Aquifer Type
Quaternary	Alluvium		Clay, silts, sand, gravel, floodplain alluvium	15-35	Unconfined (resource aquifer)
Tertiary	Suttor Formation		Clay, silt, sand, gravel, colluvium, fluvial and lacustrine deposits including cross-bedded quartz sandstone, 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 – base hydrogeological GAB
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 and equivalents		Coal, brown and green sandstone, conglomerate, carbonaceous shale, tuff	100-600	Confined aquifer (coal) and confining unit (interburden)
	Moranbah Coal Measures		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

14.4.2 Aquifers and Aquitards

The regional-scale aquifers in the central plains of the Bowen Basin were described in the previous section (Table 14-2) and are illustrated in a conceptual model of a west-east cross-section through the Project area (Figure 14-4). Each of the major aquifers and aquitards in the conceptualisation are described below. Figure 14–4 also shows the basic features of the hydrologic cycle, typical fault systems and groundwater flow directions.

The main resource aquifer is the Quaternary alluvial aquifers that occur in discontinuous lenses along major streams and rivers throughout the Isaac River and Mackenzie River sub-catchments.

Groundwater in the alluvium is generally ephemeral and strongly linked to surface water flow. At certain times and locations the alluvium may be partially saturated or even dry. The most significant and reliable groundwater resources occur outside the Project area in Fennel Creek, Nebo Creek, Denison Creek and the Connors River.



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BOWEN GAS PROJECT EIS

IMPORTANT STRUCTURAL ELEMENTS OF THE STUDY AREA

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Figure: 14-3

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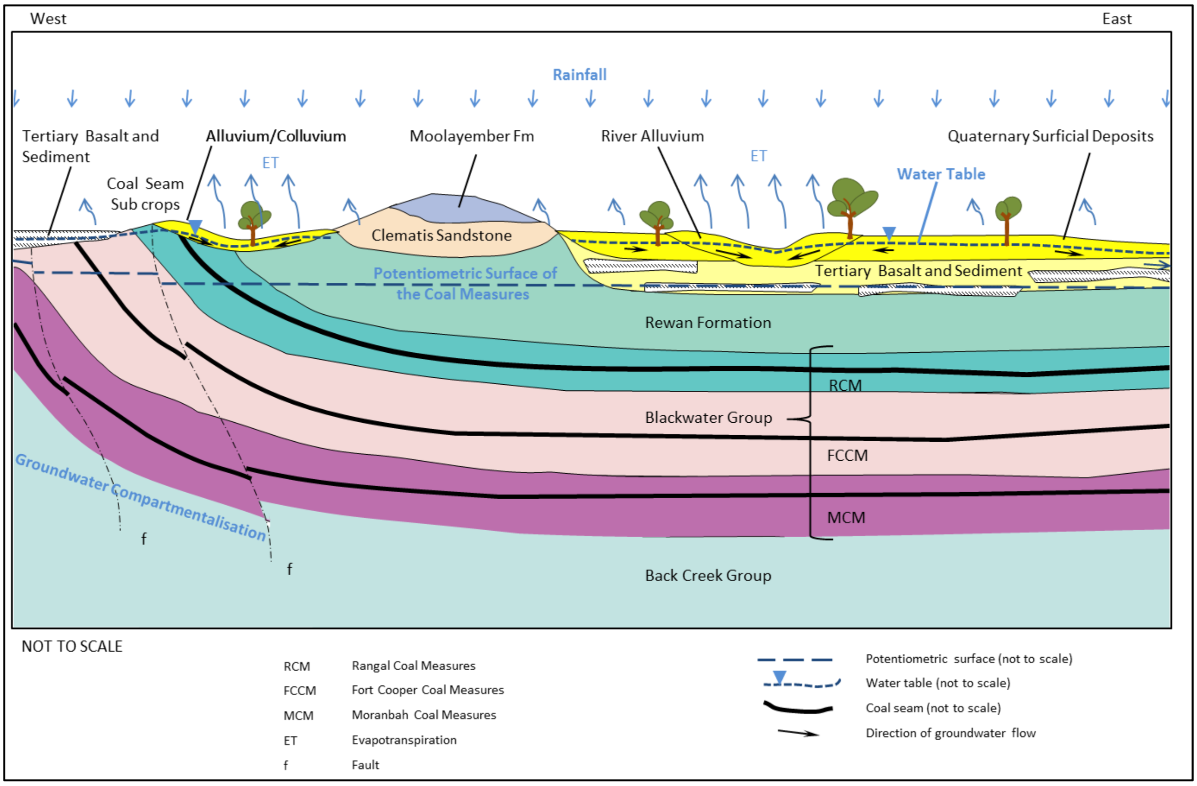
Figure 14-4 Basic Conceptual Hydrogeological Model of the Project Area Prior to Development



Tertiary basalt aquifers are a locally important groundwater resource within the Bowen Basin that occurs mostly along the northwest and eastern fringes of the Basin. These aquifers occur extensively in Authority to Prospect Application (ATPA) 742 and ATP 1103, and are discontinuous and heterogeneous due to weathering and jointing of the basalt. The groundwater of the Tertiary basalt aquifers is typically of poor quality. Shallow Tertiary age sediments, including the undifferentiated sediments, Suttor Formation, and Duaringa Formation, occur in the Project area but these are considered 'poor aquifers' or 'aquitards' depending on local bore yields and water quality.

The GAB Clematis Sandstone aquifer occurs only as isolated outcrops in the northern part of the Project area and southeast of ATP 1025, near Blackwater. The Moolayember Formation aquitard overlies the Clematis Sandstone in some locations.

The confined coal seams of the Permian Blackwater Group are targeted for CSG production in the Project area. The coal seams are the most permeable aquifer units within the Project area and contain saline-sodic groundwater. Bores constructed in the coal seams produce low-to-moderate yields and the groundwater is brackish and unsuitable for agricultural or domestic use.

The main aquitards, shown in Figure 14-4, are the Rewan Formation and the interburden layers of the Blackwater Group (Permian). The coal seams of the Blackwater Group are confined from above by the Rewan Formation (along the central axis of the Bowen Basin) and by interburden layers of low-permeability shale, mudstone and siltstone. In the centre of the Project area, between Dysart and Middlemount, the confining Rewan Formation narrows.

The Back Creek Group (Permian) is a regional-scale aquitard that underlies the Blackwater Group, and is considered the basement of the Project area.

14.4.2.1 Quaternary Alluvium Aquifers

The total alluvial area in the Isaac Connors sub-catchment is approximately 295,000 ha. The distribution of the Quaternary alluvium (Figure 14-5) occurs mainly along the Upper Isaac River and Stephens Creek, and typically has a saturated thickness of 15 to 25 m. Quaternary alluvium consists of irregular sequences of unconsolidated clay, silt, sand and gravel, with a typical thickness between 15 and 35 m. Groundwater within the alluvium is generally unconfined and possibly semi-confined where overlain by clay.

The alluvial deposits are generally thin, linear, irregular and lensoidal. This is due to the meandering and braided nature of the depositional environment that includes cross-cutting and reworking of older alluvial deposits. The alluvium is also discontinuous because of bedrock and bounding by clays. The Upper Isaac River has well-defined alluvial channels, whereas the Lower Isaac River (outside the Project area) has anabranches. Along Funnel Creek, east of the Project area, the alluvium is heavily braided.

Alluvial groundwater resources are exploited along the Isaac River but the distribution of production bores is erratic (Pearce and Hansen, 2006). A ground penetrating radar (GPR) survey along the Isaac River, north of Moranbah, (JBT Consulting, 2010) indicated that 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 not saturated year round. Available drilling data further 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). Due to the generally shallow saturated thickness and the lack of continuity of the more permeable gravel and sand sections, the Quaternary alluvium is not considered a significant aquifer. However, during periods of creek or river flow, the alluvium may become fully saturated.

The major productive aquifers in the region are located outside the Project area in the river alluvium of Cooper Creek, Denison Creek, Funnel Creek, and Connors River, and include the Braeside borefield, a groundwater supply scheme located in alluvium (SKM, 2009a).

The Quaternary alluvial 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 alluvial aquifers within the Bowen Basin.

14.4.2.2 Tertiary Sediment Aquifers

The Tertiary sediments include the undifferentiated sediments, Suttor Formation and Duaringa Formation (Figure 14-5), and are generally comprised of palaeochannel gravels and sands separated by sandy silts, sandy clays and clays. Much of the Tertiary sequence is concealed by overlying Quaternary alluvium and colluvium.

The Tertiary sediments generally consist of a lens of palaeochannel gravels and sands separated by sandy silts, sandy clays and clays. The Tertiary sediments in the Project area is comprised of mud, sands, gravels, residual soils of the undifferentiated Tertiary strata; as well as the sandstone, mudstone, claystone, minor oil shale, diatomite, and carboniferous claystone of the Suttor Formation.

Tertiary basalt flows occur as small discontinuous remnants within the Tertiary sediments, and act as thin sediment covers in some areas. Thicker remnant flows have filled former drainage systems and palaeochannels and can act as aquifers themselves (Section 14.4.2.3). A review of relevant borehole logs (near Moranbah) showed the Tertiary sediments vary in thickness up to 80 m with a typical thickness of approximately 15 m. The thickness and extent of these Tertiary sediments are variable and for the most part, groundwater resources are limited and typically have poor quality.

The Duaringa Formation contains mudstone and siltstone (i.e. low permeability strata); however it does contain modest amounts of groundwater in places. This is evidenced by 15 registered bores in the northern Bowen Basin that yield groundwater from the formation (Section 14.5.1.1).

The Tertiary sediment aquifer(s) is classed as a primary porosity aquifer where groundwater movement is via inter-granular flow. Depending on the location, degree of weathering and clay content, this aquifer can be confined or unconfined.

14.4.2.3 Tertiary Basalt Aquifers

An aeromagnetic geophysical survey has been undertaken over the Bowen Basin (GSQ, 2004). The resultant magnetic data indicates that Tertiary basalt exists as small discontinuous remnants. In the Project area, an isolated mass of Tertiary basalt exists near Moranbah, which is composed of flat lying flows that contain a high number of vesicular layers. In general, the basalt is less than 50 m thick and almost completely weathered (Pearce and Hansen, 2006). The vesicular basalt acts as localised, discontinuous aquifers within the Tertiary sediments, both adjacent to and beneath the Quaternary alluvial aquifers in the Project area.

For the majority of exploration boreholes that intersected basalt, the basalt is logged as highly to extremely weathered, clayey and dry. Groundwater is principally stored and transmitted in the fractures, joints and other discontinuities within the basalt. 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 recharge is low. Depth to groundwater in the Tertiary basalt aquifers have historically been measured at between 23 and 34 metres below ground level (mbgl) (AGE, 2004). Palaeo-soils have been recorded between some basalt flows and typically provide storage and increased hydraulic conductivity to the Tertiary basalt aquifers. These soils typically consist of lenses of river channel gravels and sands separated by sandy silts and clays, and are located within the irregular erosional surface of the Permian strata and covered by basalt flows.

14.4.2.4 Clematis Sandstone Aquifers

The Clematis Sandstone has been mostly eroded from the northern Bowen Basin, however, a few remnants occur in outcrops as topographic highs with a northwest-southeast orientation spanning ATPA 742, ATP 1103, and ATP 759 (Figure 14-5). There are no registered monitoring bores within these remnants and, in terms of regional flow, appear disconnected as they are underlain by the Rewan Formation. Further south, near the south-eastern side of ATP 1025, the Clematis Sandstone occurs in outcrop as a large plateau known as the Blackdown Tableland National Park, which is underlain by the Rewan Formation (aquitard).

The Clematis Sandstone is considered an aquifer (Worley Parsons, 2010); however, within the Project area it has no known groundwater resources. A literature review of the aquifer properties of the Clematis Sandstone (refer Groundwater and Geology Technical Report (Appendix L) of this EIS) indicates moderate to good aquifer permeability and porosity.

14.4.2.5 Rewan Formation Aquitards

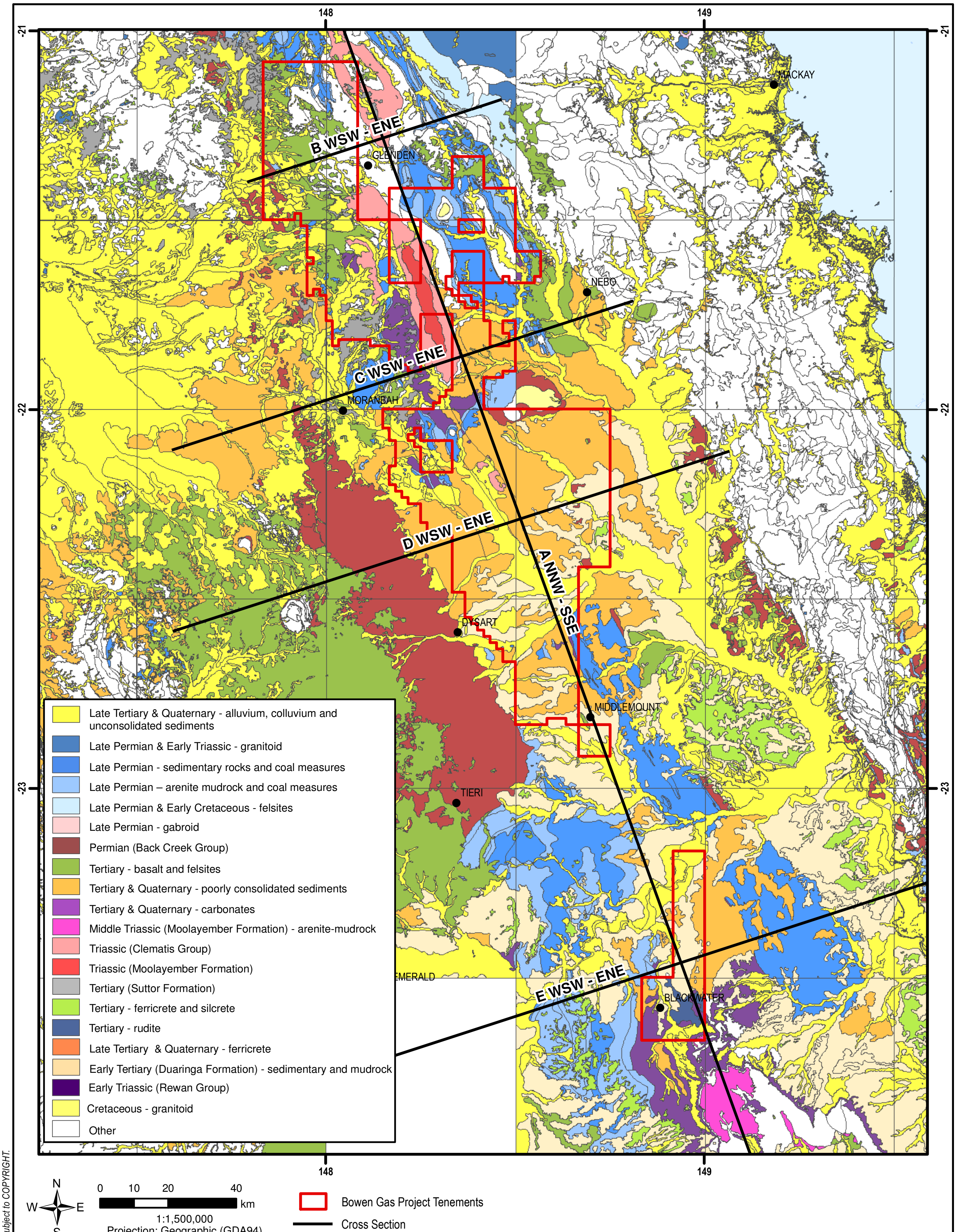
The Rewan Formation, which underlies the Clematis Sandstone, comprises mudstone, siltstone, sandstone, and shale. These are low-permeability rocks that provide a regional-scale confining unit or aquitard (Worley Parsons, 2010). It occurs along most of the central axis of the Bowen Basin (Figure 14–3) but is absent from the east and west flanks of the basin. It has a typical thickness of between 0 to 800 m and a maximum encountered thickness of 1,363 m (cited in Worley Parsons, 2010).

14.4.2.6 Permian-Triassic Strata Aquifers and Aquitards

The two dominant Permian formations in the Project area are the Blackwater Group and the Back Creek Group (Table 14-2; Section 14.5.2.2). As with the rest of the Bowen Basin, the coal seams are the main aquifers within the Permian sequences. Three target coal seams (Table 14-2) are identified as continuous across the Project area and constitute the most extensive aquifers. These include the Rangal Coal Measures, Burngrove Formation (Fort Cooper Coal Measures equivalents), and Moranbah Coal Measures (and equivalents) of the Blackwater Group.

The coal seams of the Blackwater Group have dual-porosity with primary-porosity provided by the matrix and a secondary porosity provided by fractures (joints and cleats). Natural fractures and cleats in the coal may be the dominant space for groundwater storage and the principal pathway for groundwater movement dependent on fracture interconnectivity. The coal seam aquifers exist as isolated confined units with poor quality groundwater (SKM, 2009a; Worley Parsons, 2010).

The confining units are considered (based on piezometeric pressure differences in the coal seams) to have very low vertical hydraulic conductivity, which limits vertical flow and limits recharge to the coal seam aquifers. 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). The entire Blackwater Group is further confined from above by the Rewan Formation and from below by the Back Creek Group. Back Creek Group aquifers within the central Bowen Basin are deep and confined with poor quality groundwater (SKM, 2009a; Worley Parsons, 2010). Shallow unconfined groundwater can occur in outcrops and subcrops of the Back Creek Group where these occur along the east and west margins of the Bowen Basin.



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arrow energy go further

BOWEN GAS PROJECT EIS

SURFACE GEOLOGY OF THE STUDY AREA

URS

GROUNDWATER

Figure: **14-5**

File No: **42626960-g-1083.mxd** Drawn: **XL** Approved: **DS** Date: **06-11-2012** Rev. **A** A4

14.4.3 Faults

A complex array of faults, with roughly north-west to south-east strike, is present in the Bowen Basin (Figure 14–3). The regional tectonic stress is mostly compressive such that thrust faulting and folding are dominant types (URS, 2012b). It is considered (URS, 2012b) that these faults and folds are ‘tight’ and act as hydraulic barriers that will ‘compartmentalise’ groundwater. Where compartmentalisation occurs, then the roughly east-west lateral flow in the Blackwater Group of coal measures may be restricted within these fault compartments.

It is considered that, although not recorded, faults can potentially have relatively higher vertical permeability (Anderson and Bakker, 2008). Consideration of faults within the proposed CSG fields will, therefore, be given to allow for the possibility for vertical interconnection between units.

14.4.4 Hydrologic Cycle

Important features of the basic conceptual hydrogeological model for the Project area include:

- Diffuse and localised groundwater recharge;
- Evapotranspiration; and
- River baseflow.

These are the main ‘drivers’ of regional groundwater flow in the Bowen Basin. Diffuse recharge is that rainfall recharge which occurs uniformly over the landscape (Scanlon *et al.*, 2002) whereas localised recharge occurs near drainage lines, rivers and creeks. Localised stream recharge is likely to be the main factor producing pockets of fresh groundwater. Although rainfall is variable on an annual basis, average groundwater recharge in the northern Bowen Basin is expected to be similar to that of the GAB, and hence the GAB recharge estimates (0.5 to 28.2 mm a year (mm/yr)) by Cook *et al.* (2006) have been adopted as a guide. Empirical estimates of the localised recharge are also available as a percentage of rainfall, 2.1 to 18% (SKM, 2009a), or as a percentage of stream flow, 0.5 to 7% (SKM, 2009a).

An analysis of 348 shallow groundwater bores in the study area of the Bowen Basin found that the water table in the unconfined alluvium, sediments and basalt, occurs at between 5 to 20 mbgl in most locations. Based on this information it is interpreted that shallow groundwater flows towards the surface drainage lines where it is lost as stream baseflow and as evapotranspiration via riparian vegetation and trees.

Refer to the Groundwater and Geology Technical Report (Appendix L) and the Groundwater Model Technical Report (Appendix M) of this EIS for initial estimates of diffuse and localised recharge rates, stream baseflow rates, evapotranspiration rates and their approximate uncertainty ranges and spatial distribution.

14.4.5 Groundwater Dependent Ecosystems

GDEs are ecosystems that rely on groundwater for some or all of their water requirements. Based on the large scale of the Project there is the potential for GDEs (such as wetlands, terrestrial vegetation and fauna) to exist in the study area. The GDEs in the study area are most likely to be found in river baseflow systems, stream pools, hyporheic zones and riparian zones.

Dependence of these ecosystems on groundwater is described using the following classification system developed by Hatton and Evans (1998):

- Entirely dependent;
- Highly dependent;
- Proportionally dependent;
- Opportunistically dependent or limited dependency; and
- Without any apparent dependency.

The main information currently available for defining locations of GDEs includes:

1. A map of interpreted river baseflow provided in SKM (2009b);
2. A Geographic Information System (GIS) map provided by the EHP that shows water courses, wetlands and 'regional ecosystem' (RE) types; and
3. Aerial photographs provided by Arrow.

The RE types were originally defined by Sattler and Williams (1999) as vegetation communities associated with a combination of geology, landform and soil and have since been modified.

SKM investigated GDEs in the Isaac-Connors sub-catchment and concluded that these GDEs have a "high ecological value" (2009b). GDEs in the study area are unlikely to depend on groundwater during periods of high rainfall and flooding (short-term events) but are likely to depend on groundwater during seasonally dry periods and droughts (long-term events). Droughts are considered a period when cumulative drawdown is typically the greatest, and as a result effects on GDEs are the most severe within this time. Effects on GDEs tend to be non-linear (stepped and lagged) when an ecological threshold is passed (SKM, 2009b). Groundwater will offer refuge during droughts for some niche specific flora and fauna species (SKM, 2009b).

SKM identified a number of river and creek reaches with a high probability of having sustained groundwater baseflow (i.e. river baseflow systems) and these are conservatively assumed to coincide with GDEs of a 'high' or 'entire' groundwater dependence (2009b). Of these river baseflow systems, the following four are located within the study area:

- Connors River (upper and mid reaches);
- Funnel Creek (upper and mid reaches);
- Lotus Creek; and
- Isaac River (lower reaches).

14.4.6 Springs

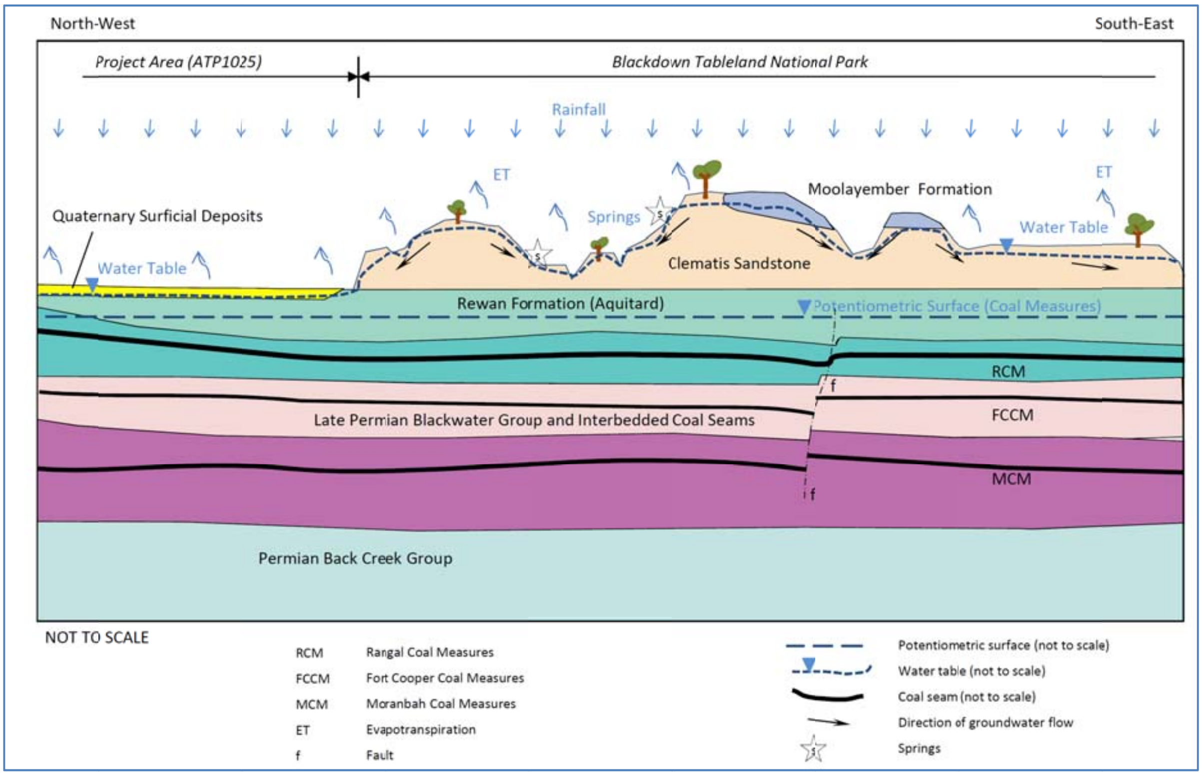
The locations of springs in the Bowen Basin were obtained from a list of registered springs collated by the Queensland Herbarium (Fensham and Fairfax, 2005). No springs were listed within the Project area, which is consistent with the observation that groundwater is either unconfined or sub-artesian.

Seventeen springs occur outside the Project area, some 10 to 40 km south and southeast of Blackwater, on a sandstone plateau comprised of Clematis Sandstone and known as the Blackdown Tableland National Park (~320 km^2). The sandstone plateau is situated within the Mimosa Management Area of the GAB, adjacent to, and few isolated overlaps with, Project tenement

ATP 1025 (Figure 14-2). The springs are known as the 'Blackdown Tableland Spring Complex' and are situated on top of the plateau, up to 650 m above the plains. Two of the recorded springs are located on the western base of the plateau and are likely to be fed by groundwater flowing down through the sandstone plateau.

In a regional context, such springs are common along the eastern recharge zones of the GAB and are termed 'recharge springs' or 'recharge reject springs'. At the local scale, these springs form because the sandstone can absorb significant amounts of rainwater but then may discharge some of this groundwater through rock fractures and topographic discontinuities. The actual details of each spring are site-specific, and in general terms, the springs on the Blackdown Tableland National Park are considered to be the product of recent recharge-discharge that occurs on the plateau (Figure 14-6).

Figure 14-6 Basic Conceptual Model of Spring Flow in the Blackdown Tableland National Park Prior to Development



Geology maps (1:250,000) of the area indicate that the Clematis Sandstone is underlain by the Rewan Formation (Figure 14-3) and the conceptual hydrogeological model of the plateau (Figure 14–6) suggests that the Rewan Formation and Blackwater Group interburden (aquitards) will contain the impacts of CSG depressurisation. The springs are fed by recent rainfall on the plateau and are contiguous with perched groundwater in the plateau. Hence potential impacts on the plateau groundwater and associated springs are unlikely to occur because:

- The groundwater system is perched above the plains of the Bowen Basin; and
- The Rewan Formation (aquitard) is confining the groundwater from below.

Consequently no drawdown impact is interpreted for the Blackdown Tableland spring complex.

14.5 Groundwater System

14.5.1 Groundwater Baseline Data

A literature review of government and consultants reports was undertaken, allowing for Project specific data to be collated. These information sources are described in the Groundwater and Geology Technical Report (Appendix L) of the EIS and include:

- Extracts from the NRM (formerly DERM) groundwater database, including bore registrations, aquifer descriptions, stratigraphy, casing details, facility, groundwater quality, and monitored groundwater levels (where available);
- Extracts from the Bureau of Meteorology (BOM) climate database, including monthly and annual averages (rainfall, evaporation and temperature) and long-term rainfall records for a number of stations;
- Extracts from the (BOM) Data Drill database showing annual long-term averages of rainfall and actual evapotranspiration over the data search area in grids;
- Extracts from the EHP's Water Entitlements Registration Database (WERD) including entitlement registration, status, issuance, nominal volume, works type and location by lot and plan for the bores and consumed water;
- Extracts from of the Queensland Herbarium, Environmental Protection Agency Springs of Queensland – Distribution and Assessment dataset;
- Extracts from the EHP surface water database, including stream flows and salinity; and
- Extracts from Arrow's CSG field studies, field testing programs, and other operations.

The following lists the spatial information collated from publicly available reports, maps, photographs, and GIS databases:

- A map of rivers and streams that appear to receive sustained groundwater baseflow (SKM, 2009b);
- GIS maps of EHP (2012) topographic contours based on digital elevation modal (DEM) 25 m-grid data for the Fitzroy River and Burdekin River Catchments;
- GIS maps of river drainage basins, catchments, and stream gauges;
- GIS maps of the surface geology (1:100,000) and regional geology (1:250,000) maps;
- GIS maps of river drainage basins, catchments, and stream gauges;
- GIS maps of inferred groundwater recharge zones and groundwater chemistry zones;
- GIS maps of water courses, wetlands, and RE types;
- GIS maps of coal resources, coal mines, mine tenements, outlines of open-pit and underground works, and target seams based on satellite imagery and a literature review;
- GIS maps of perennial rivers as defined by the Australian Hydrological Geospatial Fabric (BOM 2012); and
- GIS maps of cadastral boundaries for groundwater entitlements and associated registered groundwater bores.

The most important of these information types are the bore yields, bore standing water levels, and bore water quality. These data are described in the paragraphs that follow.

14.5.1.1 Existing Monitoring Bores

A query of the NRM groundwater database, a database of all registered groundwater bores within Queensland was conducted in an effort to understand the primary aquifers utilised within the study area, at what capacity, and for what purposes. The query resulted in 15,184 bore records for the whole study area, including:

- 9,603 existing bores;
- 4,799 abandoned and destroyed bores;
- 758 abandoned but still useable bores; and
- 24 proposed bores.

In order to collate the most relevant data for the groundwater impact assessment, only those registered bores that satisfied the following criteria were considered:

- Bores located inside the Project development area (267 bores) or within the northern geologic Bowen Basin (3,660 bores);
- Bores with at least one water level record; and
- Bores completed in an aquifer that can be identified.

The total number of bores that satisfy all three criteria was 1,127 bores (Table 14-3). These registered bores are associated with the aquifer units listed in Table 14-2. Only 64 bores associated with the aquifer units within the Project area were identified, and are listed in Table 14-4.

The total number of NRM registered bores that have groundwater level data and are located within the Project area is only approximately 6% of the total number of registered bores in the study area. Whilst this is a relatively small number of bores for the 8,000 km^2 Project area, a low bore density is consistent with limited groundwater resources in the central plains of the Bowen Basin and the small number of bores is not unexpected. It is noted that there are no registered groundwater monitoring bores in the Clematis Sandstone in the Project area. Monitoring of the Clematis Sandstone is not warranted due to limited outcrop, as it occurs mostly in raised landforms (i.e. just west of Coppabella). It is considered that there are unregistered (not required) stock watering bores within the Clematis Sandstone.

Monitoring bores across the Project area include those constructed by the Queensland Government, monitoring bores installed by Arrow, and other private monitoring bores generally constructed by coal mining companies. Groundwater level records are available for 29 bores located near Moranbah as part of the Moranbah Gas Project.

Table 14-3 Approximate Number of NRM Bores Registered in the Northern Geologic Bowen Basin with Reported Water Level Data

Age	No. Unique Aquifer Descriptions	Units	Number of Registered Bores	Percentage
Quaternary	29	Alluvium in various rivers and creeks	410	36%
Tertiary	5	Basalt, sedimentary formations	539	48%

Age	No. Unique Aquifer Descriptions	Units	Number of Registered Bores	Percentage
Triassic	2	Rewan Group and Clematis Sandstone	9	1%
Permian	8	Back Creek Group, Burngrove Formation, Fair Hill Formation, Blackwater Group, and four individual coal measures	169 (19)	15%
Total	44	(all aquifers listed above)	1127	100%

Table 14-4 Approximate Number of NRM Bores Registered in the Project Area with Reported Water Level Data

Geologic Age	No. Unique Aquifer Descriptions	Units	Number of Registered Bores1	Percentage of Registered Bores1
Quaternary	2	Isaac River Alluvium and Alluvium	13	20%
Tertiary	3	Basalt, Duaringa Formation and Undefined	15	23%
Triassic	1	Rewan Group	3	5%
Permian	4	Back Creek Group, Fair Hill Formation, Blackwater Group, and Rangal coal measures	33 (1)	52%
Total	10	(all aquifers listed above)	64	100%

14.5.1.2 Bore Yields

NRM registered bores are generally tested for yield using techniques such as bailing, air test (blow yield), pump test or flow test. Yields for NRM bores in the study area and within the boundaries of the Project area tenements were summarised to assist in identifying the occurrence of groundwater, as shown in Table 14-5 and Table 14-6, respectively. The data clearly shows that the majority of bores (84%) are low yielding (<5 litres per second (L/s)) and most of the high yielding bores are constructed within either the Quaternary alluvium or Tertiary basalt. A summary of bore yields for the Project area indicate that proportionally, more bores are low yielding and none are high yielding (i.e. no bores reported yields greater than 10 L/s).

Table 14-5 Number of Registered Bores within the Northern Geologic Bowen Basin Classified by Yield

Age	Unit	Bore Yield (L/s)				
		<1	1 to <5	5 to <10	10 to <50	≥50
Quaternary	Alluvium	48	39	9	20	0
Tertiary	Basalt	125	153	30	17	1

Age	Unit	Bore Yield (L/s)				
		<1	1 to <5	5 to <10	10 to <50	≥50
Tertiary	Duaringa	12	11	1	1	0
Tertiary	Other Units	21	30	10	8	0
Triassic	Clematis	0	0	1	0	0
Triassic	Rewan	2	1	0	0	0
Triassic	Other Units	0	1	0	0	0
Permian	Coal Seams	9	6	4	0	0
Permian	Back Creek	39	22	5	1	0
Permian	Blackwater	23	18	2	0	0
Permian	Other Units	0	1	0	0	0
All Ages	All Units (Total)	279	282	62	47	1
	All Units (Total)	42%	42%	9%	7%	0%

Table 14-6 Number of Registered Bores in the Project Area Classified by Yield

Age	Unit	Bore Yield (L/s)				
		<1	1 to <5	5 to <10	10 to <50	≥50
Quaternary	Alluvium	5	1	1	0	0
Tertiary	Basalt	2	3	1	0	0
Tertiary	Duaringa	1	2	0	0	0
Tertiary	Other Units	0	3	0	0	0
Triassic	Clematis	0	0	0	0	0
Triassic	Rewan	1	0	0	0	0
Triassic	Other Units	0	0	0	0	0
Permian	Coal Seams	0	0	1	0	0
Permian	Back Creek	4	2	0	0	0
Permian	Blackwater	12	7	1	0	0
Permian	Other Units	0	0	0	0	0
All Ages	All Units (Total)	25	18	4	0	0
	All Units (Total)	53%	38%	9%	0%	0%

14.5.1.3 Standing Water Levels

Available groundwater level data were compiled from the NRM groundwater database, Arrow groundwater monitoring program, and some private bores (Groundwater and Geology Technical Report (Appendix L) of this EIS). Within the Project area, groundwater level data were available for a total of 64 bores completed within the unconfined Quaternary and Tertiary aquifers and the confined

Triassic and Permian aquifers. Most of these bores only have one reported water level measurement. Long-term (transient) groundwater level data were only available for the following nine bores:

- Isaac River alluvium (RNs 13040180, 13040181, 13040183, 13040184 and 97180);
- Undefined Tertiary-age sediments (RN 13040287);
- Duaringa Formation (RN 13040286);
- Blackwater Group (RN 13040284); and
- Back Creek Group (RN 13040291).

Of these bores, six are located within the Project area and are currently monitored for water levels. Inactive bores include RNs 13040183, 13040184 and 97180. Hydrographs for these nine bores are presented in the Groundwater and Geology Technical Report (Appendix L) of this EIS.

A summary of groundwater levels, as maximum, minimum and averages, for all bores in the Project area are presented in Table 14-7. These statistics show that groundwater in the Project area is generally unconfined or sub-artesian. In other parts of northern Bowen Basin (i.e. outside the study area) there are records of marginally artesian groundwater bores in basalt and some highly artesian bores in Clematis Sandstone (cited in Worley Parsons, 2010) however these bores are not regionally important and do not influence the assessment.

Table 14-7 Summary of Average Recorded Groundwater Levels in the Project Area

Hydrostratigraphic Unit	Aquifer / Aquitard	Min. SWL (mbgl)	Max. SWL (mbgl)	Avg. SWL (mbgl)	Count (-)
NRM Registered Bores in the Bowen Gas Project Area					
Quaternary Alluvium[1,2]	Aquifer	0.5	18.3	14.0	281
Tertiary Basalt	Aquifer	8.0	40.0	22.8	6
Tertiary Sediment	Aquifer	11.1	44.4	21.3	9
Rewan Group	Aquitard	4.5	7.6	6.1	2
Permian Strata (Blackwater Group)	Aquifer / Aquitard	8.0	55.0	29.3	16
Permian Strata (Back Creek Group) [2]	Aquitard	15.1	27.4	22.4	7
Arrow Monitored Bores in the Moranbah Gas Project Area					
Quaternary Alluvium, Tertiary Sediment & Basalt	Aquifer	9.1	28.8	19.8	9

Notes:
*SWL – Static Water Level
1. Statistics for the Quaternary Alluvium are based on the transient SWL records where available. Statistics for other bores are based on time-averages.
2. For some bores SWL data were only recorded at the time of bore installation.

14.5.1.4 Groundwater Quality Map

Raymond and McNeil (2011) undertook a detailed study of NRM groundwater chemistry data and geology, rainfall and land use for the whole Fitzroy catchment to provide a map of interpreted groundwater zones (Table 14-8; Figure 14-7). The existence of two major groundwater sequences in the Fitzroy Basin was interpreted, namely:

- ‘Alluvial sequence’ of groundwater has a rainfall-ionic signature and mostly includes alluvial groundwater near streams along the east side of the Bowen Basin and areas of relatively high rainfall; and
- ‘Sodic sequence’ of groundwater has a near-marine ionic signature and mostly includes deep groundwater in sedimentary rocks in low rainfall areas.

There are eight groundwater chemistry zones within the Project area and a further five zones neighbouring the Project area (Figure 14-7). Table 14-8 lists the salinity ranges and ionic characteristics of each zone in terms of ‘shallow’ and ‘deep’ groundwater, where deep is greater than 30 mbgl. Raymond and McNeil (2011) analysed chemical parameters to produce the map including: electrical conductivity (EC), hardness, pH, alkalinity, concentrations of major anions and cations, selected metals, sodium absorption ratio (SAR), Residual Alkali Hazard and reduction potential. The water quality statistics of Raymond and McNeil (2011) are tabulated in the Groundwater and Geology Technical Report (Appendix L) of this EIS.

The groundwater zones in Figure 14-7 cover the Project area where NRM groundwater data are available. Due to a paucity of data for latitudes north of Nebo and the area between Phillips Creek and Sawmill Creek, groundwater in these areas are not classified; however, provides a useful baseline for future comparisons.

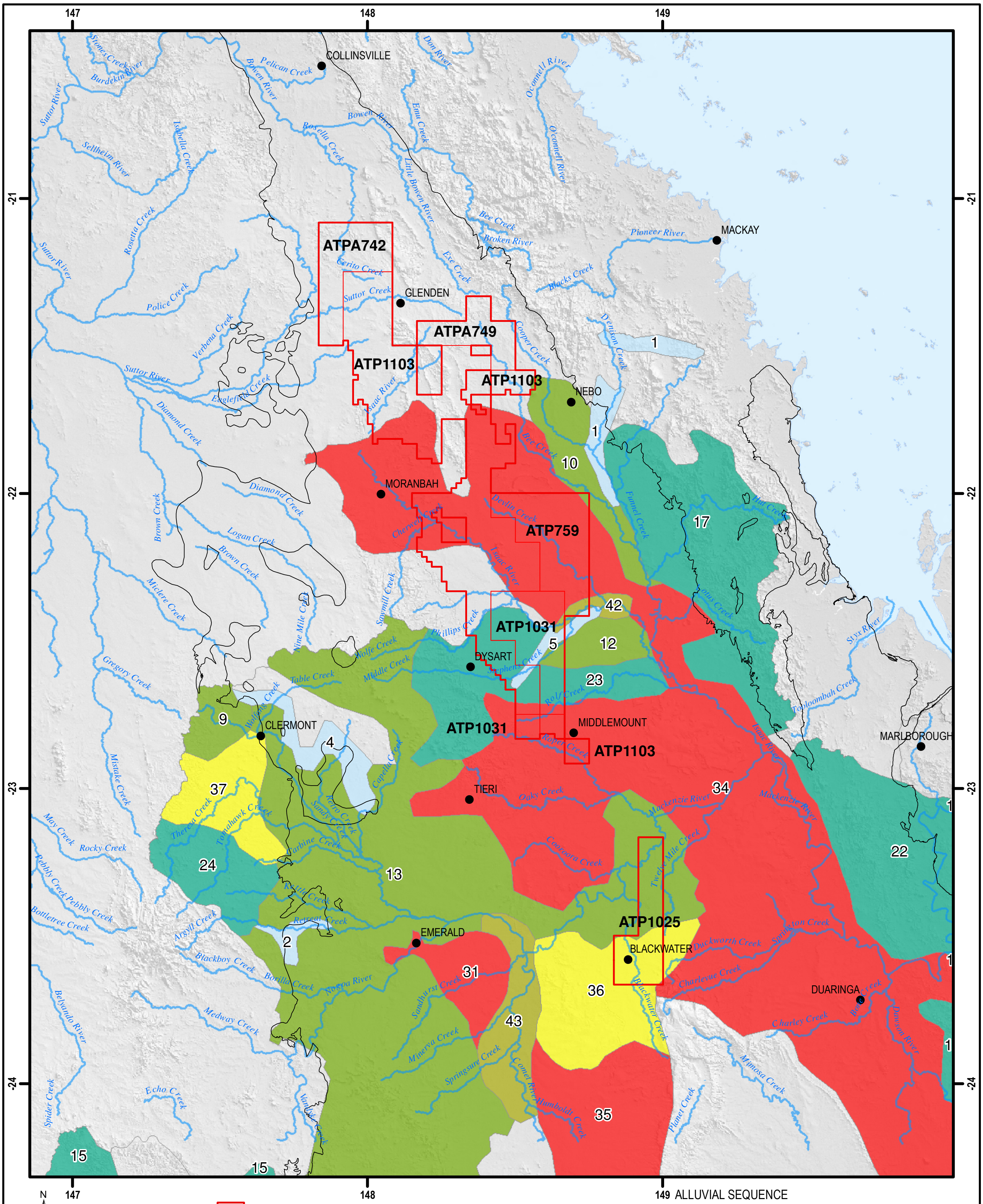
Table 14-8 Groundwater Quality Zones in the Study Area (adapted from Raymond and McNeil 2011)

Zone[5]	**Depth[1]**	**Zone Name**	**Quality Type[6]**	**Salinity Class**	**EC 20th Percentile (µS/cm)[2]**	**EC 50th Percentile (µS/cm)[2]**	**EC 80th Percentile (µS/cm)[2]**	**Major Cations**	**Major Anions**
1	D	Dennison	Alluvial	Fresh	345	565	901	Balanced	HCO_3
1	S	Dennison	Alluvial	Fresh	490	640	984	Balanced	HCO_3
5	**D**	**Lower-Stephens**	**Alluvial**	**Slightly Saline**	**914**	**2,400**	**4,219**	**Na**	**Cl, HCO_3**
5	**S**	**Lower-Stephens**	**Alluvial**	**Fresh**	**633**	**680**	**750**	**Balanced**	**HCO_3**
10	**D**	**Bee-Cooper**	**Alluvial**	**Fresh**	**475**	**800**	**1,200**	**Na**	**HCO_3**
10	**S**	**Bee-Cooper**	**Alluvial**	**Fresh-Slightly Saline**	**485**	**739**	**2,360**	**Na**	**Cl, HCO_3**
12	**D**	**Stephens-Isaac**	**Alluvial**	**Slightly Saline**	**1,298**	**1,835**	**2,085**	**Na**	**HCO_3**
12	**S**	**Stephens-Isaac**	**Alluvial**	**Fresh**	**690**	**761**	**832**	**Na**	**HCO_3, Cl**
13	**D**	**Phillips-Fairbairn-Meteor**	**Alluvial**	**Fresh-Slightly Saline**	**720**	**1,256**	**1,950**	**Na**	**HCO_3**
13	**S**	**Phillips-Fairbairn-Meteor**	**Alluvial**	**Fresh-Slightly Saline**	**630**	**1,150**	**2,509**	**Na**	**HCO_3**
17	D	Lotus-Connors-Funnel	Alluvial	Slightly Saline	2,370	3,000	4,925	Na	Cl
17	S	Lotus-Connors-Funnel	Alluvial	Fresh-Slightly Saline	414	900	2,276	Na	Cl
22	D	Fitzroy	Alluvial	Slightly-Moderately Saline	1,507	2,735	5,276	Balanced	Cl
22	S	Fitzroy	Alluvial	Slightly Saline	1,403	2,220	3,722	Balanced	Cl
23	**D**	**Dysart**	**Alluvial**	**Slightly-Moderately Saline**	**2,496**	**3,465**	**7,450**	**Na**	**Cl**
23	**S**	**Dysart**	**Alluvial**	**Slightly Saline**	**3,333**	**3,850**	**4,506**	**Na**	**Cl**
31	D	Sandhurst	Sodic	Slightly Saline	2,151	3,150	3,540	Na	Cl, HCO_3
31	S	Sandhurst	Sodic	Slightly Saline	8,74	2,450	4,200	Na	Cl, HCO_3
34	**D**	**Isaac-Dawson**	**Sodic**	**Slightly-Very Saline**	**3,419**	**6,100**	**16,000**	**Na**	**Cl**
34	**S**	**Isaac-Dawson**	**Sodic**	**Slightly-Moderately Saline**	**4,98**	**2,150**	**8,910**	**Na**	**Cl**
36	**D**	**Blackwater**	**Sodic**	**Slightly-Moderately Saline**	**3,475**	**4,150**	**7,255**	**Na**	**Cl, HCO3**
36	**S**	**Blackwater**	**Sodic**	**Slightly-Moderately Saline**	**3,100**	**6,300**	**7,410**	**Na**	**Cl, HCO3**
42	**D**	**Black Hole**	**Alluvial**	**Moderately Saline**	**8,080**	**11,500**	**12,220**	**Balanced**	**Cl**

42	**S**	**Black Hole**	**Alluvial**	**Fresh to Slightly Saline**	**4,65**	**560**	**1,738**	**Na**	**Cl**
43	D	Lower-Comet	Alluvial	Slightly to Moderately Saline	3,460	5,500	7,720	Balanced	Cl
43	S	Lower-Comet	Alluvial	Slightly to Moderately Saline	2,725	6,300	15,495	Na	Cl

Notes:

1. Depth ranges are 'S' for shallow (< 30 mbgl) and 'D' for deep (> 30 mbgl).
2. Salinity is the measure of Total Dissolved Solids (TDS) in units 'mg/L' (milligrams per litre) or EC in units 'µS/cm' (microSiemens per centimetre), where TDS (mg/L) ≅ EC (µS/cm) × 0.67 (ANZECC and ARMCANZ 2000)
3. Salinity descriptions are based on irrigation ratings supplied by ANZECC and ARMCANZ (2000)
4. Zone data were adapted from Raymond and McNeil (2011).
5. Zones with shaded cells occur in the Project area.
6. Sodic groundwater has a SAR > 12.



N W E S

0 10 20 40 60 km

1:2,000,000

Projection: Geographic (GDA94)

Bowen Gas Project Tenements

Bowen Basin

Watercourse

SODIC SEQUENCE

- Low-moderate salinity: Na, HCO_3>Cl
- Low-moderate salinity: Na, Cl>HCO_3
- Saline: Na, Cl

ALLUVIAL SEQUENCE

- Low salinity: balanced cations, HCO_3
- Low-moderate salinity: balanced cations, HCO_3, Cl
- Moderate salinity: Na>Mg>Ca, Cl (SO_4 above average)
- Saline: Na, Cl

arrow energy go further

BOWEN GAS PROJECT EIS

GROUNDWATER QUALITY ZONES IN THE STUDY AREA

URS

GROUNDWATER

Figure: **14-7**

File No: **42626960-g-1084.mxd** Drawn: **XL** Approved: **DS** Date: **06-11-2012** Rev. **A** A4

14.5.2 Groundwater Levels and Flow

Monitored groundwater levels (alluvium, sediment and basalt) are important for assessing seasonal variations, interpreting types of recharge and responses to rainfall, contours of averages water levels (Australian Height Datum (AHD) and mbgl) and flow paths.

14.5.2.1 Alluvial, Sediment and Basalt Aquifers

The shallow groundwater of the Quaternary and Tertiary aquifers is mostly unconfined and numerous groundwater hydrographs for the northern Bowen Basin show the influence of rainfall patterns on these aquifers (Pearce, 1983; PPK, 1998; Coffey, 2003 and 2005). The 1971 - 2011 hydrograph for bore RN 13040180, which is located in Isaac River alluvium the Project area, is shown in Figure 14-8 with the Moranbah rainfall residual mass curve (RRMC) for the same period (1971 - 2011). 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 Niño* (dry / drought) and *la Niña* (wet / flood) rainfall conditions over eastern Australia.

The data for RN 13040180 in Figure 14-8 appears not to have sufficient temporal resolution to clearly define the seasonal (summer / winter) variation in groundwater levels, and there are also four spikes in groundwater levels that may be related to high-rainfall (flooding) events but are shown as data outliers. To interpret the regional hydrogeology it is necessary to examine hydrographs of bores with higher sampling frequencies, such as for RN 13040068, which is located in Denison Creek alluvium outside the Project area (Figure 14-9). Between 1984 and 2008, the sample frequency at bore RN 13040068 was monthly, and this was sufficient to show the effects of:

- Intra-annual seasonal variations;
- *El Niño* (dry / drought) and *la Niña* (wet / flood) conditions;
- Groundwater consumptive use; and
- Recharge ‘spikes’.

All five groundwater hydrographs for Quaternary and Tertiary aquifers in the Project area are presented in the Groundwater and Geology Technical Report (Appendix L) of this EIS (i.e. RNs 13040180, 13040181, 13040183, 13040184 and 97180, RN 13040287, and RN 13040286). None of these groundwater hydrographs (for the Project area) clearly show seasonal variations or spikes because the sampling frequency was too low.

Section 14 Groundwater

Figure 14-8 Groundwater Hydrograph for Bore RN 13040180 Located in Isaac River Alluvium inside the Project Area (1971-2011): Seasonal Variations and Spikes are not Discernible

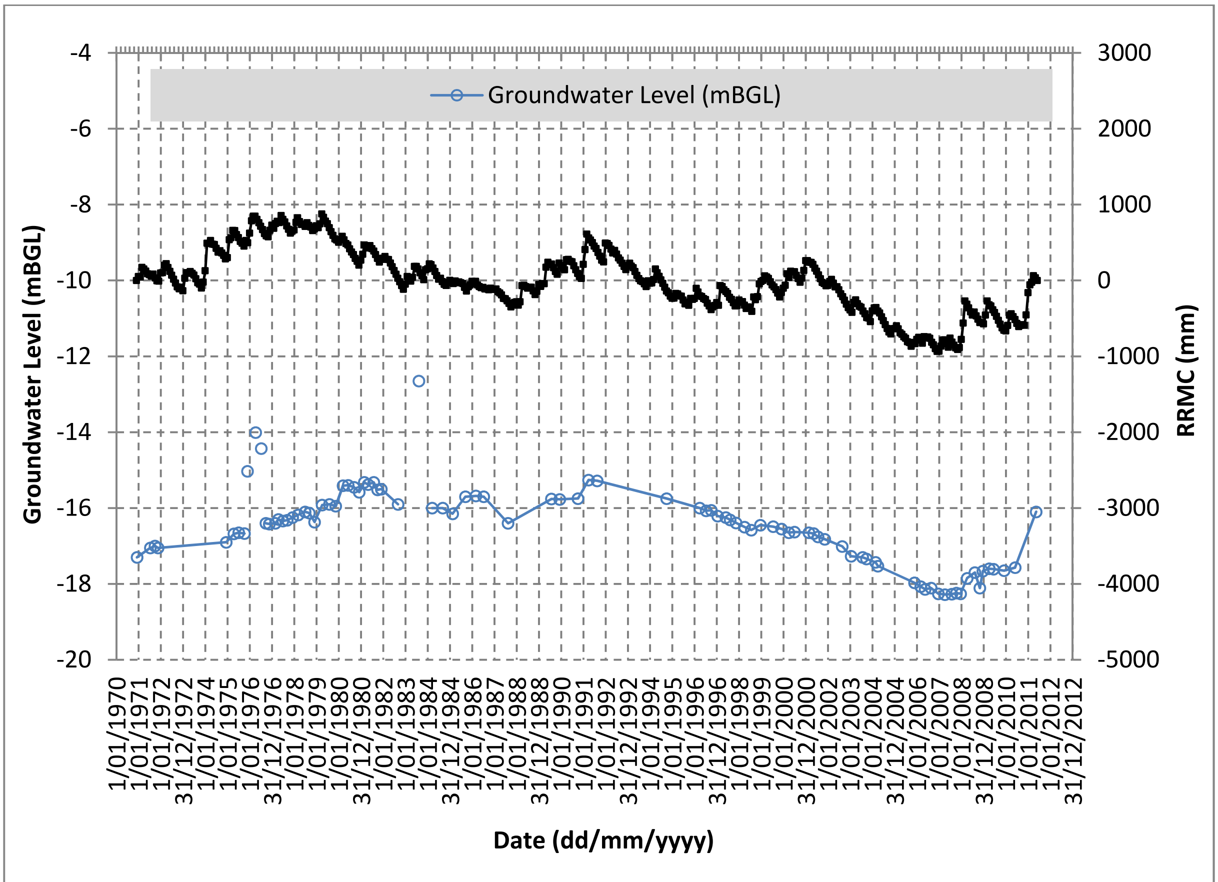
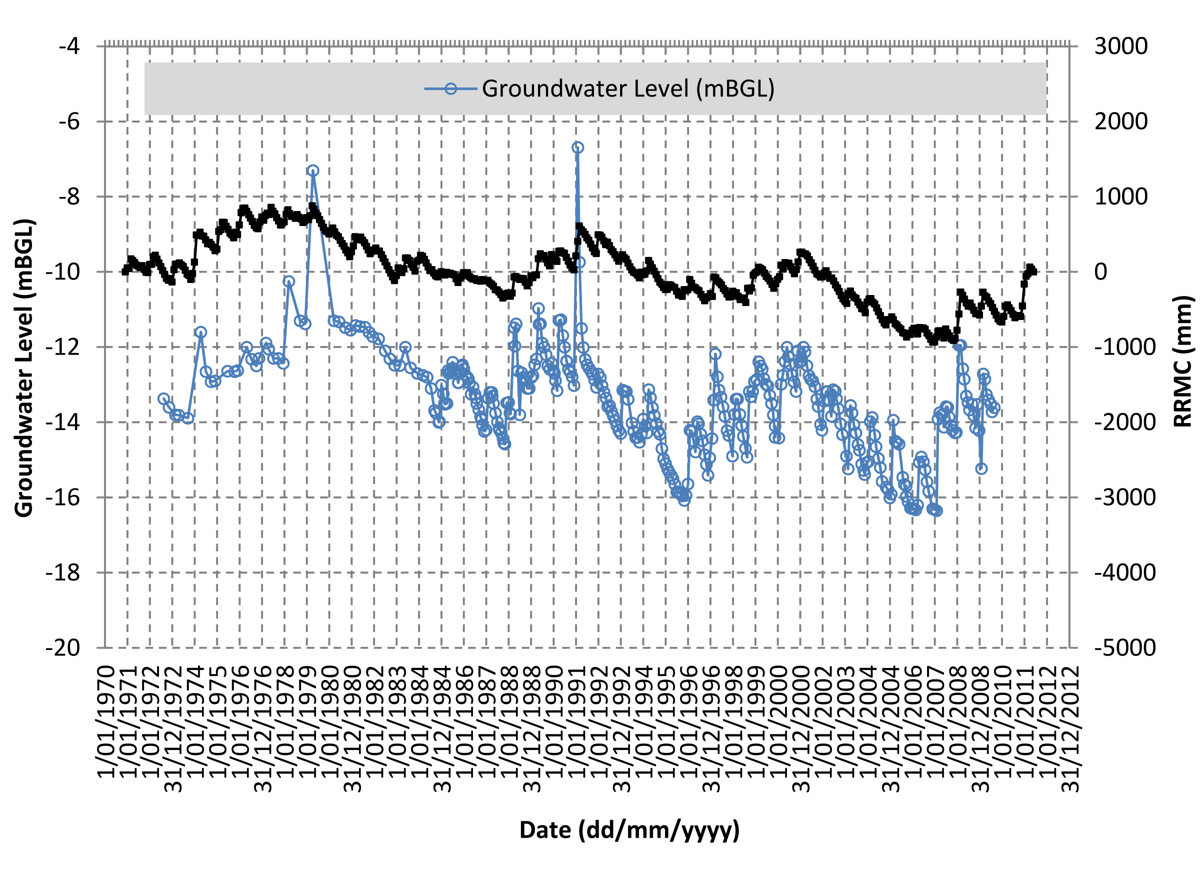


Figure 14-9 Groundwater Hydrograph for Bore RN 13040068 Located in Denison Creek Alluvium outside the Project Area (1971-2011): Seasonal Variations and Spikes are Clearly Shown



The hydrographs for shallow bores in the Project area (the Groundwater and Geology Technical Report (Appendix L) of this EIS) highlight the challenges of data interpretation, for instance, the hydrograph for RN 13040181 is erratic and appears to be dominated by man-made groundwater disturbances. The six hydrographs, for RNs 97180, 13040181, 13040183, 13040184, 3040286, and 13040287, are of relatively short duration and also suffer from a low sampling frequency. The main conclusions derived from these Project area hydrographs are:

- Decadal-scale variations in groundwater levels are linked to el Niño and la Niña years and possible groundwater consumptive use;
- Seasonal variations and sudden spikes in groundwater levels are unclear because of infrequent sampling; and
- Groundwater levels at RN 13040181 may have been disturbed by activities such as mining.

Given these limitations, a review of groundwater data for shallow bores outside the Project development area was conducted. Three hundred and forty-eight registered bores completed within the alluvial aquifers of the northern Bowen Basin were assessed. These data indicate that the water level associated with the unconfined shallow aquifers (since 1970) was typically 5 to 20 mbgl.

Recorded groundwater levels from both CSG and private bores near Moranbah (Arrow, 2011a; Arrow, 2012a; Arrow, 2012b) similarly indicate that groundwater levels in the Isaac River Alluvium, Tertiary basalt and other shallow sediments range from about 9 to 29 mbgl. These data reflect similarities between localised flow systems observed at various points throughout the basin.

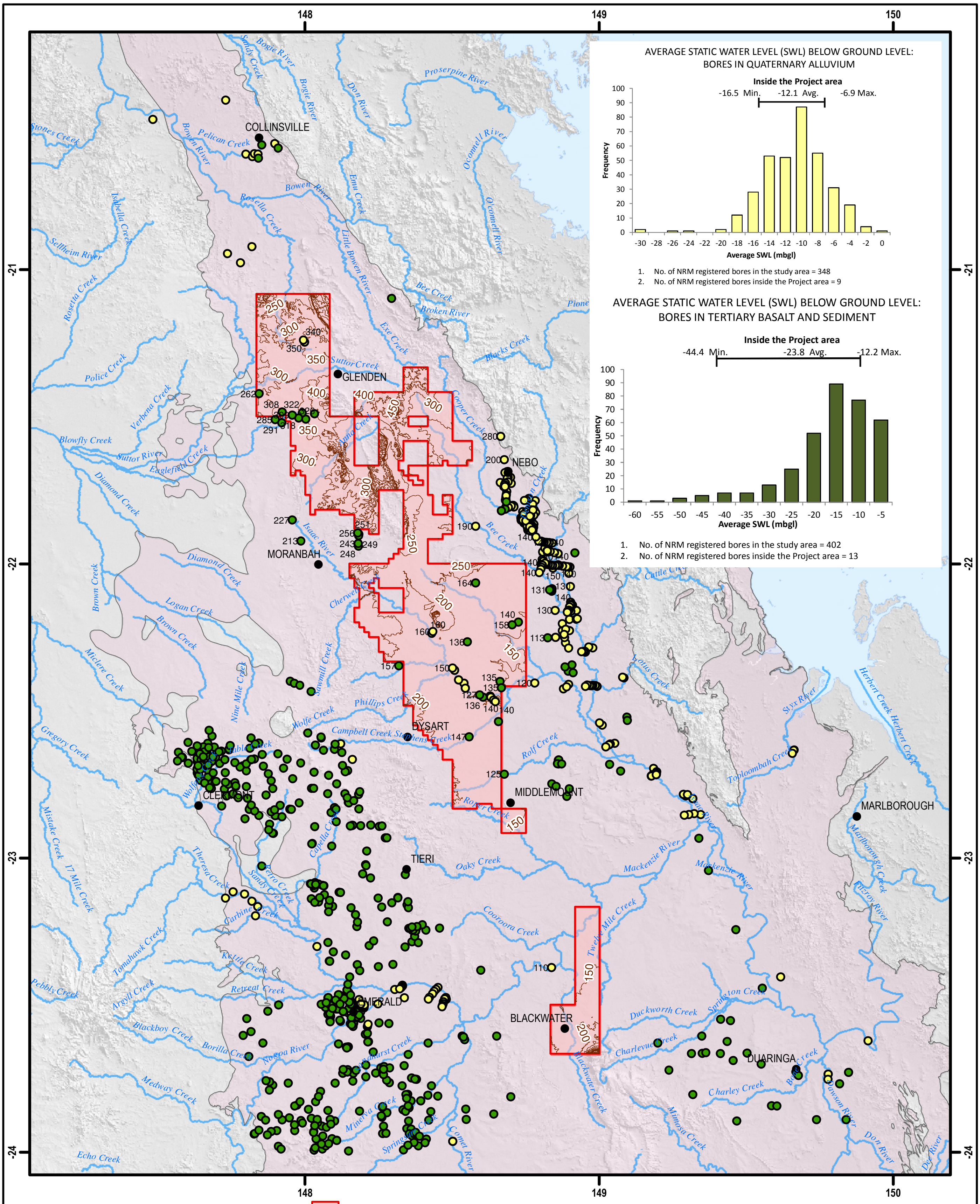
Based on all of the data sets, it was inferred that the regional water table generally mimics surface topography albeit smoother and more 'subdued' (Toth, 1963; Haitjema and Mitchell-Bruker, 2005). The average groundwater levels of the shallow bores for the whole study area were converted to elevations in AHD and plotted in Figure 14-10. Most of the shallow bores are located in the most favourable groundwater resources, in basalt on the western side of the basin, and in alluvium and sediments on the eastern side of the Basin.

Shallow lateral groundwater flow is generally towards surface drainage lines, where it is discharged via creek baseflow and evapotranspiration (Figure 14-11). Lateral groundwater flow will be greatest through high permeability alluvium of the river and stream channels but given the heterogeneous nature of the alluvium this flow is expected to be non-uniform. Some groundwater may also be lost as vertical seepage into deeper units however this is not quantified and is limited by the Rewan Formation and other aquitards. There is limited data and information on the interactions of groundwater between the alluvial aquifers and adjacent and underlying aquifers.

14.5.2.2 Permian-Triassic Strata Aquifers

Long-term groundwater hydrographs for the confined Permian aquifers are presented in Figure 14-12 below. These bores, RN 13040283 (Back Creek Group), RN 13010005 (Blackwater Group), and RN 13040294 (Blackwater Group), 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 wet and dry seasonal cycles (cited in Worley Parsons, 2010).

The interpretation of groundwater level trends in Permian strata aquifers is complicated by significant east-west differences in Permian strata depth, thickness of Rewan Formation (aquitard), and degree of confinement. The Permian strata along the west and east margins of the Bowen Basin subcrop (Figure 14-14) and, as a result, groundwater levels in these areas are typically shallow, unconfined and exposed to potential rainfall recharge. Figure 14-13, for example, illustrates groundwater level variations within a subcrop of the Back Creek Group (bore RN 13020136), located in the western portion of the Bowen Basin. These data reflect typical variations of shallow (rainfall recharge), unconfined conditions. Average groundwater levels reported for the Blackwater Group within the Project study area range from approximately 8 to 55 mbgl. Interpolated regional potentiometric contours at 25 m intervals (Figure 14-14) illustrate the groundwater flow pattern within the Blackwater Group. The average groundwater level contours indicate a regional flow pattern with flow from east and west margins towards the central axis of the basin, with some groundwater flowing to the southeast and some to the north (i.e. there appears to be a groundwater divide near Glenden). This result suggests that some diffuse groundwater recharge into the Blackwater Group is occurring along the west and east margins of the basin. Groundwater movement within the Blackwater Group may also be constrained by major fault systems most of which have a roughly north-south strike (Figure 14-14).



Bowen Gas Project Tenements
Bowen Basin
Surface Contour (50 m)
Watercourse
Tertiary Bores (mAHD)
Quaternary Bores (mAHD)

N W E S

0 10 20 40 60 km

1:2,000,000

Projection: Geographic (GDA94)

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BOWEN GAS PROJECT EIS

GROUNDWATER LEVELS IN SHALLOW AQUIFERS

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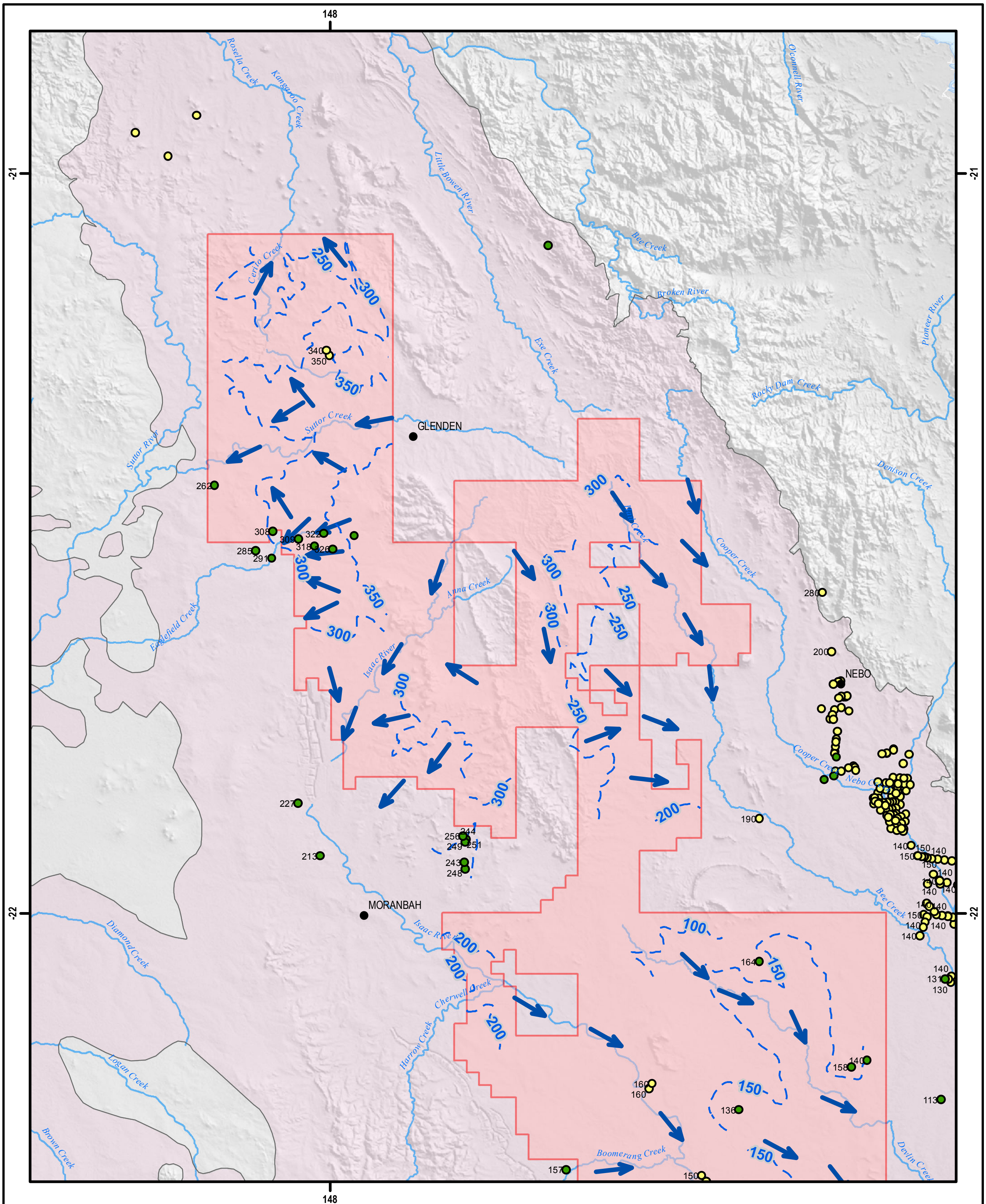
GROUNDWATER

Figure: 14-10

File No: 42626960-g-1085.mxd Drawn: XL Approved: DS Date: 06-11-2012 Rev. A A4



Bowen Gas Project Tenements	Approximate Groundwater Flow Direction	Tertiary Bores (mAHD)
Bowen Basin	-200- Groundwater Contour Inferred from Topography (mAHD)	Quaternary Bores (mAHD)
	Watercourse	

N W E S

0 6 12 18 24 km

1:800,000

Projection: Geographic (GDA94)

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BOWEN GAS PROJECT EIS

INFERRED GROUNDWATER LEVEL CONTOURS IN SHALLOW AQUIFERS

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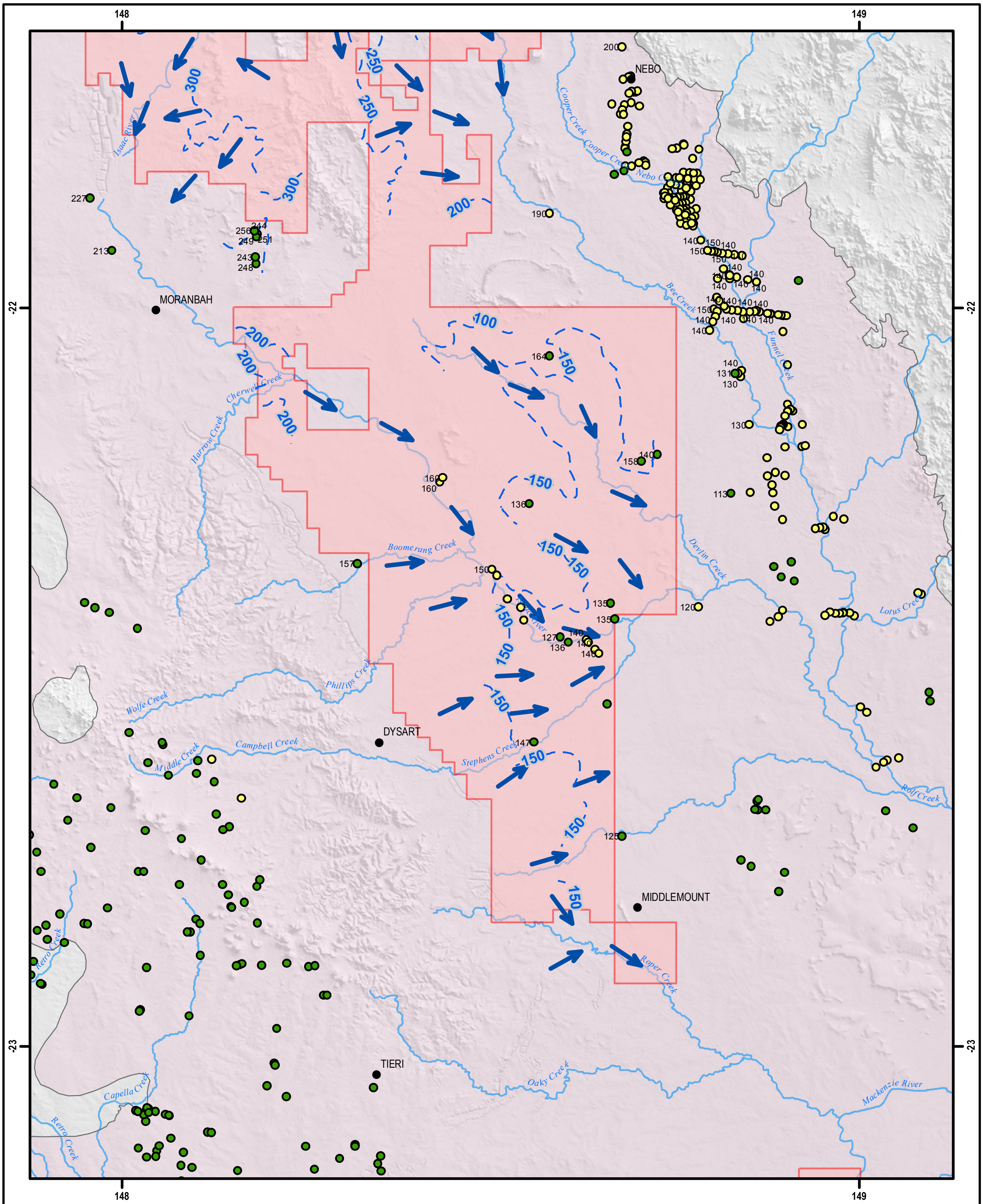
GROUNDWATER

Figure: **14-11a**

File No: **42626960-g-1086.mxd** Drawn: **XL** Approved: **DS** Date: **06-11-2012** Rev. **A** A4



Bowen Gas Project Tenements

Bowen Basin

Approximate Groundwater Flow Direction

-200- Groundwater Contour Inferred from Topography (mAHD)

Watercourse

Tertiary Bores (mAHD)

Quaternary Bores (mAHD)

0 6 12 18 24 km

1:800,000

Projection: Geographic (GDA94)

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BOWEN GAS PROJECT EIS

INFERRED GROUNDWATER LEVEL CONTOURS IN SHALLOW AQUIFERS

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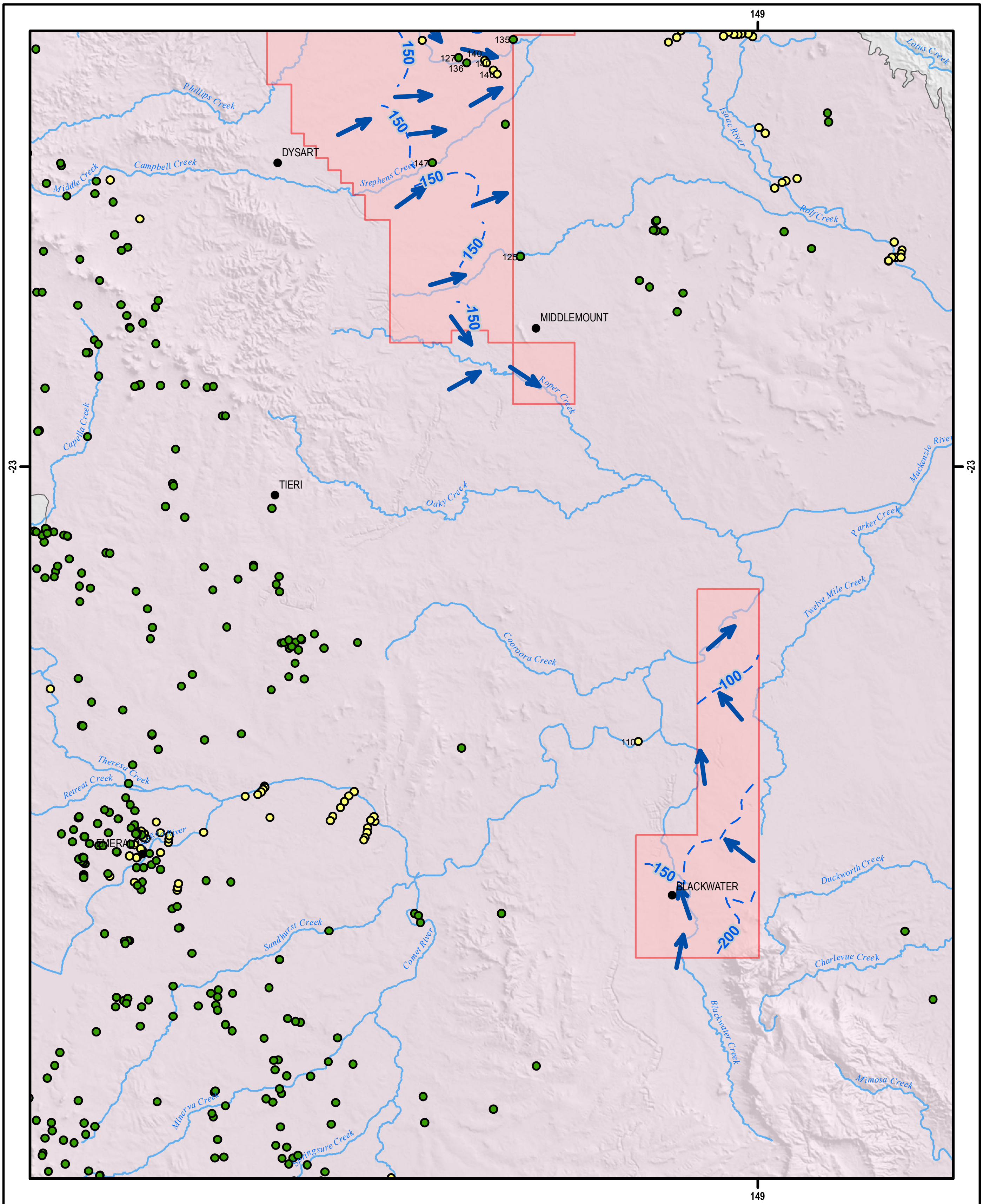
GROUNDWATER

Figure: 14-11b

File No: 42626960-g-1086.mxd | Drawn: XL | Approved: DS | Date: 06-11-2012 | Rev. A | A4



N W E S

0 6 12 18 24 km

1:800,000

Projection: Geographic (GDA94)

Bowen Gas Project Tenements

Bowen Basin

Approximate Groundwater Flow Direction

-200- Groundwater Contour Inferred from Topography (mAHD)

Watercourse

Tertiary Bores (mAHD)

Quaternary Bores (mAHD)

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BOWEN GAS PROJECT EIS

INFERRED GROUNDWATER LEVEL CONTOURS IN SHALLOW AQUIFERS

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GROUNDWATER

Figure: 14-11c

File No: 42626960-g-1086.mxd Drawn: XL Approved: DS Date: 06-11-2012 Rev. A A4

Figure 14-12 Groundwater Hydrograph for Three Bores Located in Confined Permian Strata Aquifers outside the Project Area

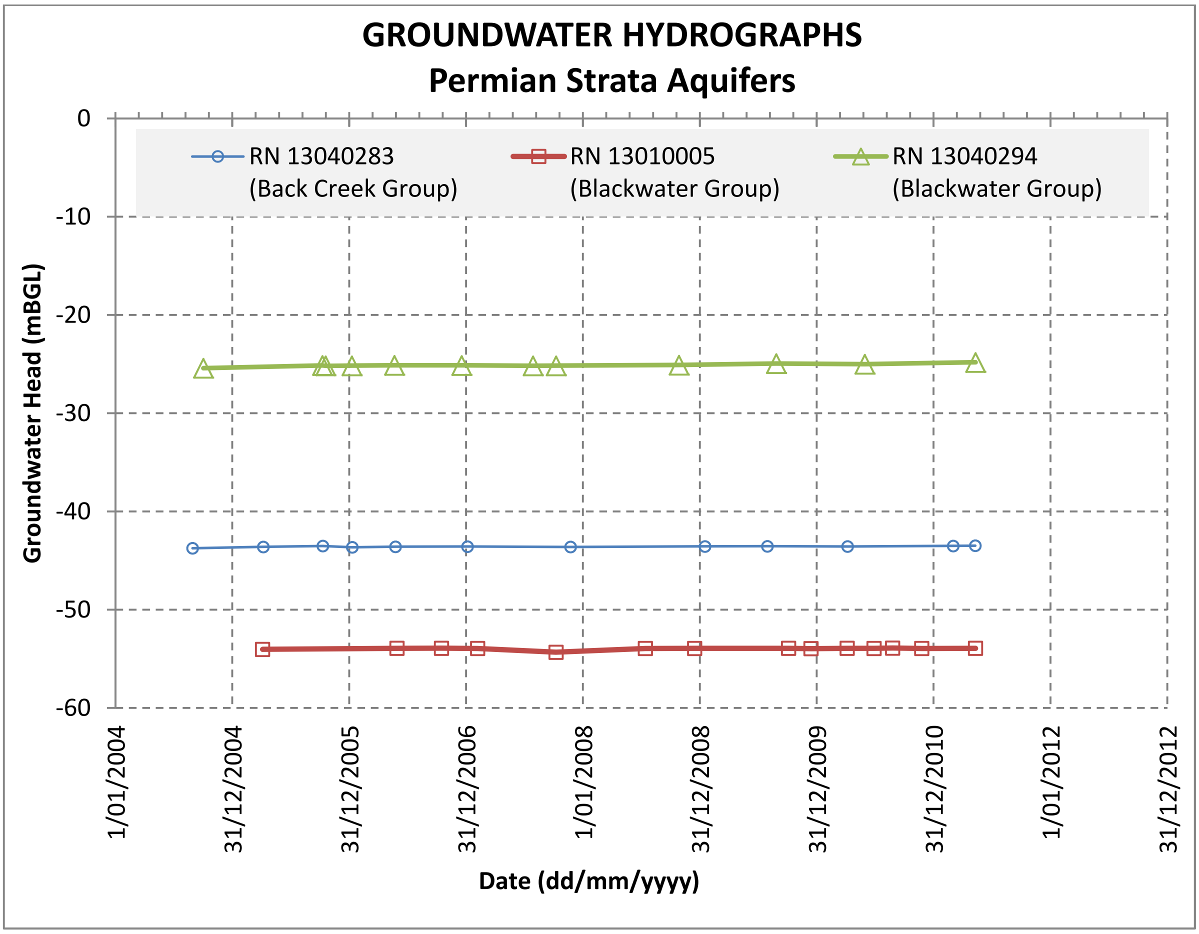
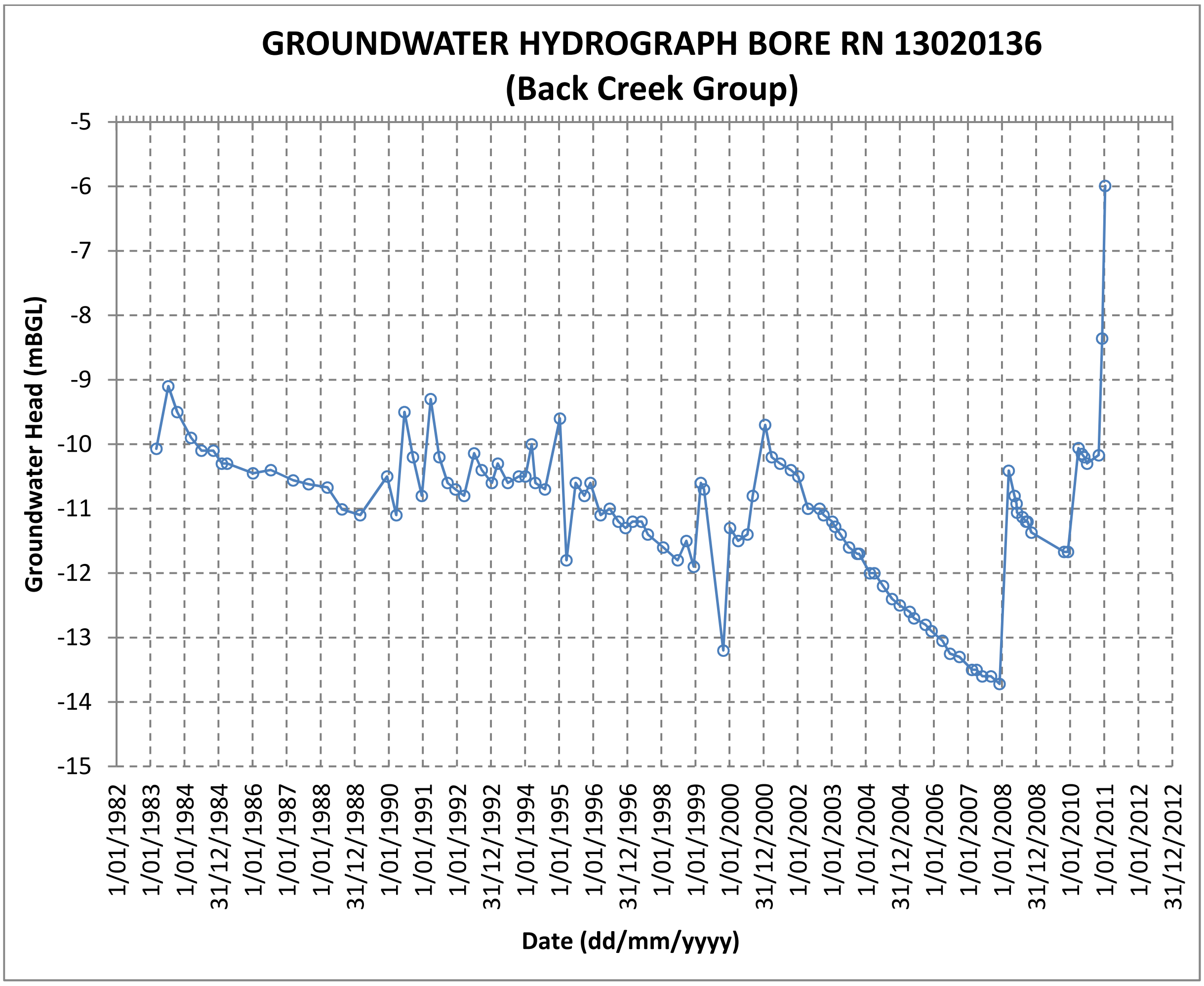
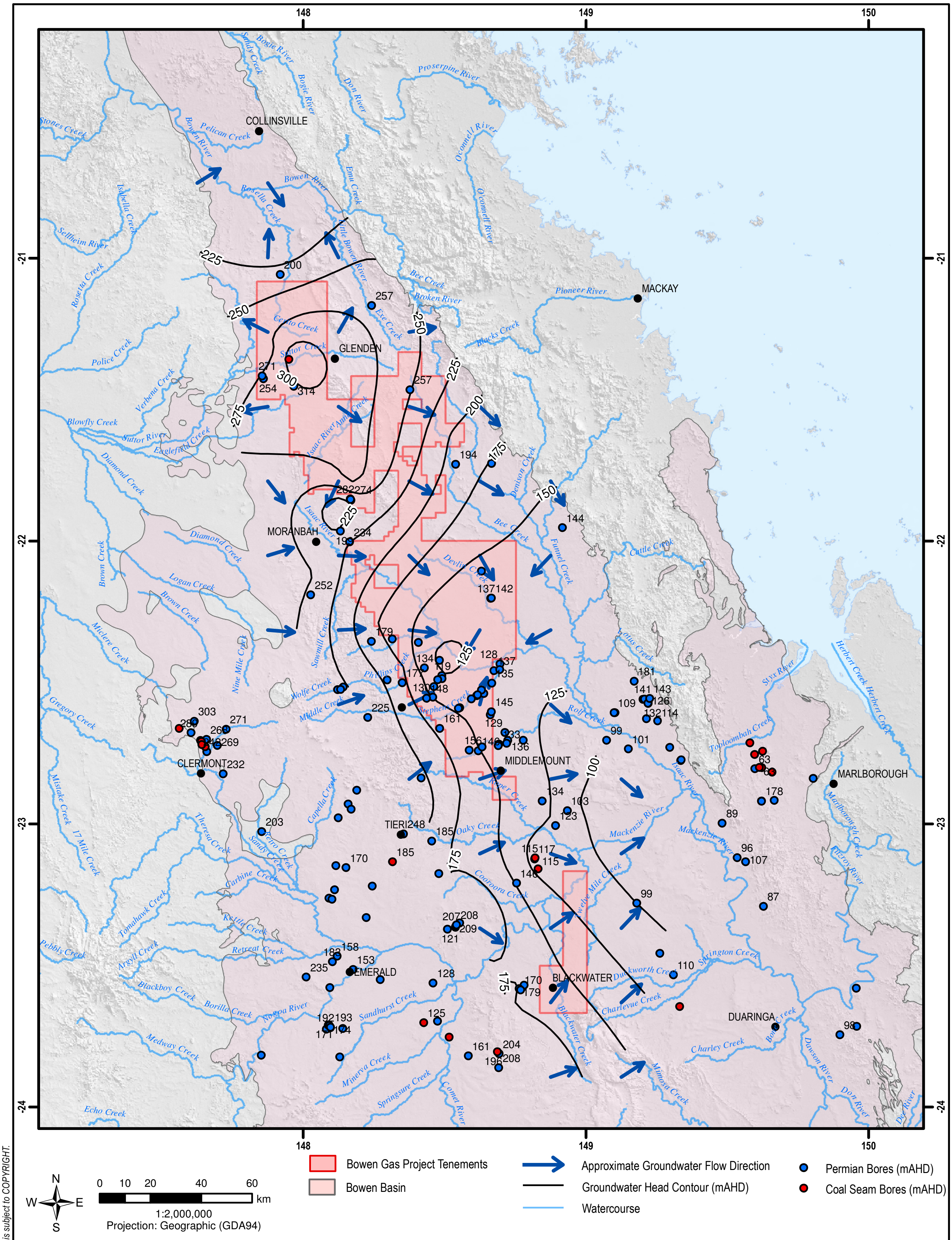


Figure 14-13 Groundwater Hydrograph for Bore RN 13020136 Located in Shallow Back Creek Group outside the Project Area





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BOWEN GAS PROJECT EIS

GROUNDWATER LEVELS IN THE BLACKWATER GROUP (PERMIAN) AQUIFERS AND GROUNDWATER CONTOUR FLOW

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GROUNDWATER

Figure: 14-14

File No: 42626960-g-1087.mxd Drawn: XL Approved: DS Date: 06-11-2012 Rev. A A4

14.5.2.3 Groundwater - Surface Water Interaction

Interactions between groundwater and surface-water are regionally important but depend on the local differences between the stream stage and the water table height. These height differences govern the groundwater flux direction (gain or loss) and rate. During periods of high rainfall the ephemeral rivers and streams have flowing water and tend to recharge the alluvial aquifers, but during low rainfall periods these same rivers and streams can be groundwater sinks. Groundwater in the alluvial aquifers will continue discharging into the streams until the water table falls below the stream bed and the rooting depth of riparian vegetation.

Connectivity between streams and alluvium is described by SKM as 'moderate to high'(2009a). Most of the rivers and streams within the Project area are (potentially) losing during flow events and thus provide recharge to the alluvium.

In the perennial rivers and creeks to the east side of the Isaac-Connors catchment, these surface water bodies are mostly gaining from groundwater baseflow (SKM 2009a). The relative abundance of groundwater on the east side of the Isaac-Connors catchment is directly related to the higher average annual rainfall on the Connors Ranges (600-1,000 mm/yr) compared with the plains (550-650 mm/yr).

It was considered when assessing potential impacts of the Project that impacts of induced flow, from the alluvium to the underlying coal seam subcrops, could potentially reduce baseflow. However, predictive groundwater modelling (Section 14.7) indicated little or no potential for induced flow from the alluvium. Thus groundwater – surface water interaction across the Project area tenements is not considered to be markedly altered by the Project.

14.5.3 Groundwater Quality

Groundwater quality in the Project area is described based on the investigations of Pearce and Hansen (2006) for the National Action Plan for Salinity and Water Quality and the groundwater quality mapping (Figure 14-7) of the Fitzroy catchment by Raymond and McNeil (2011). In addition, site-specific data was available in Arrow's groundwater monitoring database and NRM's groundwater database. A summary of findings is provided below and in the Groundwater and Geology Technical Report (Appendix L) of this EIS.

14.5.3.1 Alluvial, Sediment and Basalt Aquifers

Area between the Upper Isaac River and Bee Creek

The groundwater quality map (Figure 14-7) shows that most of the contiguous Project area is within the regionally dominant 'Isaac-Dawson' groundwater quality zone (No. 34), which is extensive around Moranbah and Middlemount. Groundwater in this zone is brackish (i.e. slightly to moderately saline), sodic, and has with an ionic balance dominated by Na^+ and Cl^-. The pH, salinity and major ions for four private bores in undefined aquifer units (near Moranbah) and seven bores constructed in the Duaringa Formation (in the Project area) are presented in the Groundwater and Geology Technical Report (Appendix L) of this EIS. Groundwater in these bores is mostly unacceptable for domestic use and is mostly too saline for stock watering or crop irrigation.

In the Project area, within the river alluvium of the Upper Isaac River, the groundwater is mostly brackish and poor quality, but has a spatially variable salinity and pockets of low-salinity groundwater occur in places (Raymond and McNeil, 2011). The pH, salinity and major ions for shallow NRM groundwater monitoring bores that are located in Upper Isaac River alluvium in the Project area were analysed. This data show that the alluvial groundwater has a highly variable salinity, ranging from fresh to very saline and an ionic balance dominated by Na^+ and Cl^-.

The site specific data confirm that groundwater in the 'Isaac-Dawson' zone of the contiguous Project area is mostly unacceptable for domestic use and is mostly too saline for stock watering or crop irrigation although there may exist pockets of low-salinity groundwater. Raymond and McNeil (2011) described the alluvial groundwater as having an EC of 498 to 8,910 µS/cm (depth <30 mbgl) and 3,419 to 16,000 µS/cm (depth >30 mbgl).

Dysart Area

Within the southern part of the contiguous Project area, east of Dysart, the 'Lower Stephens' groundwater quality zone (No.5 in Figure 14-7) is characterised by fresh groundwater considered, by Raymond and McNeil (2011), suitable for livestock, irrigation and possibly for domestic use (with treatment). This groundwater is associated with Stephens Creek, a tributary of the Isaac River.

Around Dysart there occur three other groundwater quality zones as seen in Figure 14-7:

- (No. 42) 'Black Hole';
- (No. 12) 'Stephens-Isaac' along Lucky Creek and Lower Isaac River; and
- (No. 23) 'Dysart' along Phillip Creek, Campbell Creek, Graveyard Gully and Rolfe Creek.

The shallow aquifers (<30 mbgl) of the 'Stephens-Isaac' and 'Black Hole' contain fresh groundwater that have a potential to be used for stock watering, irrigation and domestic use (with treatment). Whilst the shallow groundwater (<30 mbgl) at 'Black Hole' is considered (Raymond and McNeil, 2011) fresh (EC is 465 to 1,738 µS/cm), the deep groundwater (>30 mbgl) in the 'Black Hole' quality zone is considered brackish (EC of 8,080 to 12,220 µS/cm) indicating a steep vertical salinity gradient. This salinity gradient may be the result of an upward flux of saline-sodic groundwater mixing with stream recharge.

Area between Phillips Creek and Sawmill Creek

The portion of the of the contiguous Project area between Phillips Creek and Sawmill Creek remains unmapped, however groundwater there is likely to be saline-sodic like the 'Isaac Dawson' due to a relatively small upstream catchment areas. According to Figure 14-5, this area contains discontinuous river alluvium and undifferentiated sediments; however, groundwater chemistry data are too limited to provide a reliable description.

Glenden Area

The northern half of the contiguous Project area around Glenden (for latitudes north of Nebo) remains unmapped for groundwater chemistry; however, groundwater there is likely to be saline-sodic like the 'Isaac Dawson' due to a relatively small upstream catchment areas in the Suttor River and Bowen

River catchments. According to Figure 14-5, this area contains discontinuous river alluvium; however, groundwater bores are scant and groundwater chemistry data are too limited to provide a reliable description.

Middlemount Area

In the Mackenzie sub-catchment near Middlemount, a branch of river alluvium traverses the Project area (ATP 1103 and ATP 1031) in association with Roper Creek. Around Middlemount (Figure 14-7) the groundwater is characterised by the regionally dominant 'Isaac Dawson' groundwater quality zone (No. 34) which is 'sodic' and has an ionic balance dominated by Na^+ and Cl^- but includes some shallow pockets of low-salinity groundwater. The groundwater is generally unacceptable for domestic use and is mostly too saline for stock watering or crop irrigation and there are no NRM registered groundwater bores in this area.

Blackwater Area

In the Mackenzie sub-catchment around Blackwater (ATP 1025) there is alluvium in association with the Mackenzie River and Blackwater Creek, and an extensive exposure of sedimentary rocks (Duaringa Formation). Within this area occur these two groundwater zones (Figure 14-7):

- (No. 36) 'Blackwater' south of about 23.5°S; and
- (No. 13) 'Phillips-Fairbairn-Meteor' north of about 23.5°S.

'Blackwater' (No. 36) contains saline-sodic groundwater that is brackish (slight to moderately saline) and is generally unacceptable for domestic use, stock watering or irrigation. 'Phillips-Fairbairn-Meteor' (No. 13) contains an alluvial sequence of groundwater that is fresh to slightly-saline. This groundwater may have utility as stock water; however, there are no NRM registered groundwater bores in this area.

14.5.3.2 Permian-Triassic Strata Aquifers

Groundwater quality data for the Blackwater Group were analysed from three sources:

- Arrow's groundwater monitoring bores of the Moranbah Gas Project with detailed chemistry data (Table 14-9 and Figure 14-15);
- Sixty-eight additional CSG production and monitoring bores of the Moranbah Gas Project with EC and pH data for coal seams; and
- NRM monitoring bores located in the Project area (the Groundwater and Geology Technical Report (Appendix L) of this EIS).

The NRM data show that the groundwater in the Blackwater Formation is mostly brackish but ranges between fresh to very saline. Pockets of fresh groundwater may occur in the more shallow sub-crops of the Blackwater Group where rainfall recharge occurs. The Arrow EC and TDS data show that groundwater in the coal formations around Moranbah are uniformly brackish (moderately saline) and has an ionic composition dominated by Na^+ and Cl^-. This EC data are reasonably consistent with an EC range of 4,800 to 19,000 µS/cm cited in Worley Parsons (2010) for the Blackwater Group.

The proposed Project will produce groundwater from the coal formations of the Blackwater Group therefore, the quality of this groundwater is important for associated water management. The groundwater from the Moranbah coal measures can be classified as brackish (moderately saline) where TDS reportedly ranges from 4,310 to 12,760 mg/L and EC has been reported to range from 2,536 up to 7,670 µS/cm. Therefore, this water is generally unsuitable for stock watering, crop irrigation, or domestic use. Groundwater chemistry variations are further discussed in the Groundwater and Geology Technical Report (Appendix L) of this EIS.

Groundwater quality data for the Back Creek Group in the Project area are limited to six NRM bores (the Groundwater and Geology Technical Report (Appendix L) of this EIS). The salinity of the groundwater samples is highly variable (fresh to moderately saline) but is mainly brackish. Groundwater EC in the Back Creek Group farther afield range between 2,800 and 30,000 µS/cm, as quoted in Worley Parsons (2010). This groundwater is generally not suitable for stock watering, irrigation or domestic use; however, there may be areas of low-salinity groundwater in the shallow sub-crops where rainfall recharge occurs. Variations in groundwater quality across the Project area are further discussed in the Groundwater and Geology Technical Report (Appendix L) of this EIS.

Table 14-9 Summary of Groundwater Quality of Coal Formations (Blackwater Group) near Moranbah

Parameter	Unit	Min	Max	Average	No. Samples
pH	pH units	6.95	8.29	7.61	58
pH (c)	pH units	6.30	9.30	7.91	528
Conductivity	uS/cm	4,310	12,760	9,056	58
Conductivity (c)	uS/cm	1,020	15,300	8,464	530
TDS	mg/L	2,536	7,670	5,344	58
Ca	mg/L	12	101	41	58
Mg	mg/L	3	58	16.8	58
Na	mg/L	964	2,940	1,967	58
Cl	mg/L	1,151	4,500	2,792	58
HCO3	mg/L	369.66	2,293.6	1,001	58
SO4	mg/L	<1	2.3	<1	58

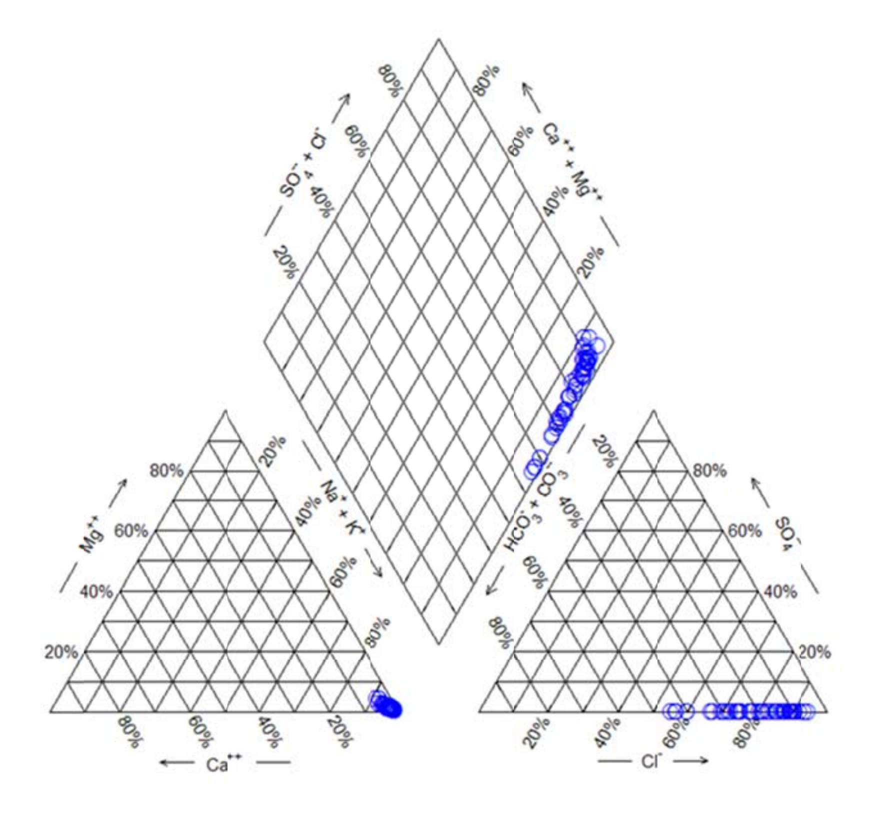
Notes:

a. Ca = Calcium, Mg = Magnesium, Na = Sodium, Cl = Chloride, HCO_3 = Bicarbonate, SO_4 = Sulphate

b. Data sourced from Arrow (see Appendix L)

c. Data sourced from Arrow (other Moranbah CSG Project monitoring and production bores not listed in Appendix L due to data validation limitations)

Figure 14-15 Piper Plot of Groundwater Quality for Coal Formations (Blackwater Group) near Moranbah (Arrow, Moranbah Gas Project)



14.5.3.3 Spatial Variation

The main feature of the groundwater chemistry across the Project area is the dominance of a near-marine ionic 'signature', particularly in deep sedimentary aquifers, including the Blackwater Group (Rangal, Fort Cooper, and Moranbah Coal Measures) and to a lesser degree, in the shallow surficial aquifers away from streams and rivers. The groundwater with a near-marine ionic signature is a 'sodic sequence' (Raymond and McNeil, 2011) with relatively high sodium (Na^+) content and a SAR > 12. The sodic sequence is a connate groundwater that occurs in locations away from streams and stagnant aquifers such as the confined coal seams. The salinity of the sodic sequence is spatially varied (i.e. slightly to markedly saline) due mixing with infiltrated meteoric water.

The Piper Plot (Figure 14-15) for the Moranbah coal seams shows that this water relatively stagnant with near seawater ionic ratios (TDS of seawater is ~35,000 mg/L). Stagnation can be attributed to confinement from above by the Rewan Formation and interburden. Average groundwater contours for the Blackwater Group (Figure 14-14) show that this groundwater is flowing in roughly the same direction as the topographic gradient and hence is receiving some diffuse recharge (inputs) over the more permeable outcrops.

An important feature of the shallow groundwater is the rainfall-ionic signature found near streams. This groundwater type is called the 'alluvial sequence' and has salinity in the 'fresh' to 'moderately saline' range and is generally fresher than the 'sodic sequence'.

14.5.4 Groundwater Allocations and Use

Groundwater entitlements (or allocations) recorded for the Isaac-Connors and McKenzie River sub-catchments were obtained from NRM's WERD. Thirty-five of the groundwater allocations (totalling 14,165 megalitres per year (ML/yr)) are associated with the Isaac-Connors sub-catchment whereas only four (totalling 3,034 ML/yr) are associated with the McKenzie sub-catchment. A low reliance on groundwater in the McKenzie sub-catchment is balanced by significantly greater reliance on surface water from the Mackenzie River which receives controlled dam releases during seasonal dry periods and droughts. Groundwater resources in the McKenzie River sub-catchment are "…effectively untouched with only a few production bores scattered throughout the sub-catchment" (Pearce and Hansen, 2006).

Groundwater entitlements are absent from the study area to the north of Nebo because there are no requirements to register bores or obtain licences outside the Highlands Groundwater Management Area (Figure 14–16). The shallow aquifers in this area are likely to contain saline-sodic groundwater (i.e. poor quality) as indicated by low rainfall, high potential evaporation, minor deposits of river alluvium, and a small surface catchment for stream-recharge (note that the upstream area is limited by the borders of the Belyando-Suttor, Bowen River and Isaac-Connors catchments).

A review of the data was undertaken to determine the aquifers from which the groundwater is sourced (Table 14-10) and the way in which groundwater is used (Table 14-11) in terms of both volume (ML/yr) and the number of entitlements. The review does not include groundwater extraction at the Moranbah Gas Project (MGP) or coal mine de-watering, which mostly occurs along the western side of the Bowen Basin. The statistics are approximate because small stock and domestic bores do not require entitlements and many of the groundwater entitlements have multiple uses (i.e. volumes were weighted evenly as an approximation). The main source of groundwater (12,859 ML/yr or 91% by volume) is from alluvial aquifers and minor groundwater sources include basalt (424 ML/yr), sedimentary rocks and coal of the Blackwater Group (842 ML/yr) and sedimentary rocks of the Back Creek Group (40 ML/yr). The groundwater extraction from the Back Creek Group is in the west of the basin where the Back Creek Group subcrops or outcrops.

A location map of the groundwater entitlements was prepared by associating symbols with the lots and plans (cadastral information) of the bores for each entitlement (Figure 14-16). The size of the symbols are scaled to show the relative volume (ML/yr) of each entitlement and colour-coded to show the aquifer source. Figure 14-16 shows that the vast majority of groundwater allocations are associated with river alluvium outside the Project area and in the following locations:

- Braeside Borefield at the confluence of Nebo and Denison Creeks, and around Bee Creek;
- Funnel Creek just upstream of the Connors River junction; and
- Lower Isaac River downstream of the Yatton stream gauge.

Within and near the Project area itself, there appears to be only two entitlements, one from the Isaac River alluvium (65 ML for domestic supply, irrigation and stock) and one from the Rangal Coal

Measures (2 ML for coal mine test purposes). There also exist a number of groundwater entitlements within 5 to 10 km of the Project area for basalt, alluvial and coal seam groundwater (various amounts for irrigation, stock, mine testing and industrial uses). In contrast, the northern Project area (ATPA 742, ATP 1103, ATPA 749, ATP 759, and ATP 1031) hosts relatively small groundwater licenses and the southern Project area (ATP 1025) hosts no groundwater licenses. These limited volumes of allocated groundwater in the Project area are consistent with a generally low-density of NRM registered bores in the Project area. Most of the NRM registered bores are associated with the productive alluvial aquifers along the east side of the Bowen Basin.

WERD data for the entire Isaac-Connors sub-catchment shows that approximately 50% (by volume) of groundwater allocations are for irrigation and approximately 25% (by volume) are for a combination of intensive stock watering, domestic and town supply, commercial, industrial, and mining use. The remaining approximate 25% (by volume) is allocated to a variety of uses, including amenities, aquaculture, educational, roadwork, and testing. Many of the irrigation developments associated with these entitlements are yet to be developed and irrigation entitlements are generally not fully utilised (SKM, 2009a).

NRM does not require metering of groundwater bores (except at Braeside borefield) and so the actual groundwater usage is not recorded. A study by SKM (2009a) suggests that actual groundwater usage under non-metered licenses is approximately 20% of the allocations for irrigation purposes and approximately 90% of the allocations for urban and industrial purposes, hence the statistics presented tend to over-emphasise actual reliance on groundwater by irrigators.

Table 14-10 Groundwater Allocations by Stratigraphic Unit in the Study Area

Stratigraphic Unit	Allocation Volume (ML/yr)	Allocation Volume (%)	No. of Allocations (-)	No. of Allocations (%)
Isaac-Connor's Sub-Catchment				
Quaternary (Alluvial Aquifers)	12,859	90.8%	28	80.0%
Tertiary Group (Fractured Basalt Aquifers)	424	3.0%	2	5.7%
Mimosa Group (Sedimentary Rocks)	0	0.0%	0	0.0%
Blackwater Group (Sedimentary Rocks and Coal)	842	5.9%	4	11.4%
Back Creek Group (Sedimentary Rocks)	40	0.3%	1	2.9%
Sub-Total	14,165	100.0%	35	100.0%
Mackenzie Sub-Catchment				
Quaternary (Alluvial Aquifers)	0	0.0%	0	0.0%
Tertiary Group (Fractured Basalt Aquifers)	5	0.2%	1	25.0%
Mimosa Group (Sedimentary Rocks)	0	0.0%	0	0.0%
Blackwater Group (Sedimentary Rocks and Coal)	3,029	99.8%	3	75.0%
Back Creek Group (Sedimentary Rocks)	0	0.0%	0	0.0%

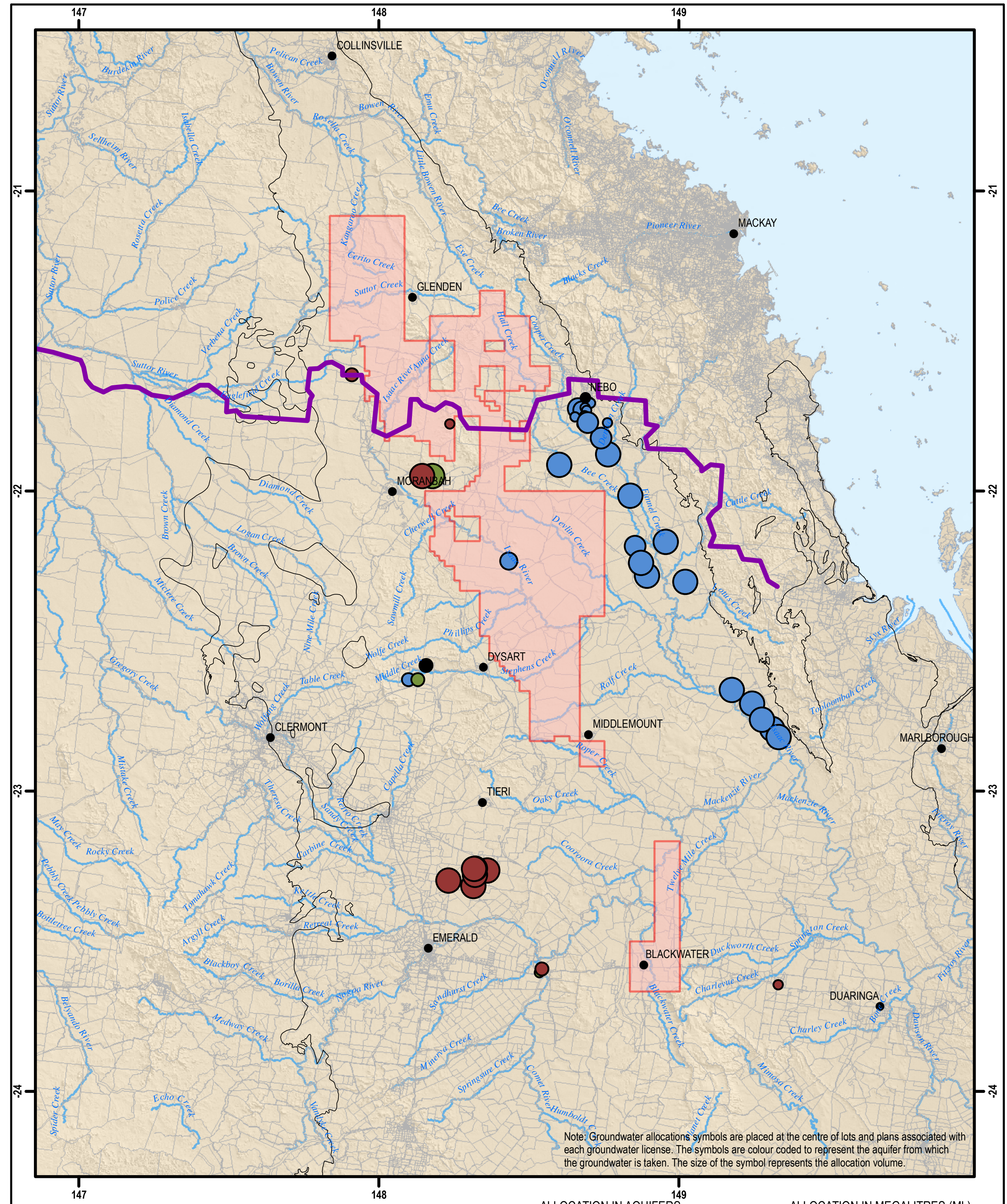
Stratigraphic Unit	Allocation Volume (ML/yr)	Allocation Volume (%)	No. of Allocations (-)	No. of Allocations (%)
Sub-Total	3,034	100.0%	4	100.0%
Total of Sub-Catchments	**17,199**		**39**	

Notes:

1. Additional extraction from stock and domestic purposes are not registered as allocations.
2. Groundwater extractions outside the Highlands Sub-artesian Area (declared area) are not recorded.
3. Actual groundwater extractions are not metered except at Braeside borefield.

Table 14-11 Groundwater Allocations by Purpose in the Study Area

Purpose	Allocation Volume (ML/yr)	Allocation Volume (%)	No. of Allocations (-)	No. Allocations (%)
Isaac-Connor's Sub-Catchment				
Irrigation	7,158	50.5%	18	50.5%
Stock Intensive	1,584	11.2%	6	16.2%
Domestic / Town Supply	772	5.4%	3	7.6%
Commercial	0	0.0%	0	0.0%
Industrial	1,053	7.4%	4	10.0%
Mining	150	1.1%	1	1.4%
Other	3,448	24.3%	5	14.3%
Sub-Total	14,165	100.0%	35	100.0%
Mackenzie Sub-Catchment				
Irrigation	25	0.8%	1	25.0%
Stock Intensive	0	0.0%	0	0.0%
Domestic / Town Supply	5	0.2%	1	25.0%
Commercial	4	0.1%	1	25.0%
Industrial	3,000	98.9%	1	25.0%
Mining	0	0.0%	0	0.0%
Other	0	0.0%	0	0.0%
Sub-Total	3,034	0.0%	4	0.0%
Total of Sub-Catchments	**17,199**		**39**	



Bowen Gas Project Tenements
Bowen Basin
Cadastre
Watercourse
Highlands Sub-Artesian Area Northern Boundary

N W E S

0 10 20 40 60 km

1:2,000,000
Projection: Geographic (GDA94)

ALLOCATION IN AQUIFERS
- Quaternary (Alluvial Aquifers)
- Tertiary Group (Fractured Basalt Aquifers)
- Later Permian Age, Blackwater Group (Sedimentary Rocks and Coal)
- Early Permian Age, Back Creek Group (Sedimentary Rocks)

ALLOCATION IN MEGALITRES (ML)
- 0 to 20
- 20 to 50
- 50 to 80
- 80 to 200
- 200 to 2,300

arrow energy go further

BOWEN GAS PROJECT EIS

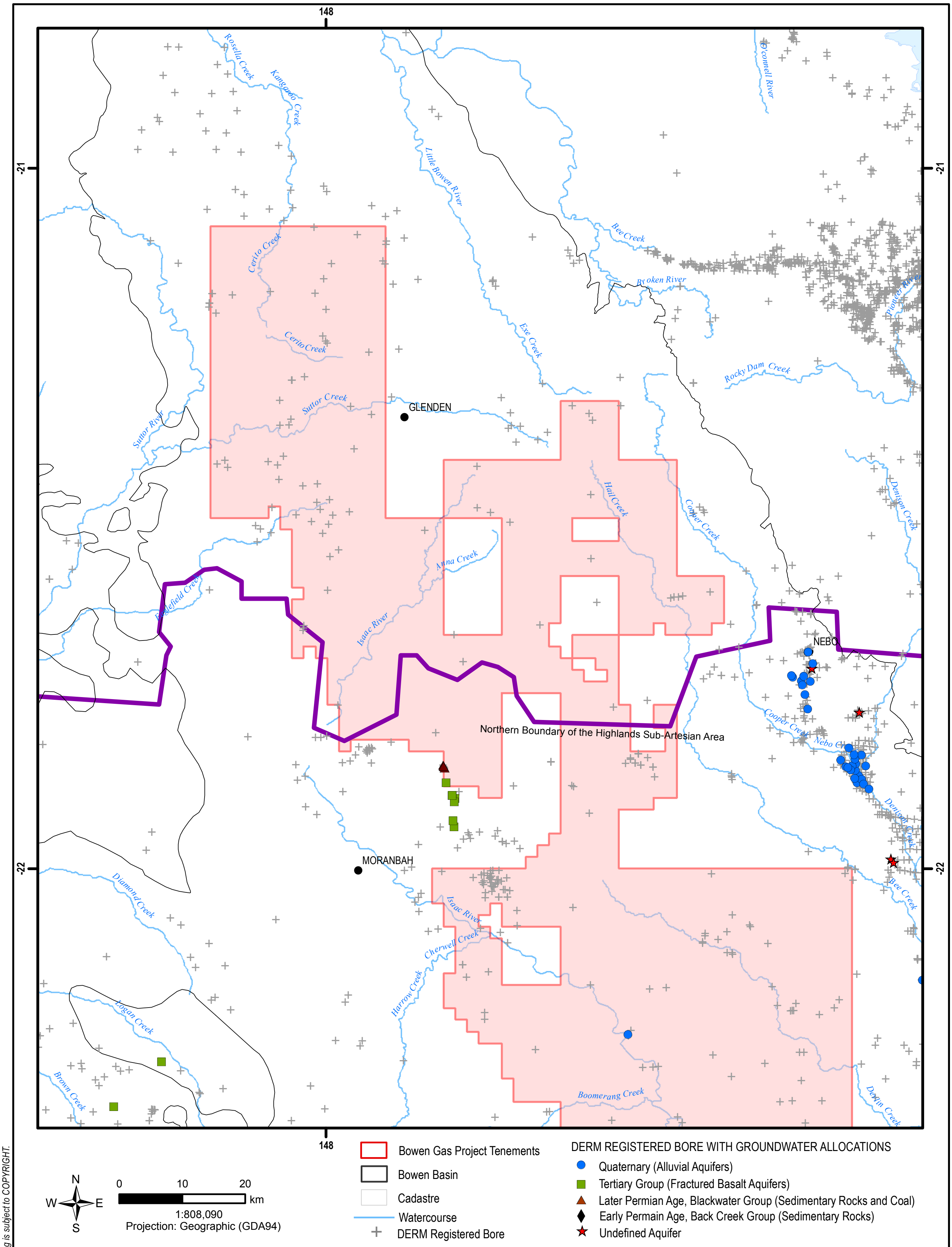
LOCATIONS OF LICENCED GROUNDWATER ALLOCATIONS IN THE STUDY AREA

URS

GROUNDWATER

Figure: 14-16

File No: 42626960-g-1088.mxd Drawn: XL Approved: DS Date: 06-11-2012 Rev. A A4



arrow energy go further

BOWEN GAS PROJECT EIS

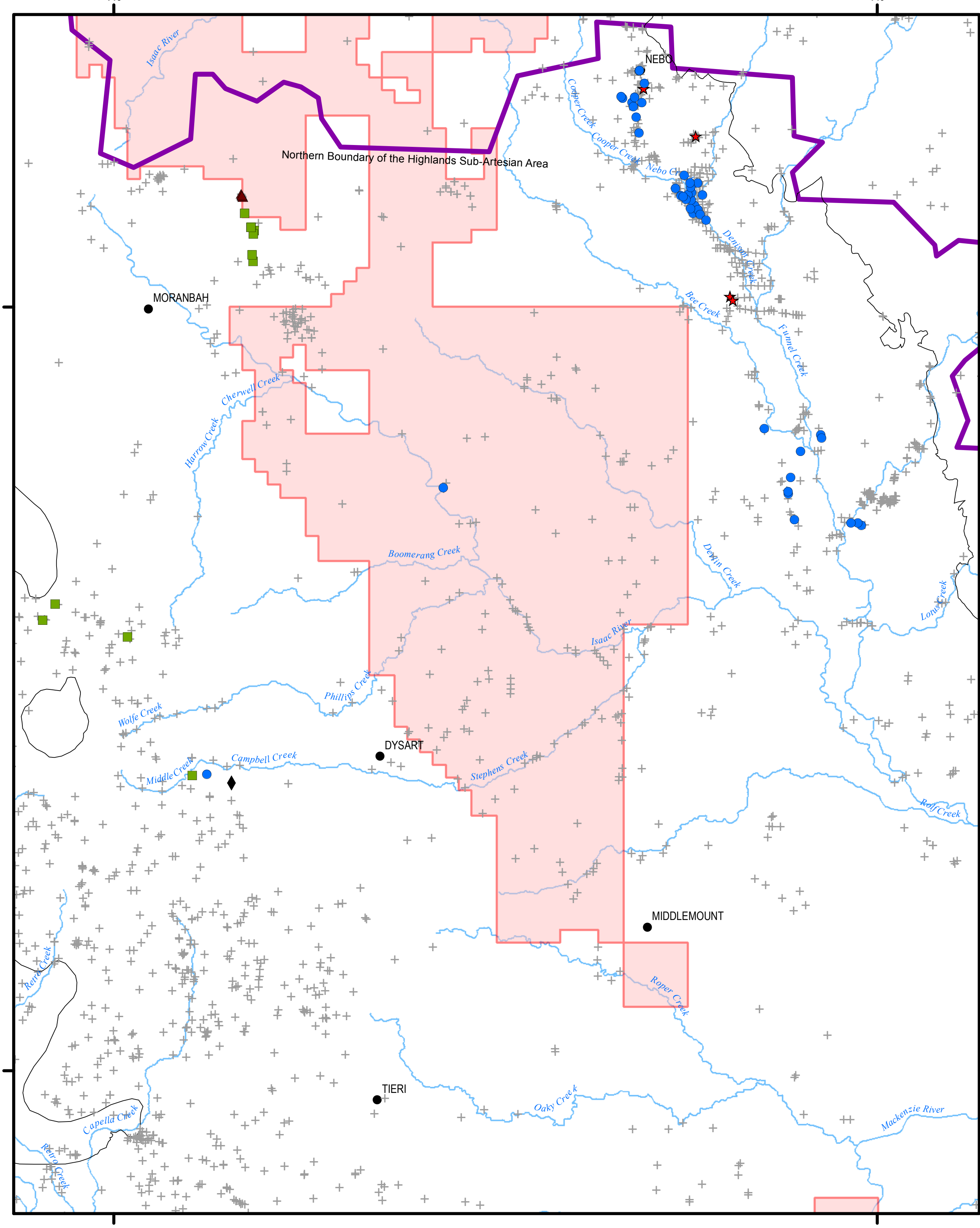
LOCATIONS OF NRM REGISTERED BORES IN THE STUDY AREA

URS

GROUNDWATER

Figure: 14-17a

File No: 42626960-g-1089.mxd | Drawn: RG | Approved: DS | Date: 06-11-2012 | Rev. B | A4



N W E S

0 10 20 km

1:808,090

Projection: Geographic (GDA94)

- Bowen Gas Project Tenements
- Bowen Basin
- Cadastre
- Watercourse
- DERM Registered Bore

DERM REGISTERED BORE WITH GROUNDWATER ALLOCATIONS

- Quaternary (Alluvial Aquifers)
- Tertiary Group (Fractured Basalt Aquifers)
- Later Permian Age, Blackwater Group (Sedimentary Rocks and Coal)
- Early Permain Age, Back Creek Group (Sedimentary Rocks)
- Undefined Aquifer

arrow energy go further

BOWEN GAS PROJECT EIS

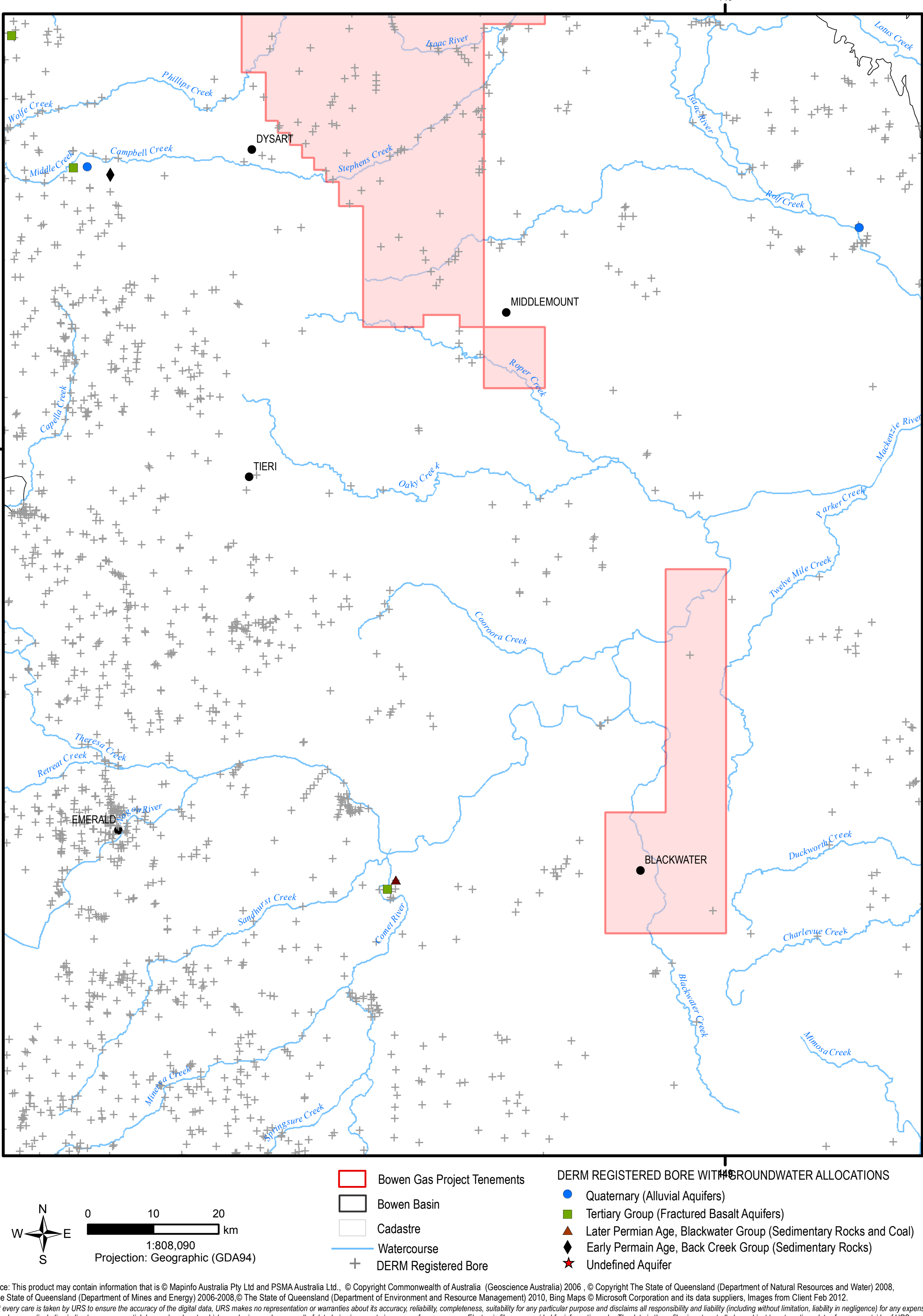
LOCATIONS OF NRM REGISTERED BORES IN THE STUDY AREA

URS

GROUNDWATER

Figure: **14-17b**

File No: **42626960-g-1089.mxd** Drawn: **RG** Approved: **DS** Date: **06-11-2012** Rev. **B** A4



arrow energy go further

BOWEN GAS PROJECT EIS

LOCATIONS OF NRM REGISTERED BORES IN THE STUDY AREA

URS

GROUNDWATER

Figure: 14-17c

File No: 42626960-g-1089.mxd | Drawn: RG | Approved: DS | Date: 06-11-2012 | Rev. B | A4

14.6 Environmental Values

This section identifies and describes groundwater related environmental values in the study area including extractive uses, support of GDEs and cultural values. The EPP (Water) provides a framework for identifying the environmental values, and establishes water quality guidelines and objectives to enhance or protect Queensland waters. For the purposes of this assessment the 'values', as defined in the EPP (Water), are those attributes of the groundwater systems within the potential impact area (and Project area) that are sufficiently important to be protected or enhanced.

The majority of the proposed Project area is within the Isaac River sub-basin of the Fitzroy Basin as described in Schedule 1 of the EPP (Water). The scheduled environmental values for groundwater to be enhanced or protected in the area are the following qualities:

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

The existing groundwater environment within the groundwater survey area has been assessed against these environmental values.

14.6.1 Biological Integrity of a Pristine or Modified Aquatic Ecosystem

14.6.1.1 Assessment

The majority of the Project area has been predominantly cleared for agriculture and cattle grazing, as well as for coal mining purposes. These practices modify the landscape which indirectly affects the volume and rate of rainfall runoff, the flow characteristics of the creeks, and recharge to groundwater. As such, the aquatic ecosystems of the area have been modified.

GDEs are ecosystems that have their species composition and natural ecological processes determined in part by groundwater. The groundwater parameters that sustain GDEs are flow rate, level, and quality, with dependence potentially being a function of one or all of these factors.

The groundwater level measurement data (Section 14.5.2) indicate that static water levels related to all aquifers within the Project area are generally greater than 10 mbgl, except the Quaternary alluvium aquifers (ephemeral, unconfined aquifers) associated with watercourses can be less than 10 mbgl when saturated. These depths to groundwater and the lack of registered springs (Section 14.4.6) in the Project area indicate that GDEs are only likely in areas of perennial surface water. This is confirmed in the Aquatic Ecology chapter (Section 16) of this EIS. The vegetation species and regional soil / geology types suggest that the level of groundwater dependence is likely to be relatively low (riparian vegetation communities are considered as opportunistically groundwater dependent) and vegetation is likely to be able to satisfy plant water requirements using retained soil moisture. Water available to ecosystems may include a mix of groundwater with soil water (unsaturated zone) and surface water.

A desktop assessment of the likelihood of stygofauna occurrence (considering suitable groundwater conditions and habitat) was undertaken as part of the Aquatic Ecology chapter (Section 16) of this EIS. Consideration was given to whether stygofauna could potentially occur within the Project's possible zone of influence. Suitable management options have been compiled within the Aquatic Ecology chapter (Section 16 of the EIS) and not considered for additional comment in this Groundwater chapter.

Although groundwater investigations indicate very low potential for groundwater resources to be physically available to support GDEs, the groundwater analytical results, as presented in Section 14.5.3, have been assessed against the EPP (Water) (for Zone 34, which includes the Moranbah area), ANZECC and ARMCANZ (2000), and Queensland (DERM, 2009) water quality guidelines (for the protection of moderately disturbed freshwater ecosystems, central region, upland streams). This allows consideration of whether the groundwater resources in the area are of a sufficient quality to provide environmental value to possible GDEs via flow into surface water bodies.

The assessment of groundwater quality using these surface water guideline values has an inherent level of conservatism due to the assumptions made regarding the behaviour, fate and transport of the analytes detected in groundwater, and the subsequent effects in the surface water ecosystem. The existing groundwater quality concentrations are above the water quality guidelines for freshwater ecosystems for some dissolved metals and nutrients; the median concentrations of most of the major ions are above the 50th percentile water quality objectives for the Isaac River sub-basin for the deeper groundwater (Back Creek Group and Moranbah Coal Measures). These existing exceedences indicate that even if the deeper groundwater was physically available to support GDEs, it has low environmental value for sustaining the biological integrity of aquatic ecosystems. Shallow groundwater in the alluvium may, however, sustain aquatic ecosystems as flow to GDEs or surface water bodies although shallow aquifers are ephemeral, only existing for short periods after recharge.

14.6.2 Suitability for Recreational Use (Primary Recreation)

This category of environmental value is considered not applicable to groundwater in-situ. There are also no registered groundwater springs in the Project area that could be considered for recreational use. Groundwater seepage from the alluvium into water courses can provide short duration baseflow into rivers and creeks immediately after heavy rains or flooding, however, after larger flood events suitability of these waters for recreation may be limited by other factors.

The above value is common for surface water features that are accessible for recreational use and visual interaction; however, there is currently no evidence to suggest that groundwater is directly used for recreational or aesthetic purposes in the study area.

14.6.3 Suitability for Minimal Treatment before Supply as Drinking Water (Raw Water)

Fresh groundwater occurs in discrete locations with limited spatial extent within the Bowen Basin, including in river alluvium of Cooper Creek, Denison Creek, Funnel Creek, and Connors River (SKM, 2009a), and notably at the Braeside Borefield, which supplies water to coal mines, Coppabella, and a number of rural properties. However, groundwater quality on the whole across the Project is considered to be highly variable.

The suitability of water for human consumption is defined in the Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011). The groundwater quality data, as presented in Section 14.5.3, have been assessed against the Australian Drinking Water Guidelines (NHMRC NRMMC 2011). The groundwater quality indicates that in general, the groundwater is unsuitable for human consumption before treatment due to elevated levels of salinity (> 1,000 mg/L TDS) above the aesthetics guideline for unacceptable taste. The hydrochemistry data for the Permian coal seams (Table 14-9) has elevated concentrations of sodium above the EPP (Water) drinking water guideline of 30 mg/L for sodium.

Groundwater resources within the Project area are, therefore, considered to require treatment before being utilised for drinking.

The availability of reticulated mains water, rain water tank supplies, and the generally low sustainable yield and poor quality of the groundwater bores in the area, are also factors that preclude the usage and potential for usage of the groundwater as a drinking water source.

14.6.4 Suitability for Primary Industry Use

In certain locations the shallow groundwater in the river alluvium and basalt aquifers is suitable for irrigation and stock watering (Figure 14-7). Irrigation creates the greatest demand for licensed groundwater withdrawals in the Isaac Connors sub-catchment (~7,200 ML/yr). In most locations away from the rivers, creeks and basalt, the shallow groundwater is too saline-sodic for agricultural use. In deep aquifers, such as in the coal measures, the groundwater is highly saline-sodic and has limited uses. The only licences for deep groundwater are associated with industry (< 800 ML/yr) and mine well testing (42 ML/yr) and occur only in a few locations in the study area. Aquaculture is identified as a very minor use for groundwater in the study area with only one groundwater license (<2 ML/yr) recorded.

Groundwater quality results in shallower aquifers suggest that groundwater within the study area is generally suitable for stock watering for beef cattle. However it is considered that the higher salinities of the Back Creek Group and Blackwater Group aquifers could potentially result in loss of production and decline in animal condition and health as salinity concentrations are > 5,000 mg/L.

Although groundwater quality is generally acceptable for stock watering, the generally low sustainable yield of the water bores in all aquifers in the area and the salinity of groundwater in the Back Creek Group and Blackwater Group precludes the usage and potential for usage of the groundwater as a source of irrigation water.

14.6.5 Maintenance of Cultural and Spiritual Values

There are no registered groundwater springs or seeps that supply surface water bodies in the Project area.

Shallow groundwater (in the alluvium) in the Project area may sustain baseflow in the non-perennial rivers for short periods after heavy rains or flooding, although shallow aquifers are ephemeral, only existing for short periods after recharge.

Further discussion of cultural and spiritual values is presented in the Social chapter (Section 24) and Indigenous Cultural Heritage chapter (Section 25) of this EIS.

14.6.6 Summary

A number of aquifer types containing accessible water present in the study area could potentially be affected by the proposed development. The environmental values for each of these aquifer types are provided in Table 14-12 along with supporting comments.

Table 14-12 Environmental Values of Groundwater in the Project Area

Groundwater System / Aquifer	Environmental Values											Intrinsic Groundwater Properties
	[1]Biological areas				Suitability for consumptive and productive uses						Anthropomorphic	
	[6]Ecological Importance	Groundwater supports biological integrity of pristine biological systems	Groundwater supports biological integrity of slightly to moderately disturbed biological systems	Groundwater can support biological integrity of slightly to highly disturbed biological systems	Domestic & Town Supply	Irrigation	Stock Watering	Mining	Other (amenities, aquaculture, education, roadwork, and testing)	Industrial	Cultural & Spiritual Values of the Water	Groundwater supports biological integrity of slightly to moderately disturbed biological systems
Shallow Groundwater Systems (water table)												
Quaternary River Alluvium	Mod. to High	Not Expected	Some areas	Some areas	Some areas	Some areas	Some areas	Some areas	Some areas	Some areas	Pending Study	**Biological Values** Riverine wetlands, palustrine wetlands, and riparian vegetation potentially reliant on groundwater exist within the study area. These ecosystems are generally considered to be slightly to

Ground-water System / Aquifer	Environmental Values											Intrinsic Groundwater Properties
	[1]Biological areas				Suitability for consumptive and productive uses						Anthropo-morphic	
	[6]Ecological Importance	Groundwater supports biological integrity of pristine biological systems	Groundwater supports biological integrity of slightly to moderately disturbed biological systems	Groundwater can support biological integrity of slightly to highly disturbed biological systems	Domestic & Town Supply	Irrigation	Stock Watering	Mining	Other (amenities, aquaculture, education, roadwork, and testing)	Industrial	Cultural & Spiritual Values of the Water	Groundwater supports biological integrity of slightly to moderately disturbed biological systems
Quaternary Floodplain Alluvium & Sediments	Low	Not Expected	Not Expected	Not Expected	Not Expected	Not Expected	Not Expected Some areas	Not Expected Some areas	Not Expected	Not Expected	Pending Study	moderately disturbed due to anthropogenic processes caused by grazing, cropping, mining and urbanisation. It is possible that infiltration of pollutants into groundwater occurs, including nutrients from cattle and sheep grazing and agricultural chemicals.
Tertiary Basalt	Low to Mod.	Not Expected	In remote or isolated areas	Some areas	Some Areas	Not Expected	Some areas	Not Expected Some areas	Not Expected	Some areas	Pending Study	**Consumptive and Productive Use Values** Groundwater salinity across the Bowen Basin varies spatially and is mostly saline-sodic. There exist pockets of fresh

Groundwater System / Aquifer	Environmental Values											Intrinsic Groundwater Properties
	[1]Biological areas				Suitability for consumptive and productive uses						Anthropomorphic	
	[6]Ecological Importance	Groundwater supports biological integrity of pristine biological systems	Groundwater supports biological integrity of slightly to moderately disturbed biological systems	Groundwater can support biological integrity of slightly to highly disturbed biological systems	Domestic & Town Supply	Irrigation	Stock Watering	Mining	Other (amenities, aquaculture, education, roadwork, and testing)	Industrial	Cultural & Spiritual Values of the Water	Groundwater supports biological integrity of slightly to moderately disturbed biological systems
												groundwater (low salinity) with a wide range of beneficial uses. More common is groundwater (moderately saline) that is suitable for agricultural uses. **Anthropomorphic Values** Cultural heritage assessments to identify and be managed accordingly.

Ground-water System / Aquifer	Environmental Values											Intrinsic Groundwater Properties
	[1]Biological areas				Suitability for consumptive and productive uses						Anthropo-morphic	
	[6]Ecological Importance	Groundwater supports biological integrity of pristine biological systems	Groundwater supports biological integrity of slightly to moderately disturbed biological systems	Groundwater can support biological integrity of slightly to highly disturbed biological systems	Domestic & Town Supply	Irrigation	Stock Watering	Mining	Other (amenities, aquaculture, education, roadwork, and testing)	Industrial	Cultural & Spiritual Values of the Water	Groundwater supports biological integrity of slightly to moderately disturbed biological systems
Intermediate Groundwater Systems (sandstone plateaus)												
Clematis Sandstone	Mod. to High	Not expected	Not expected	Pending Study	Pending Study	Pending Study	Pending Study Some areas	Pending Study Some areas	Pending Study	Pending Study Some areas	Pending Study	**Biological Values** The intermediate aquifers in the north are generally considered to be moderately disturbed due to anthropogenic processes caused by agriculture and grazing. The intermediate aquifers in the south are generally considered to be near pristine or slightly disturbed due to conservation as a national park.

Groundwater System / Aquifer	Environmental Values											Intrinsic Groundwater Properties
	[1]Biological areas				Suitability for consumptive and productive uses						Anthropomorphic	
	[6]Ecological Importance	Groundwater supports biological integrity of pristine biological systems	Groundwater supports biological integrity of slightly to moderately disturbed biological systems	Groundwater can support biological integrity of slightly to highly disturbed biological systems	Domestic & Town Supply	Irrigation	Stock Watering	Mining	Other (amenities, aquaculture, education, roadwork, and testing)	Industrial	Cultural & Spiritual Values of the Water	Groundwater supports biological integrity of slightly to moderately disturbed biological systems
Rewan Formation	Very Low	Not expected	Not expected	Not expected	Not expected	Small scale	Possible	Minor sustain-able yields	Not expected	Minor sustain-able yields	Probably In-significant	**Consumptive and Productive Use Values** There may exist fresh groundwater in the north. Fresh water springs (and groundwater) occurs in the south however the area is a designated National Park.

Groundwater System / Aquifer	Environmental Values											Intrinsic Groundwater Properties
	Biological areas[1]				Suitability for consumptive and productive uses						Anthropomorphic	
	Ecological Importance[6]	Groundwater supports biological integrity of pristine biological systems	Groundwater supports biological integrity of slightly to moderately disturbed biological systems	Groundwater can support biological integrity of slightly to highly disturbed biological systems	Domestic & Town Supply	Irrigation	Stock Watering	Mining	Other (amenities, aquaculture, education, roadwork, and testing)	Industrial	Cultural & Spiritual Values of the Water	Groundwater supports biological integrity of slightly to moderately disturbed biological systems
Deep Groundwater Systems (Coal Seams)												
Coal Measures	Very Low	Not expected	Not expected	Not expected	Not expected	Small scale	Possible	Minor sustain-able yields	Not expected	Minor sustain-able yields	Probably In-significant	**Biological Values** The deep groundwater have little or no biological value due to poor quality and limited yields, limited interaction due to aquitards. **Consumptive and Productive Use Values** Limited yields of poor quality. **Anthropomorphic Values** Pending study.
Back Creek Group	Very Low	Not expected	Not expected	Not expected	Not expected	Small scale	Possible	Minor sustain-able yields	Not expected	Minor sustain-able yields	Probably In-significant	

1. The biological environmental values of water to be protected under the EPP (Water) include:

- For high ecological value waters –The biological integrity of an aquatic ecosystem that is effectively unmodified or highly valued; and
- For slightly modified disturbed waters – The biological integrity of an aquatic ecosystem that is affected adversely to a relatively small but measurable degree by human activity;
- For highly disturbed waters – The biological integrity of an aquatic ecosystem that is measurably degraded and of lower ecological value than waters mentioned above; and
- Spring complexes (although not identified) could be considered under biological and anthropomorphic values.

Relevant assessment guidelines for the consumptive and productive use environmental values to be protected include:

2. Australian Drinking Water Guidelines 2004 (NHMRC and NRMMC 2004).
3. ANZECC 2000 - Australian Water Quality Guidelines for Irrigation Water Quality.
4. ANZECC 2000 - Australian Water Quality Guidelines for Fresh and Marine Waters – Guidelines for Livestock Watering.
5. Groundwater quality criteria are specific to application.
6. Unconfined groundwater systems can have high quality groundwater, and could support ecosystems such as streams and wetlands, and thereby have moderate to high ecological importance.

14.7 Potential Impacts

14.7.1 Approach

The ToR provided by the EHP request a definition of the areal extent of groundwater resources likely to be affected by the Project development and a description of possible environmental harm throughout the development, operation and post-closure of the Project. To help address these questions the Potential Impact Areas for groundwater are interpreted from the results of a numerical groundwater model developed by Ausenco - Norwest (2012) (see Groundwater Model Technical Report (Appendix M) of this EIS). Other potential impacts that are considered include potential contamination of groundwater resources including, but not limited to, surface storage of untreated associated water / residual brine and cross contamination between aquifers.

Potential groundwater related impacts resulting from the proposed CSG development may include:

- Direct impacts caused by coal seam depressurisation;
- Indirect impacts caused by coal seam depressurisation;
- Impacts caused by field and infrastructure development, operation and decommissioning;
- Cumulative impacts caused by this and other projects requiring the dewatering and depressurisation of the Permian coal measures; and
- Impacts post-closure.

The potential impacts associated with the Project activities were evaluated in order to assist in decision making in regards to Project design, implementation, and impact mitigation measures (Framework Approach) to be developed. An assessment of the significance of impacts and mitigation measures is presented in Section 14.8.

14.7.2 Potential Impacts during Development

The Project conceptual field development is summarised in the Project Description chapter (Section 4) of this EIS. Field development activities that have potential to impact on groundwater environmental values in the region result from:

- CSG field development; and
- CSG infrastructure development (Table 14-13).

Mitigation measures and residual impact significance related to field development and operations are discussed in Section 14.8.

14.7.2.1 Drilling and Well Construction

CSG production requires the drilling and construction of production wells across a defined field development area. In addition, groundwater and gas monitoring and/or investigation wells will be constructed across the Project area.

The well installation process and installed wells have some potential to impact groundwater through the introduction of drilling fluids and muds, leaks and spills at the wellhead during drilling, the interconnection and cross-contamination of aquifers, and the migration of gas from coal seams. These potential impacts are typically a result of incomplete or incorrect well construction and/or improper well installation techniques.

In addition, wells will require decommissioning when no longer required. Some of the potential impacts associated with the drilling and installation of production wells also apply to drilling of monitoring wells. Other sub-surface activities with potential to impact intersected aquifers include the installation of gathering lines to transfer gas and water between wells and associated facilities and leaks and spills from subsurface infrastructure, e.g. gathering lines.

14.7.2.2 Hydraulic Stimulation

An assessment of the main considerations regarding the possible hydraulic stimulation that may be required during the Project was compiled by Arrow (Groundwater and Geology Technical Report (Appendix L) of this EIS). It was considered that the main potential risks associated with hydraulic stimulation include:

- The exposure of people (other than suitably trained and equipped workers) and ecological receptors to chemicals used or formed during stimulation; and
- The potential impacts of hydraulic stimulation on the physical nature of the target coals and interbedded units resulting in increased interconnection of geological units and the possible blending of groundwater quantities.

Consideration of the stratigraphy, the confining nature of the units between the coal seams within the Blackwater Group, and the confining units above (Rewan Formation) and below (Back Creek Group) the Blackwater Group, indicates limited groundwater resources. Thus any increased hydraulic conductivity (vertical or horizontal) within these aquitards as a result of hydraulic stimulation would have limited area of influence and affect on aquitards and coal seams.

14.7.2.3 Summary

Table 14-13 provides a summary of the potential impacts to groundwater resources as a result of CSG field development.

Table 14-13 Potential Impacts of Field Development on Groundwater

Impact	Potentially Affected Groundwater System(s)
Well field Development and Sub-surface Impact	
Hydraulic Stimulation – interconnection and cross-contamination	All groundwater systems intersected
Well installation – cross-contamination of aquifers	Production and monitoring wells will potentially intersect all groundwater systems above the Back Creek Group.
Well installation – contamination by drilling process	

Impact	Potentially Affected Groundwater System(s)
Well installation – contamination by surface process	Sub-surface activities can potentially impact all groundwater systems.
Installation of sub-surface infrastructure – contamination from leaks and spills	
Water Storage, Infrastructure, Processing and Distribution Impacts	
Contamination of groundwater systems - storage of chemicals, fuels, oils	Shallow groundwater systems. The deep Groundwater System is excluded based on depth and isolation from these surface processes.
Contamination of groundwater systems - waste generation and storage	
Contamination of groundwater systems - waste water and sanitation (effluent)	
Infrastructure Footprint Impacts	
Reduced aquifer recharge	Shallow, Intermediate and CSG Groundwater Systems. The Deep Groundwater System is excluded based on depth and isolation from these surface processes.
Installation of gas reticulation facilities and compressor stations	Groundwater Systems. The Deep Groundwater System is excluded based on depth and isolation from these surface processes

14.7.3 Potential Impacts during Operation

14.7.3.1 Induced Seismicity

Induced seismicity refers to typically low magnitude earthquakes and tremors caused by human activities that alter stresses on the earth's crust.

Induced seismicity could result from Project activities such as drilling, geophysical (seismic) surveys, hydraulic stimulation and injection.

Hydraulic stimulation increases the coal seam permeability by introducing fluid under pressure into the target coal seam to propagate and widen fractures. When fractures are generated or deformed the rock stress state (equilibrium) changes and induced seismic activity can occur.

Hydraulic stimulation induced seismicity records indicate minor seismic events that generally register less than 2.0 on the Richter Magnitude Scale. Events of this level are not felt at ground surface, and are only detectable with sensitive equipment. Records of production induced ground motions in the Roswinkel gas field in the Netherlands (Dowding *et al.,* 2011) as a result of hydraulic stimulation and field operations between 1992 and 2003 indicate moment magnitude 2.25 events

A review of seismic records show that there had been 30 earthquakes in the Project area since records began in 1955. Five were classed as 'significant' with maximum recorded magnitudes of 3.6 and 4.7 (Richter Magnitude Scale). The 3.6 magnitude earthquake occurred in 1990 at a depth of approximately 10 km below ground surface and was likely associated near a fault. This suggests the presence of active faults within the Bowen Basin is likely.

Induced seismicity, as a result of hydraulic stimulation, is considered to result in minor seismic events, which are most likely to be less that the historically recorded magnitudes or those generated by mining activities.

14.7.3.2 Direct Impacts of Coal Seam Depressurisation

Groundwater in the target coal seams of the Blackwater Group, within the Rangal Coal Measures and Moranbah Coal Measures, will typically be depressurised during CSG production to about 40 to 50 m (of hydraulic head) above the top of the target coal seams. Considering target coal depths of 350 to 750 m below surface with associated potentiometric pressures of about 50 mbgl, this translates to approximately 265 to 690 m of drawdown below the pre-development groundwater pressure in the coal seams (Table 14-14). Each CSG well is predicted to produce a drawdown cone within the target coal seams and these drawdown cones will super-impose (amalgamate) to create a regionally extensive depressurisation impact within the target coal seams of the Blackwater Group (Figure 14-18). Although the estimated drawdowns in Table 14-14 are substantial, the pressures disturbances are mostly contained within the coal seams by low-permeability interburden and the Rewan Formation. Subsequently the induced groundwater flow and depressurisation is mostly lateral, through the coal seams, rather than vertical, between the coal seams and interbedded formations.

Table 14-14 Estimate of Maximum Drawdown in Target Coal Seams of the Blackwater Group

Parameter	Reference	Low	Middle	High
Coal Seam Target Depth (mbgl)	[1]	350 to 750	350 to 750	350 to 750
Ground Surface Elevation (m AHD)	[2]	150	250	350
Coal Seam Target Elevation (m AHD)	[3]=[2]-[1]	-200 to -600	-100 to -500	0 to -400
Approx. Pressure Head (m AHD)	[4]	125	215	300
Approx. Depressurisation Target (m above the coal seam)	[5]	35	35	35
Approx. Depressurisation Target (m AHD)	[6]=[3]+[5]	-165 to -565	-65 to -465	35 to -365
Drawdown Estimate (m)	[7]=[4]-[6]	290 to 690	280 to 680	265 to 665

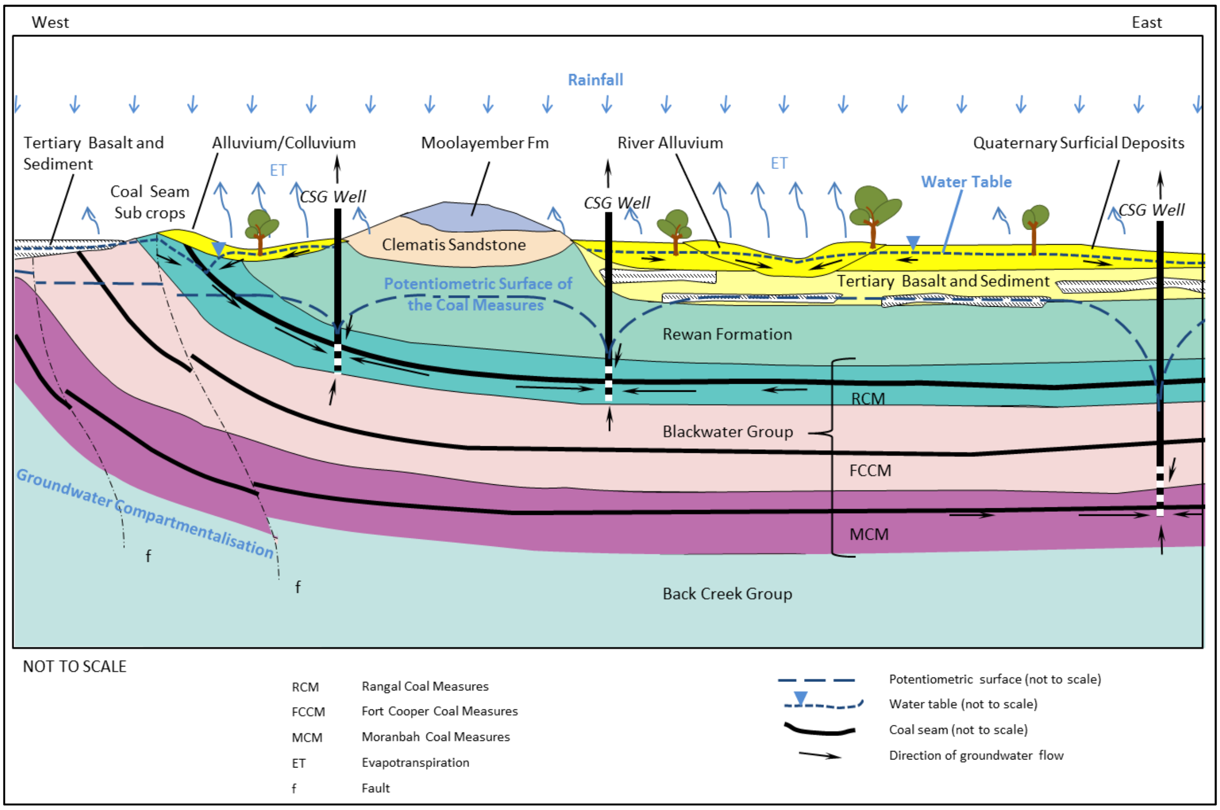
Notes:
1. Project Description (Section 4).
2. Typical elevations in the Project area (Figure 14-10).
4. Typical groundwater potentials in the Blackwater Group (Figure 14-14).
5. CSG operations In the Surat Basin typically reduce heads to within 35 m of the upper coal seam (Moran and Vink, 2010).

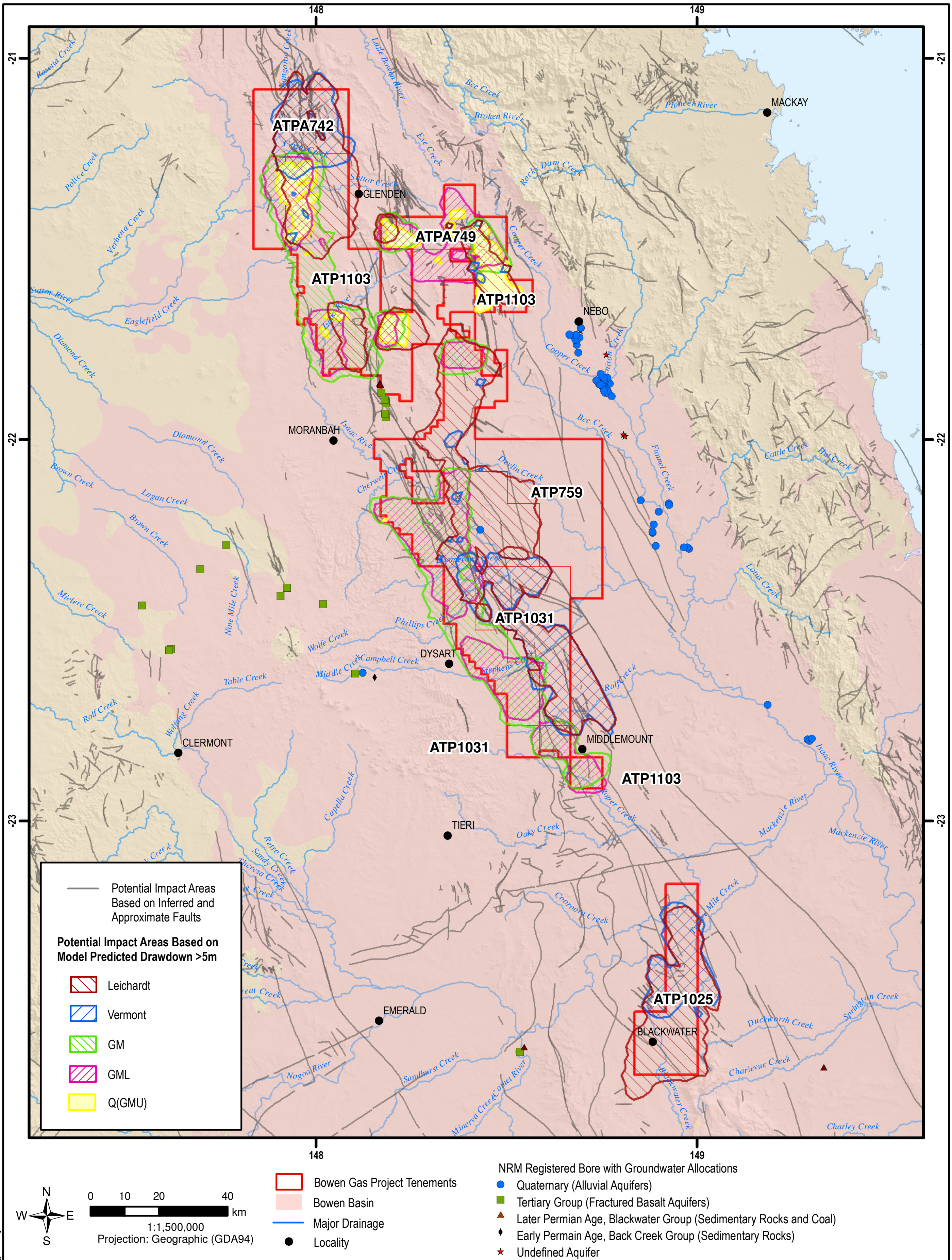
The numerical groundwater model of the Project (Groundwater Model Technical Report (Appendix M)) was used to predict the 2 m and 5 m drawdown contours in all aquifers at the cessation of CSG operations and 50 years post operations. The 5 m contour for the deeper confined aquifers projects drawdown for a distance of approximately 1 to 7 km from the CSG wells. Furthermore, the model prediction for 50 years post-operations suggests that the impacted (5 m drawdown contour) will extend an additional 0 to 4 km, depending on location. Hence the prediction is, as a direct impact of CSG production on the deeper aquifers, the 5 m drawdown will spread no more that 1 to 10 km from the CSG wells after 110 years (i.e. 50 years post-operations).

14.7.3.3 Indirect Impacts of Coal Seam Depressurisation

Indirect impacts on groundwater resources were considered based on literature reviews and base case predictive groundwater modelling (see Groundwater Model Technical Report (Appendix M) of this EIS), where the base case assess the potential impacts of the Project alone (without a cumulative scenario).

Figure 14-18 Basic Conceptual Hydrogeological Model Showing Induced Groundwater Flow during Project Operations





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BOWEN GAS PROJECT EIS

INTERPRETED POTENTIAL IMPACT AREAS FOR DEEP AQUIFERS AT THE CESSATION OF CSG OPERATIONS

URS

GROUNDWATER

Figure: **14-19**

File No: **42626960-g-1151.mxd** Drawn: **XL** Approved: **DS** Date: **06-11-2012** Rev. **A** A4

14.7.3.3.1 Shallow Aquifers

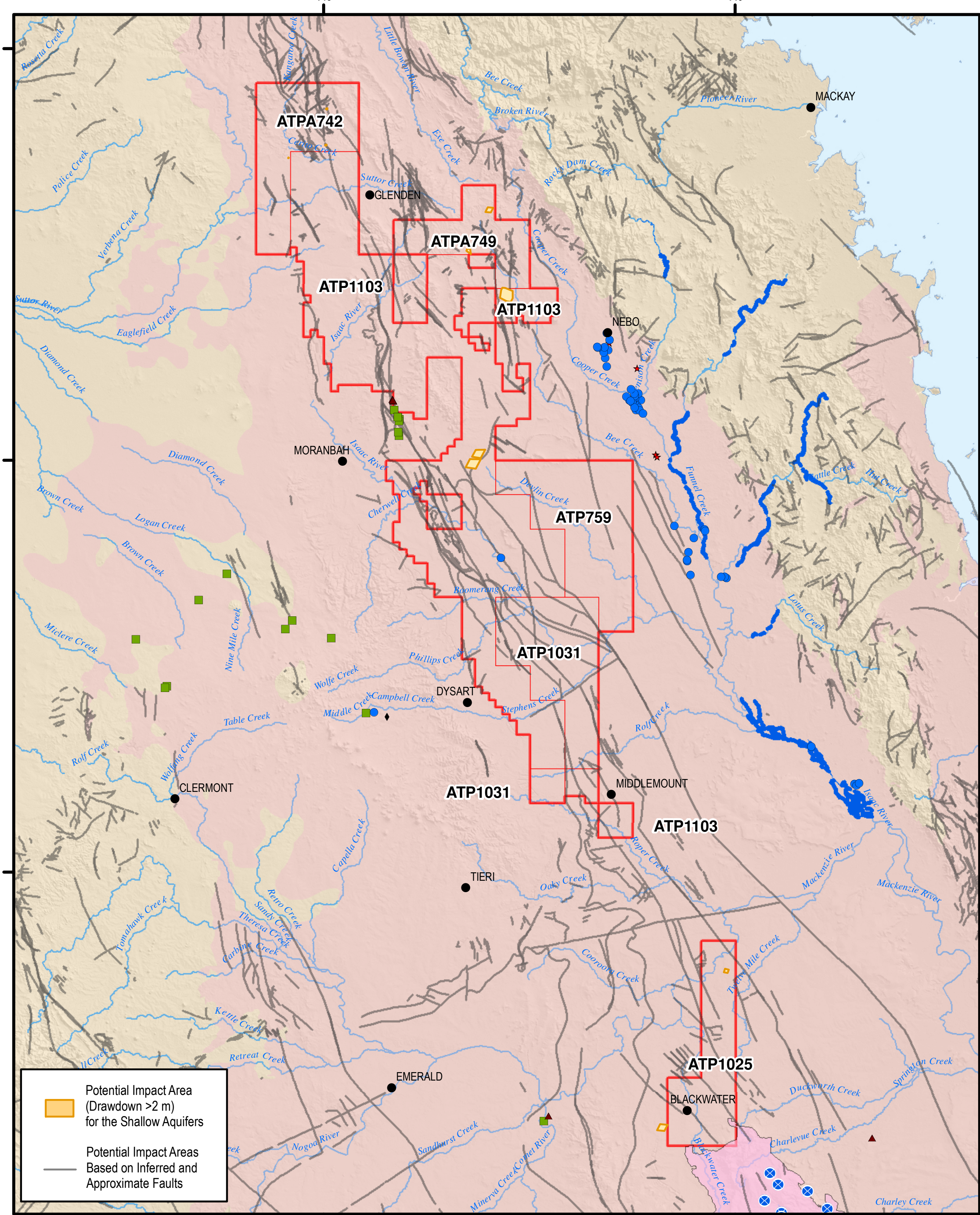
Groundwater drawdown within the shallow aquifers, as predicted by the groundwater model, is limited in magnitude and extent but can potentially occur where:

- The shallow groundwater is in direct hydraulic connection with the target coal seams (sub-crops or outcrops) as shown in Figure 14-20; or
- Where faults are vertically connected with the potential impact area of the deep aquifers.

The numerical groundwater model of the proposed Project (see Groundwater Model Technical Report (Appendix M)) was used to predict the drawdown in the shallow aquifers. The basecase model predictions (for a period of 50 years post CSG operations) indicate that no drawdown exceeding 2 m is predicted for alluvium, colluvium, Suttor Formation, and Basalt (model Layer 1) except for a single model cell in the Duaringa Formation. This drawdown, > 2 m, occurs immediately overlying the Vermont target coal seam.

As a precautionary and conservative measure (to assess worst case scenario), the model predicted drawdowns in Layer 3 of the model were used to define the Potential Impact Areas in the shallow aquifers at cessation of operations and at 50 years beyond the Project life (Figure 14-20 and Figure 14-21). This was done as there is the potential, over time (100s of years based on identified low vertical permeability), for the drawdown to propagate to model Layer 1 units (the shallow groundwater resources) through induced flow. Induced flow can potentially occur above the depressurised zones in Layer 3 (see Groundwater Model Technical Report (Appendix M)). Subsequently the indirect impacts on shallow groundwater are conservatively defined by the 2 m drawdown contours in Layer 3 of the model.

The results of the Moranbah Gas Project modelling (Arrow, 2011) indicate a drawdown of the unconfined water table of between 0.06 and 0.28 m. These results are of similar order of magnitude for the current model predictions for the proposed Project and therefore support the results of Ausenco and Norwest (see Groundwater Model Technical Report (Appendix M) of this EIS).



N
W E
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0 10 20 40 km

1:1,500,000

Projection: Geographic (GDA94)

Bowen Gas Project Tenements	Locality
Bowen Basin	Spring
Mimosa Management Area of the Great Artesian Basin	Major Drainage
	Streams with potential Baseflow

NRM Registered Bore with Groundwater Allocations
- Quaternary (Alluvial Aquifers)
- Tertiary Group (Fractured Basalt Aquifers)
- Later Permian Age, Blackwater Group (Sedimentary Rocks and Coal)
- Early Permain Age, Back Creek Group (Sedimentary Rocks)
- Undefined Aquifer

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BOWEN GAS PROJECT EIS

INTERPRETED POTENTIAL IMPACT AREAS FOR SHALLOW AQUIFERS AT THE CESSATION OF CSG OPERATIONS

URS

GROUNDWATER

Figure: 14-20

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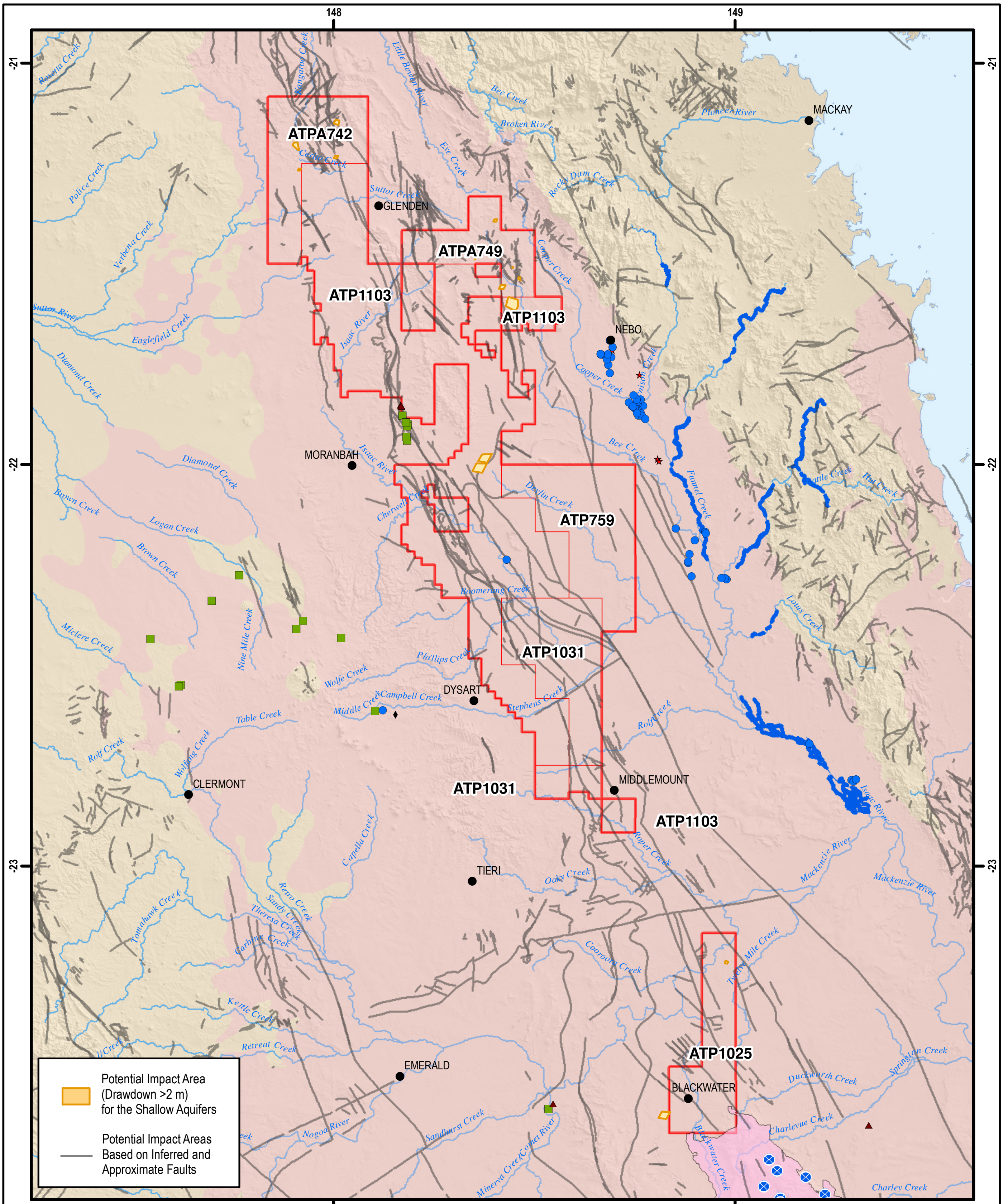

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1:1,500,000

Projection: Geographic (GDA94)

- Bowen Gas Project Tenements
- Bowen Basin
- Mimosa Management Area of the Great Artesian Basin
- Locality
- Spring
- Major Drainage
- Streams with potential Baseflow

NRM Registered Bore with Groundwater Allocations

- Quaternary (Alluvial Aquifers)
- Tertiary Group (Fractured Basalt Aquifers)
- Later Permian Age, Blackwater Group (Sedimentary Rocks and Coal)
- Early Permain Age, Back Creek Group (Sedimentary Rocks)
- Undefined Aquifer

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BOWEN GAS PROJECT EIS

INTERPRETED POTENTIAL IMPACT AREAS FOR SHALLOW AQUIFERS AT 50 YEARS POST-PRODUCTION

URS

GROUNDWATER

Figure: 14-21

File No: 42626960-g-1153.mxd   Drawn: XL   Approved: DS   Date: 06-11-2012   Rev. A   A4

14.7.3.3.2 Intermediate Aquifers in the North

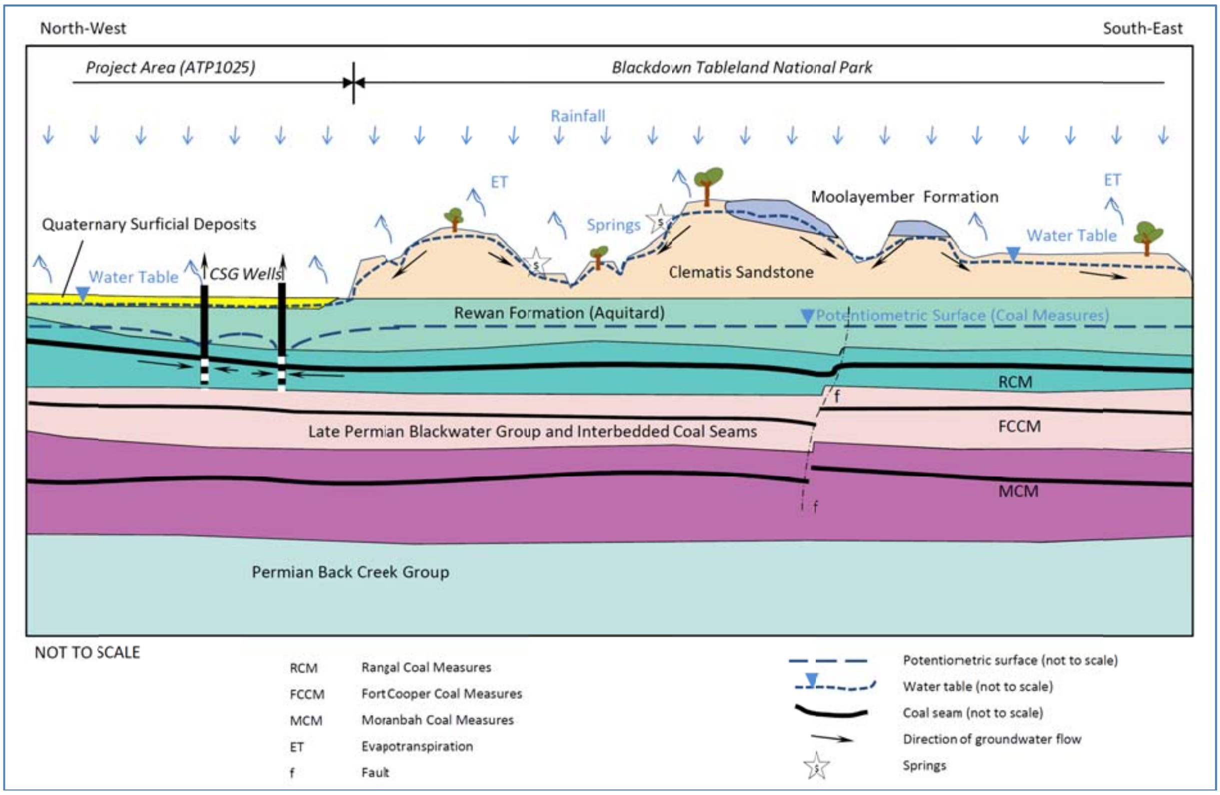
The Clematis Sandstone occurs as outcrops in the northern half of the Project area (Figure 14-5). This sandstone unit is separated from the underlying Blackwater Group coal measures (the CSG target) by the Rewan Formation (aquitard) and interburden (aquitards). According to the groundwater model effectively zero drawdown will occur in the Clematis Sandstone.

A potential pathway for induced flow from the Clematis Sandstone could be via faults, if these faults have sufficient tangential permeability and direct hydraulic connection to the depressurised target coal seams. The hydraulic properties of mapped faults are largely unknown and groundwater levels and resources in the Clematis Sandstone, in the northern portion of the Bowen Basin, are not recorded. For these reasons the major sub-vertical faults are conservatively included in the potential impact area.

14.7.3.3.3 Springs to the Southeast

The Clematis Sandstone occurs as a sandstone plateau outcrop southeast of ATP 1025 in an area called the Blackdown Tableland National Park (Figure 14-22). This plateau supports 17 springs, water falls, and rock pools, however these features occur outside the Project area, at distance of at least 10 to 40 km southeast of Blackwater and at elevations of roughly 50 to 650 m above the plains. The groundwater model (base case) predicted zero drawdown in these Clematis Sandstone aquifers; therefore, no predicted impact as a result of the Project on the springs is anticipated. This is conceptualised in Figure 14-22.

Figure 14-22 Basic Conceptual Hydrogeological Model of the Blackdown Tableland National Park Showing Induced Groundwater Flow during Project Operations



14.7.3.3.4 Fault Zones

The regional tectonic setting of the Bowen Basin is largely compressive and as a consequence faults and folds are more likely to be hydraulic barriers than conduits to lateral groundwater flow. Some faults may also limit flow by vertical displacement of units (aquifers with aquitards) or by infilling within the fractures. Faults can compartmentalise the groundwater and this may result in groundwater quality differences between compartments. Predictive groundwater modelling (see Groundwater Model Technical Report (Appendix M) of this EIS) included scenarios to assess the influence of faults on predicted drawdown. These results indicate compartmentalisation reduces drawdown extent.

Although the Bowen Basin is largely compressive and faults are considered to have limited vertical permeability, it is considered that there may be the potential for increased vertical connection along faults, which could enhance induced flow between units. Faults also have potential to act as preferential flow paths for gas migration, where sufficient vertical permeability exists. An indirect impact associated with coal seam depressurisation is CSG loss or migration through geological structures (faults, fractures and zones of secondary alteration).

Assessment of geological structures should be considered when developing CSG fields.

14.7.3.3.5 Land Subsidence

Subsidence is defined as the movement of the surface strata in response to the loss of underground support (Nagel, 2001). A loss of underground support can potentially result from groundwater extraction from an aquifer and associated strata compaction. Although the impact of subsidence may be more noticeable in the vertical direction, mediating the occurrence of subsidence can be equally important in the horizontal direction (Allen and Mayuga, 1970). While hydrocarbon industry-related subsidence is well documented, some of the fundamental phenomena and mechanisms encountered in CSG production from coal have not been studied in detail, and are unable to be explained by the current level of knowledge, such as long term consequence effects (Harpalani and Chen, 1997; Siriwardane *et al*., 2009).

Land subsidence as a result of CSG production has been documented in the Powder River Basin (PRB), Wyoming, USA. Groundwater has been extracted in the PRB for coal bed methane (CBM), a CSG equivalent term, production at rates approximately 94 million gallons per day (356 ML per day). As a result of aquifer compaction, several centimetres of land subsidence have been measured via interferometric synthetic aperture radar (InSAR). The largest subsidence values measured over the RB was 4 to 6 cm and in these areas; subsidence was correlated to large clusters of coal bed methane pumping wells (Grigg, 2012). InSAR has also been used to quantify the surface response to aquifer depletion in the vicinity of CBM production in the San Juan Basin of Colorado and New Mexico. Results show that there has been enough groundwater production to result in measurable (several centimetres) of subsidence above the CBM fields of the San Juan Basin (Katzenstein, 2012). Given the large areas of these basins, approximately 32,375 and 12,070 km^2 respectively, land subsidence as a result of CBM production is generally viewed as negligible.

14.7.3.3.6 Subsidence in Coal Formations

One potential mechanism for subsidence occurring from the production of CSG is volumetric changes in the coal formation and adjacent overburden (referred to as matrix volumetric strain). In some circumstances a volumetric decrease can occur due to pore pressure reduction which increases the stress applied to the rock matrix. Pore pressure reduction can occur during both dewatering and methane production stages (Myer, 2003). Swelling of coal due to sorption of liquids has been reported by Gregg (1961) and Green *et al.* (1985). Swelling of coal in the presence of an adsorptive gas (i.e. methane) has also been investigated in the past. Moffat and Weale (1955) reported studying the swelling and shrinkage of coal with adsorption or desorption of methane. Documented literature estimating the magnitude of subsidence occurring with CSG is limited. Generally, subsidence effects in coal formations appear to be negligible. Preliminary estimates of subsidence in the PRB due to aquifer draw down are deemed insignificant at approximately 1.3 cm (Case *et al.,* 2001).

14.7.3.3.7 Reservoir Compaction

Compaction of reservoir formations and overburden can occur from the thinning of the reservoir layers. The process is governed by three primary parameters; increasing effective stress, reservoir thickness, and reservoir rock compressibility (Nagel, 2001). Reservoir compaction occurs when the underground system (initially in equilibrium) experiences a physical change through the removal of groundwater (for depressurisation) and gas. The pore pressures decline and the effective stress (the difference between the external pressure and the pore pressure) is increased (Nagel, 2001). This change to the effective stress acting upon a depressurised coal seam can result in compaction until a new equilibrium is reached with the new effective stress state (degree of compaction is dependent on rock compressibility).

Compressibility is difficult to measure, itself being a function of rock mass constituent composition, the degree of sorting, the nature of mineral decomposition or alteration, cementation and the porosity of the rock (Nagel, 2001).

Permeability of coal seams is recognised as the most important parameter for CSG production (Shi and Durucan, 2004) and a loss of permeability will result in a loss of gas production. Permeability of the coal seam is influenced in two ways; through phase-relative permeability effects, and through a change in the effective stress within the seam (Harpalani and Chen, 1997). Methane desorption results in matrix shrinkage, which whilst significantly increasing coal permeability, may cause subsidence of the overburden (Myer, 2003).

14.7.3.3.8 Overburden Compaction

Pore pressure reduction can also occur in the overburden or confining layers due to dewatering. The magnitude of the volumetric decrease will depend on the compressibility and thickness of the affected strata. In non-structural reservoirs, such as CSG formations in horizontal or sub-horizontal strata, shear displacements as a result of volumetric deformation may be less likely. Instead, matrix shrinkage may be more an issue. In addition, matrix shrinkage may have an impact on long-term gas production from CSG reservoirs (Harpalani *et al.,* 1997; Siriwardane *et al.,* 2009).

14.7.3.3.9 Risks Associated with Coal Seam Subsidence

Available literature on risks associated with coal seam subsidence focuses on the impact of coal seam shrinkage upon gas production; while limited data was found regarding the occurrence of subsidence from CSG production or the impacts of CSG induced subsidence. These data suggest subsidence as a result of CSG production will be negligible: maximum recorded land subsidence range of 4 to 6 cm (correlated to large clusters of coal bed methane pumping wells) (Grigg, 2012) over a large CSG field (approximately 32,375 km^2), and estimates of coal seam subsidence have been approximated at 1.3 cm (Case *et al.,* 2001). Although there is a lack of reported cases in the literature, the potential for subsidence to occur is still relevant to an impact assessment.

Land subsidence is a process that can occur over a wide range of temporal scales, from almost instantaneous settlement to very slow rates of ground level drop over long time-periods. The occurrence of subsidence can cause changes to flood plain morphology (Zekster *et al.,* 2005). This could influence surface water runoff and may cause changes to flood regimes, and could precipitate a need to revise flood mapping.

The most immediate impact of marked subsidence may involve surface structures (Nagel, 2001). However, in cases of regional subsidence the effects may not be as damaging to structures as localised subsidence. Subsidence and compaction can also affect gas and water production, and well casing deformation can occur due to axial buckling in the reservoir or horizontal shearing in the overburden. Fissuring can be produced through differential settlement of subsiding lands (Zekster *et* *al.,* 2005). Fissures may be produced at pre-existing faults. Risks of failure or slip of pre-existing faults within the coal formation due to subsidence within the formation are dependent on the depth, in-situ stress state, pressure drawdown, coal strength, and poro-elastic properties (Nagel, 2001). As a formation compacts, system changes may cause large principal stress differences increasing the potential for failure and slippage.

Although the permeability of coal increases with desorption of methane gas during production, the increase in effective stress due to a reduction in pressure also tends to cause a reduction in coal permeability. Results from Harpalani *et al.,* (1997) suggest that the decrease in permeability due to increased effective stress is balanced by the overall increase in permeability from matrix shrinkage.

14.7.3.3.10 Summary

CSG production and groundwater depressurisation activities in the Project area will have varying impacts on the groundwater levels in the coal seam aquifers depending on the CSG schedule and management. Due to the low permeability of the confining Rewan Formation and the low permeability of the interburden layers (aquitards) of the Blackwater Group, the predicted groundwater drawdown is restricted to the coal seams (aquifers) and proximal to the proposed CSG fields. Predictive modelling indicates that drawdown in deep aquifers may extend no further than 1 to 10 km from the CSG wells after 50 years post-operations.

Potential impacts on groundwater resources in shallow alluvial and basalt aquifers were also predicted by modelling but these are generally less the 2 m trigger threshold for unconsolidated aquifers.

Based on the literature assessment, it is considered that the risk of land subsidence is not high but cannot be entirely ruled out, and it is recognised that pressure reductions will occur in geological formations comprising consolidated rock. Due to the significant depth of the target coal seams and the large aerial extent of the depressurisation, effects of any subsidence are considered unlikely to have significant impact on surficial structures.

14.7.3.4 Other Impacts

14.7.3.4.1 Water Storage, Infrastructure, Processing and Distribution Impacts

Ancillary infrastructure associated with CSG field development and expansion within the CSG fields, which may impact on groundwater resources include:

- Facilities (field compression facilities, central gas processing facilities and integrated processing facilities);
- Gas and water gathering line networks;
- Maintenance and lay down yards;
- Electricity generation facilities;
- Workers accommodation, including sewage treatment plants;
- Workshops; and
- Storage facilities.

14.7.3.4.2 Associated Water Impacts

Managing associated water is challenging due to its variable quality and estimated volumes, approximated to be 5.4 gigalitres per year for the proposed Project. Quality issues such as elevated concentrations of salts commonly leaves the associated water unsuitable for release to the environment or for many beneficial uses without treatment.

Based on the *Coal Seam Gas Water Management Strategy* (Arrow, 2012), a summary of the potential impacts caused by associated water is provided in Section 14.8.5. Previously, a common technique to manage and dispose associated water was to use evaporation ponds. Changes to government policy have evolved necessitating the use of associated water for beneficial purposes. Details of Arrow's associated water management strategy are included in the Coal Seam Gas Water and Salt Management Strategy (Appendix AA) of the EIS.

14.7.4 Cumulative Potential Impacts

14.7.4.1 Coal Mining in the Bowen Basin

Approximately 40 open pit and underground coal mines operate within the Bowen Basin (see Groundwater Model Technical Report (Appendix M) of this EIS). Most are located on the western limb of the basin, targeting the Permian coal seams. Predictive groundwater modelling for coal projects in the Moranbah area indicates that groundwater drawdown, within the confined target coal seams could potentially extend 5 to 30 km depending on mine dewatering requirements. Drawdown within the coal seams generally corresponds to the seam floor elevations, approximately 0 to 240 m for open pit mines and between 100 and 400 m for underground mines.

Underground coal projects in the Moranbah area have the potential to impact on the water table in the surficial aquifers. The impact of underground longwall mining occurs as goafing leads to increased vertical permeability and hydraulic connection between mine voids and overlying units.

A review of publicly available mine data within the Project area yielded insufficient information on the 40 mines (i.e. geometries, schedules and dewatering rates) to enable the accurate modelling of their cumulative groundwater impacts. A review of existing NRM groundwater database reveals that there are no bore water level records showing distinct mine-related impacts in the northern Bowen Basin. Consequently, cumulative impacts of this coal mining were not able to be included in the proposed numerical groundwater model of the Project.

14.7.4.2 Groundwater Use in Bowen Basin

The Project will operate concurrently with the Moranbah Gas Project and private groundwater users in the Bowen Basin. The cumulative impacts of these groundwater users may, therefore, be relevant for groundwater impact assessment.

Predictive groundwater modelling was conducted for the Project area but not for other (current or future) CSG operations due to the paucity of data, and large number of assumptions required (making the model output unreliable).

14.7.4.3 CSG Production in the Surat Basin

The Queensland Water Commission (QWC) developed a regional groundwater flow model to predict the potential impacts of cumulative groundwater extraction by the petroleum and gas activities in the Surat CMA. The model was a key tool in the development of a draft Underground Water Impact Report (UWIR) for the Surat and Bowen Basins, which includes (QWC, 2012):

- Maps showing predicted water level impacts;
- An ongoing water monitoring program;
- A spring impact management strategy; and
- An assignment of responsibilities for individual petroleum and gas operators to carry out activities such as specific parts of the regional monitoring program.

The UWIR maps showing CSG tenements and groundwater recharge areas immediately affected and long-term affected areas in the Blackwater area are reproduced in the Groundwater Model Technical Report (Appendix M) of this EIS. The maps indicate that future groundwater level impacts in the Blackwater area do not exceed the trigger threshold drawdown of 5 m for consolidated aquifers and 2 m for unconsolidated aquifers (QWC, 2012).

The most southerly Project tenement, ATP 1025 at Blackwater, is located within the Surat CMA (Figure 14-2). This tenement was, however, included in the Bowen Project predictive modelling.

14.7.4.4 Groundwater Users in the Bowen Basin

The Project will operate concurrently with private groundwater extraction in the Bowen Basin. The cumulative impacts of these groundwater users may therefore be relevant for groundwater impact assessment. For this purpose the numerical groundwater model (see the Groundwater Model Technical Report (Appendix M) of this EIS) will be used to evaluate these cumulative impacts.

14.7.5 Potential Impacts Post-Closure

14.7.5.1 Impacts on Regional Groundwater Levels

After CSG operations are completed, the groundwater system will re-adjust over a long period. It is expected that due to low rates of diffusive recharge into the coal seams and little or no induced flow potential, the groundwater levels and piezometeric pressures within the coal seam aquifers will, over a long time frame, attain a new equilibrium. The rate of groundwater recovery may be further slowed by ongoing mining and CSG operations within the Bowen Basin.

It is considered that the hydraulic heads in the confined coal seams will not recover to pre-operational levels for such a long time, potentially for hundreds if not thousands of years, that the groundwater will be effectively ‘mined’ by the CSG operations. Cumulative impacts associated with other groundwater abstraction will thus not markedly change the potential impacts in the long-term.

14.7.5.2 Impacts on Groundwater Quality

Induced groundwater pressure gradients and flows will be towards the coal seams. The induced pressure gradients will be sustained for long periods of time, such that the risk of groundwater seeping away from the CSG production zone of influence is interpreted as being negligible.

14.8 Significance Assessment and Impact Mitigation

14.8.1 Approach

The extent of depressurisation impacts and cumulative impacts on groundwater resources need to be evaluated through the life of the Project. The following significance assessment and impact mitigation advice are based on groundwater impact predictions. The assessments and advice were based on current understanding of the hydrogeology in the Bowen Basin and predictive numerical modelling. The modelling included predictions of groundwater depressurisation within the target coal seams and groundwater drawdowns in the alluvium, basalt, and other aquifers.

Details of the classifications and ratings used for the significance assessment are detailed in the Groundwater and Geology Technical Report (Appendix L) of this EIS.

14.8.1.1 Significance Assessment - Groundwater

In this section, the significance of the potential groundwater impacts were assessed using a *Significance Assessment Approach* to provide stakeholders and decision makers with key information concerning:

- Importance of groundwater environmental values potentially affected;
- Sensitivity of groundwater environmental values potentially affected; and
- Magnitude of potential groundwater impacts.

Understanding the significance of potential groundwater impacts enabled an informed decision-making framework. In this study, the 'significance' of a groundwater impact was defined as '*an assessment of the sensitivity of an environmental value and the magnitude of potential impacts on that value'*.

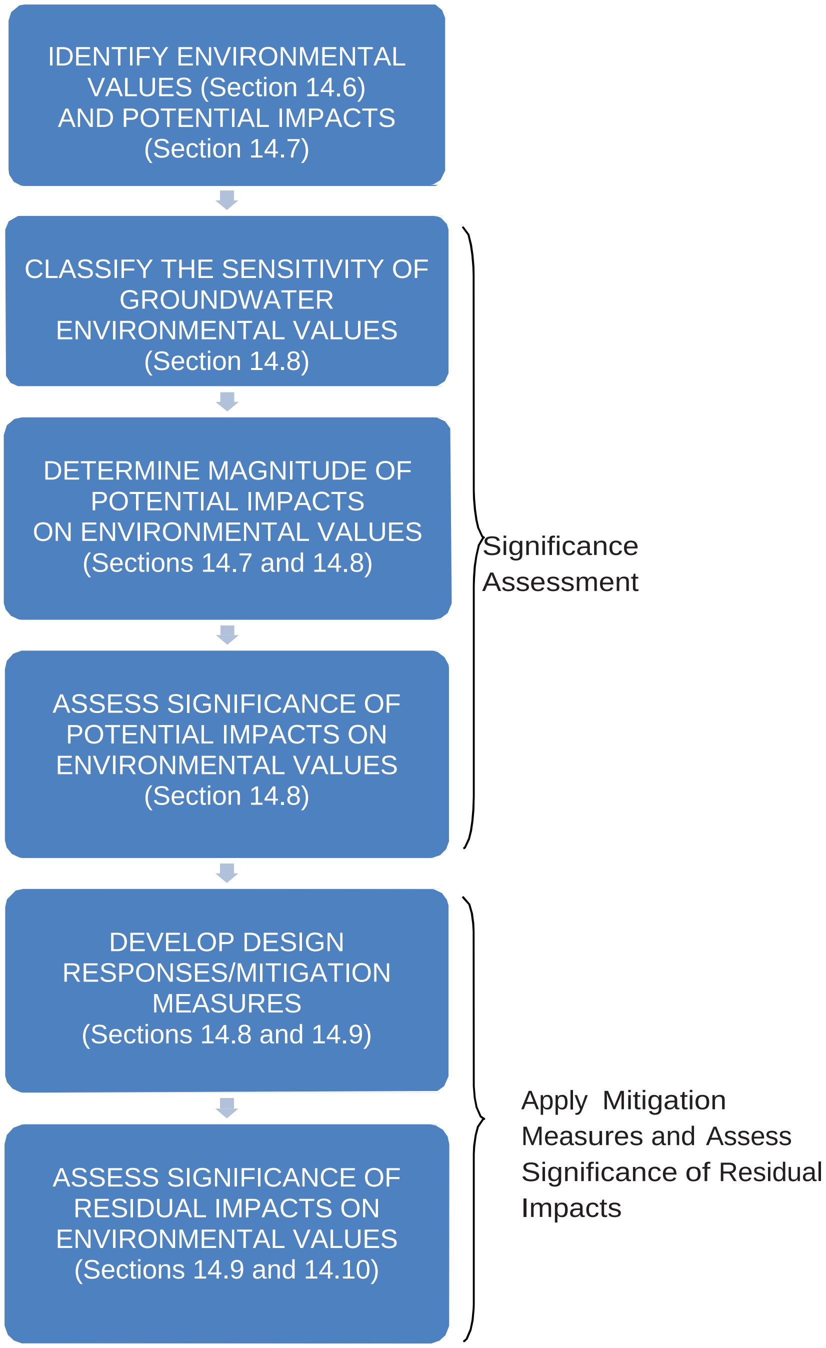
Figure 14–23 provides a flow diagram for the overall impact assessment process, with cross-references to relevant tables and sections in this report (associated with the method), that identifies those steps that comprise the significance assessment.

14.8.1.2 Impact Mitigation

The main aim of the groundwater assessment was to develop mitigation and management measures that prevent adverse impacts on the considered groundwater environmental values.

Included are *design responses* and *environmental controls* that can reduce 'residual impacts' in the potential impact area. Residual impacts are the impacts remaining after mitigation. An assessment was conducted to consider the effectiveness of mitigation measures for reducing both potential and residual impacts and to identify the need for any new measures and responses.

Figure 14-23 Impact Assessment Process Diagram (adapted from Coffey, 2011)



14.8.1.3 Environmental Constraints

During the detailed Project planning phases, locations within the Project area that could potentially be constrained or restricted for development purposes will be identified based on the sensitivity of the groundwater environmental values to be protected. That is, the sensitivity of the environmental values will be used to define areas where differing levels of control are required as follows:

- Development can proceed with standard mitigation measures in areas of low constraint and low value-sensitivity;
- Development can proceed with some additional mitigation measures (in addition to standard controls) in areas of moderate constraint and moderate value-sensitivity;
- Development can proceed with site-specific mitigation measures (in addition to standard controls) in areas of high constraint and high value-sensitivity; and
- Development is prohibited (i.e. defined as a 'no go' area) in areas of very high constraint and very high value-sensitivity as dictated by conservation status and statutory requirements.

Project activities that may impact upon groundwater values will be assigned one of the above controls, including:

- 'No go' area;
- Highly constrained;
- Moderately constrained; or
- Low constraint.

14.8.2 Sensitivity Classification of Environmental Values

To assess the sensitivity of the identified groundwater environmental values, a classification scheme was adopted based on intrinsic characteristics and susceptibility to potential changes in the groundwater system. The classification scheme, together with 'assumptions and constraints' and characteristics that determine the sensitivity of the groundwater system to potential impacts, were used to recommend sensitivity weightings for environmental values and an overall sensitivity ranking (Table 14-15).

14.8.2.1 Assumptions and Constraints

The classification scheme used to assign sensitivity considers the following assumptions and constraints:

- The *potential impacts* are assumed to be the projected estimates of (shallow) water table drawdown and (deep) groundwater depressurisation provided from the predictive modelling;
- The *potential impact area* is assumed to be the 5 m drawdown contour (confined aquifer) area and 2 m drawdown contour (unconfined) area, which is predicted using the predictive groundwater model;
- The groundwater *ecological values*, assessed in Section 14.6, are assumed to be those located in the projected *potential impact area*;
- The *cultural and spiritual values* are assumed to be those recorded in the *potential impact area* as mentioned in studies supporting the Project EIS;

- *Ecological values* are assumed to have a degree of groundwater dependence as considered in Section 6; and
- Springs do not to exist within the *potential impact area* as no registered springs are located within the Project area (Section 14.4.6 and the Groundwater and Geology Technical Report (Appendix L)).

Table 14-15 Groundwater System Sensitivity Classification Criteria

Sensitivity Criteria		Very Low Sensitivity	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Very High Sensitivity
Conservation status elements of the groundwater system as defined by statutory and regulatory authorities. **This is related to the suitability of the water to support biological values, consumptive and productive values, and anthropo-morphic values.**	Biological values	Within the potential impact area of the Project, groundwater does not support ecosystems.	Within the potential impact area of the Project, groundwater can discharge to surface features and intrinsic properties support highly disturbed ecosystems.	Within the potential impact area of the Project, groundwater can discharge to surface features and intrinsic properties support slightly to moderately disturbed ecosystems.	Within the potential impact area of the Project, groundwater has the potential to discharge to surface features and intrinsic properties may support pristine ecosystems.	Within the potential impact area of the Project, groundwater discharges to surface features and the intrinsic properties identified to support pristine ecosystems of national environmental significance.
	Consumptive and productive values	Within the majority of the potential impact area of the Project, groundwater quality is unsuitable for any practical use.	Within the majority of the potential impact area of the Project, groundwater quality is suitable for industrial use or aquaculture.	Within the majority of the potential impact area of the Project, groundwater quality is suitable for production of aquatic food for human consumption or stock watering.	Within the majority of the potential impact area of the Project, groundwater quality is suitable for agricultural use.	Within the majority of the potential impact area of the Project, groundwater quality is suitable for potable supply.
	Anthropo-morphic values	Intrinsic properties of groundwater do not support areas of spiritual or cultural significance within the potential impact area of the Project.	Intrinsic properties of groundwater support isolated areas of spiritual or cultural significance within the potential impact area of the Project.	Intrinsic properties of groundwater support numerous areas of spiritual and cultural significance within the potential impact area of the Project.	Intrinsic properties of groundwater support areas of spiritual or cultural significance within the potential impact area of the Project that are listed on the National Heritage register.	Intrinsic properties of groundwater support areas of spiritual or cultural significance within the potential impact area of the Project that are inscribed on the World Heritage List.

Sensitivity Criteria	Very Low Sensitivity	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Very High Sensitivity
Rarity of occurrence, abundance or distribution of groundwater system or aquifer type and availability of equivalent or representative alternatives	Attributes of the groundwater system are ubiquitous.	Attributes of the groundwater system are common on a local, regional and national basis, and therefore have local equivalents.	Attributes of the groundwater system are locally unique, but have regional equivalents.	Attributes of the groundwater system are locally unique, but with few regional equivalents.	Attributes of the groundwater system are unique. There are no regional equivalents.
Resilience to change (i.e. groundwater properties such as water level or pressure changes, porosity reduction)	Intrinsic properties of the groundwater system are completely resilient to change (as a result of depressurisation, for example).	Intrinsic properties of the groundwater system are highly resilient to change (as a result of depressurisation, for example).	Intrinsic properties of the groundwater system are moderately resilient to change, (as a result of depressurisation, for example) and the overall function of the groundwater system is relatively unchanged.	Intrinsic properties of the groundwater system are slightly resilient to change (as a result of depressurisation, for example) and the overall function of the groundwater system could be temporarily altered.	Intrinsic properties of the groundwater system are rigid to change (as a result of depressurisation, for example) and the overall function of the groundwater system could be permanently altered.
Dynamism of existing environment (i.e. hydrogeologic processes)	Groundwater systems with high recharge rates and short recovery periods.	Groundwater systems with moderate recharge rates and medium term recovery periods.	Groundwater systems with low recharge rates and longer recovery periods.	Groundwater systems with very low recharge rates and very long recovery periods.	Groundwater systems isolated from recharge processes where pressure reduction would be permanent.
Rehabilitation potential	Rehabilitation can be successfully achieved in all cases.	Rehabilitation can be successfully achieved in the majority of cases.	Rehabilitation is likely to be slow or only partially successful.	Rehabilitation potential is limited or only successful in the minority of cases.	Extremely limited rehabilitation potential if impact on the value cannot be avoided.

14.8.2.2 Overall Sensitivity Evaluation of Groundwater

An assessment of the sensitivity of the identified groundwater resources was conducted. A sensitivity weighting was assigned to the major groundwater values using the following weighting scale: (5) very high, (4) high, (3) moderate, (2) low or (1) very low. The weightings were then summed to provide an overall sensitivity ranking and sensitivity rating for the four groundwater systems described below. The preliminary weightings for each of the four groundwater systems are tabulated and summarised in Table 14-16. The shallower aquifer systems (Alluvium, Basalt and Clematis Sandstone) have been rated as moderately sensitive. This is a conservative approach because it focuses on the highest value groundwater resources in each of these hydrostratigraphic units. However, the occurrence of good quality groundwater resources within each of these units are rare and of limited extent.

14.8.2.3 Alluvium

The shallow groundwater associated with alluvium within the potential impact area is considered to have the following general characteristics for assessment of sensitivity:

- In most areas the groundwater quality has medium-to-high salinity and is locally common;
- In Stephens Creek, Lucky Creek, and the Lower Isaac River the groundwater quality (low-to-medium salinity) is suitable for agricultural and stock watering. It is locally unique with few licensed users at present, however, equivalents are common and more abundant to the east;
- Where underlain by the Rewan Formation and separated by aquitards, groundwater levels are resilient to groundwater depressurisation in the CSG target coal seams;
- Where alluvium directly overlies target coal seam subcrop(s) or on sub-vertical faults, groundwater levels are slightly resilient to depressurisation. This aspect is more sensitive during drought periods but are highly resilient during wet periods and may be described as moderately resilient on average (potential average CSG production drawdown is less than ~ 0.5 m);
- It is ‘moderately to highly’ dynamic because it has ‘moderate to high’ hydraulic connectivity with nearby rivers and creeks and receives localised recharge from stream flow and sporadic flooding;
- Rehabilitation can be achieved when impacts are removed; and
- Rehabilitation occurs naturally during regular seasonal rainfall.

The shallow groundwater in alluvium, away from the rivers and creeks, receive diffuse recharge through clayey soils that have low-permeability when wet and are ‘low to moderately’ dynamic. These areas have saline-sodic groundwater with limited utility.

14.8.2.4 Basalt

The shallow groundwater resources associated with altered (weathered, jointed, and fractured) basalt within the potential impact area is considered to have the following characteristics when considering sensitivity:

- Groundwater quality is variable with few licensed users;
- It is ‘low to moderately’ dynamic because of clay-rich cover (weathered olivine rich basalt) which limits effective recharge;

- It is highly resilient to depressurisation in the Blackwater Group (CSG target formation) where it is overlying the Rewan Formation;
- It is 'low to moderately' resilient to depressurisation in the Blackwater Group (CSG target formation) where it is directly overlying the Blackwater Group because of low vertical hydraulic conductivity (limited induced flow potential);
- Rehabilitation through artificial recharge can be achieved but with limited success due to low storage and permeability; and
- Rehabilitation is very limited during droughts unless artificial recharge is used.

14.8.2.5 Clematis Sandstone

Limited hydrogeological information is available for the Clematis Sandstone aquifer in the northern portion of the Bowen Basin. However, based on the geology and typical hydraulic properties associated with this unit, the following characteristics for shallow groundwater in the Clematis Sandstone within the potential impact area were interpreted for sensitivity evaluation as follows:

- Groundwater quality is highly variable, low-to-high salinity data and no licensed bores are recorded in the outcrop area due to the lack of usable groundwater resources;
- Is locally common as topographic highs in the north and central Project area;
- It is 'low to moderately' dynamic because it receives low recharge rates[3];
- It is highly resilient to depressurisation as the Clematis Sandstone is effectively separated from the target coal seams to be depressurised by the Rewan Formation aquitard; and
- Rehabilitation occurs naturally during regular seasonal rainfall.

14.8.2.6 Target Coal Seams

The confined aquifers in the coal measures within the potential impact area are considered to have the following characteristics when considering sensitivity:

- Groundwater quality data for the coal seams indicates high variability in salinity (up to 30,000 µS/cm), sodium chloride dominant, and is unsuitable for agriculture and stock watering (with few licensed users), and is regionally common;
- It has very low dynamicity with low recharge by rainfall in distal outcrops and by inter-aquifer leakage; and
- Natural rehabilitation (i.e. pressure recovery) is likely to be slow when impacts are removed because permeability is low, regional groundwater flow system is moving slowly, and recharge is low.

Upon completion of depressurisation, groundwater within the coal seams will virtually never recover to pre-CSG conditions because of the characteristics described above.

[3] Recharge rates to the intake beds of the GAB, including the Clematis Sandstone, have estimates of recharge generally between 1 and 3% of average annual rainfall and rainfall events in the order of 200 mm per month are required for effective recharge (JBT Consulting, 2010a).

Table 14-16 Assessment of Groundwater Sensitivity within the Potential Impact Area

Groundwater System	Conservation Status			Rarity of Occurrence	Resilience To Change	Dynamism of Existing Environment	Rehabilitation Potential	Sensitivity Ranking	Sensitivity Rating
	Biological Values	Consumptive and Productive Values	Cultural and Spiritual (Anthropomorphic Values)						
ALLUVIUM Shallow; Unconfined; Localised Resource	3	2	Pending Study (1)	3	2	2	2	15	Low
BASALT Shallow; Unconfined; Limited Resource	3	2	Pending Study (1)	2	3	3	2	16	Moderate
CLEMATIS SANDSTONE Shallow; Confined or Unconfined; Potential Resource	3	2	Pending Study (1)	2	3	3	3	16	Moderate
Target COAL Seams Deep; Confined; CSG Target	1	1	Pending Study (1)	2	1	4	4	14	Low

Notes:
1. Aquatic ecosystems in this case are inclusive of groundwater dependent ecosystems (GDE) as mapped using RE classifications provided by EHP REDATA (2012).
2. Groundwater Sensitivity Weighting: Very High = 5, High = 4, Moderate = 3, Low = 2, Very Low = 1
   Sensitivity Rating: Very Low = <10, Low = 10 - 15, Moderate = 16 - 20, High = 21 – 25, Very High = >25

14.8.3 Significance Assessment Methodology

14.8.3.1 Sensitivity Rating and Impact Magnitude Rating

The significance assessment methodology involved the development of: (a) a sensitivity classification for the four groundwater systems that were assessed in terms of conservation status, rarity, resilience, dynamism and rehabilitation potential; and (b) the magnitude rating criteria of potential impacts on the aquifers (refer to Groundwater and Geology Technical Report (Appendix L) of this EIS).

14.8.3.2 Impact Significance Interpretation

The significance of potential impacts on the groundwater resources assessed was determined using the following approach:

- Determination of the sensitivity rating for each aquifer;
- Determination of the magnitude rating of the impact on the aquifers;
- Apply the sensitivity and magnitude ratings obtained in the assessment matrix; and
- Interpretation of the significance of the impacts and residual impacts.

14.8.4 Impact Mitigation

This section provides a process for management and mitigation of the potential impacts. The process was to apply controls or design responses to Project activities, such as optimum well-field development, and correct associated water production and infrastructure, to ensure potential negative impacts either:

- Do not arise from the proposed activities;
- Are minor; or
- Where unavoidable are reversible over time and can be offset in the interim by make-good provisions.

CSG operations in the Project area will be conducted in accordance with Arrow's EM Plan, which will provide the minimum baseline standards for operational activities being undertaken. Arrow's EM Plan will present the level of mitigation to be applied to all locations. In areas characterised by higher environmental values, or with higher environmental constraints, schedules will be appended to the EM Plan to detail additional location-specific mitigations identified and recommended in this section. Monitoring associated with impact assessment, management, and mitigation is discussed in Section 14.9.

14.8.4.1 Mitigation of Fault-Related Impacts

The influence of faults on potential groundwater impacts has been assessed and the regional distribution of faults have been mapped (Figure 14-3). The predictive modelling indicates faults can lead to compartmentalisation and reduction in groundwater drawdown extent. Model predictions will be validated over time to compare model predictions with monitoring results. Make-good agreements with neighbouring groundwater users will be instigated should CSG production materially impact on groundwater use.

Due to the potential for vertical permeability within faults to induce flow between units an assessment of faults during detailed CSG field design will be considered. Faults that are seismically active have enhanced vertical permeability, and/or faults with high pressure differentials across them are to be identified and avoided where possible. This approach will minimise potential impacts from fault-related disturbances and potential damage to infrastructure that could adversely affect groundwater.

14.8.4.2 Mitigation of Coal Seam Depressurisation Impacts

The extent of depressurisation, impacts on current groundwater users and future groundwater resources, and cumulative impacts need to be evaluated through the life of the Project. The groundwater impact assessment and numerical model results provides an indication of the extent of depressurisation within the coal seam aquifers as well as predictions regarding possible impacts to other shallower and deeper groundwater systems.

As aquifer depressurisation is an intrinsic part of the CSG extraction process, groundwater level impacts cannot be avoided. However, because impacts to the groundwater system are reversible these impacts may be acceptable (notwithstanding impacts caused by inter-aquifer flows). Furthermore, if impaired capacity is confirmed (bore can no longer produce quality or quantity of groundwater for the authorised purpose, and the impact is due to CSG activities), make good agreements must be negotiated with bore owners. These agreements will define any make good measures that will be implemented [B234].

Impact mitigation measures, in response to groundwater impacts are provided in Table 14-17 and Table 14-18.

14.8.4.3 Mitigation of Project Development Impacts

The potential impacts involved with CSG development relate to well installation, facilities, and ancillary plant and equipment. Mitigation measures need to be included in their design to mitigate possible impacts. To reduce the likelihood of fuel, oil, or hazardous chemical releases entering the groundwater system, the following mitigation measures will be implemented [B235]:

- Fuel, oil, and hazardous chemicals will be stored above ground and contained within bunded areas;
- Domestic and industrial waste will be stored in standard facilities and managed by licensed contractors;
- Recording and auditing will be undertaken for fuel, oil, and chemical volumes purchased and stored on-site;
- Audits of disposal facilities, disposal permits, and working conditions will be undertaken; and
- Hazardous chemicals and effluent will be conveyed and stored in accordance with AS 1940 *The Storage and Handling of Flammable and Combustible Liquids* and AS 3780 *The Storage and Handling of Corrosive Substances,* and other relevant industry standards.

Changes to groundwater recharge caused by land use change (i.e. associated with well heads, access roads, facilities, electricity generation facilities and gathering lines) within the CSG fields is envisaged to be insignificant due to the relatively small area affected compared to the entire Project area.

14.8.4.4 Mitigation of Associated Water Management Impacts

A range of potential impacts relating to storage and handling of associated water have been identified. The construction and design of new dams, whether for the storage of water either prior to treatment or the resultant brine after treatment, must be in accordance with the requirements of the most recent version of *Manual for Assessing Hazard Categories and Hydraulic Performance of Dams* (NRM, 2012) and constructed under the supervision of a suitably qualified and experienced person.

14.8.5 Summary

The key identified potential impacts associated with the Project including mitigation objectives and measures for each groundwater system are included in Table 14-17, Table 14-18 and Table 14–19. The unmitigated significance rankings relate to impacts prior to the implementation of mitigation, whereas the residual significance rankings relate to impacts after mitigation has been applied. Section 9 of the Groundwater and Geology Technical Report (Appendix L) of this EIS provides details of the significance rankings.

Table 14-17 Assessment of Direct Impacts on Confined Groundwater Resources

Impacts	Unmitigated Impact Significance			Mitigation Measure	Residual (Mitigated) Impact Significance	
	Sensitivity	Magnitude	Significance		Magnitude	Significance
Depressurisation of the CSG target formations reduces groundwater supply in the same formations.						
Target coal seams include the following Blackwater Group units: • Rangal Coal Measures • Moranbah Coal Measures	Low	High	Moderate Significance (8)	• Establish baseline data set of groundwater level and quality within significant aquifers in the Project area to enable future comparison (during and at end of Project) [B237] • Conduct monitoring (water level and quality) of bores within the units of the Blackwater Group [B238]. • Assess natural (i.e. seasonal rainfall) and cumulative (i.e. mine-related) variations in groundwater levels (using background monitoring points outside predicted zone of influence) [B239]. • Make-good measures will be implemented if the Bore Assessment indicates the bore is likely to experience an impaired capacity. Make-good measures to be implemented will be negotiated between Arrow and the bore owner [B240]. • Perform groundwater modelling simulations to predict impacts on groundwater resources in overlying and underlying aquifers to evaluate the suitability of these resources for use in make-good measures [B241]. • Prepare groundwater monitoring reports in accordance with the environmental authority for each tenure [B242].	Low	Low Significance (4)
Physical impacts of hydraulic stimulation on target coal seams						
Fracturing causing increased interconnection and blending of groundwater within Permian units	Low	Low	Low Significance (4)	(i) Follow Arrow's Hydraulic Fracturing Execution Plan (ii) Undertake groundwater monitoring before and after hydraulic stimulation, where required (iii) Compile a Risk Assessment and Stimulation Impact Monitoring Program	Very Low	Very Low Significance (2)

Table 14-18 Assessment of Indirect Impacts on Unconfined Groundwater Resources

Ground water System	Unmitigated Impact Significance			Mitigation Measure	Residual (Mitigated) Impact Significance	
	Sensitivity	Magnitude	Significance		Magnitude	Significance
Depressurisation causes possible indirect impacts due to induced flow and changes in groundwater quality						
Alluvium	Moderate	Very Low	Low Significance (3)	• Establish baseline data set of groundwater level and quality within significant aquifers in the Project area to enable future comparison (during and at end of Project) [B237] • Define and undertake program of aquifer testing in dedicated groundwater monitoring wells to reduce areas of uncertainty and aim to quantify aquifer properties and groundwater velocities / inter-aquifer flows [B243]. • To ensure groundwater depressurisation is not impacting the connectivity between the Blackwater Group and other aquifers, continue the investigative program that monitors/quantifies this connectivity [B244]. Install an appropriate regional groundwater monitoring network (that satisfies Arrow's obligations as described in each UWIR) to [B245]: — establish current groundwater level and groundwater quality conditions; — assess natural variation (i.e. Seasonal variations) in groundwater levels; — monitor groundwater levels during operational phase; — monitor groundwater quality during operational phase; — establish suitable datum levels for each aquifer system; — target sensitive areas where more frequent monitoring and investigation is required (e.g. Groundwater dependent ecosystems); — monitor groundwater depressurisation as a result of CSG extraction; and — monitor impacts in accordance with the UWIR for each tenure, water act and regulations. Consider injection of suitably treated CSG water (if proven technically feasible) as part of management hierarchy to enhance shallow and deep aquifer recovery (in compliance with the P&G Act, EPP Water and *Water Supply (Safety & Reliability) Act 2008*.	Very Low	Low Significance (3)
Basalt	Moderate	Very Low	Low Significance (3)		Very Low	Low Significance (3)
Clematis Sandstone (north)	Moderate	Very Low	Low Significance (3)		Very Low	Low Significance (3)
Back Creek Group – subcrop and outcrop	Low	Very Low	Very Low Significance (2)		Very Low	Very Low Significance (1)

Ground water System	Unmitigated Impact Significance			Mitigation Measure	Residual (Mitigated) Impact Significance	
	Sensitivity	Magnitude	Significance		Magnitude	Significance
Depressurisation causes inter-aquifer flow and reduces groundwater levels and flow to streams, wetlands, riparian zones, or sites of cultural / spiritual values.						
Alluvium	Moderate	Very Low	Low Significance (3)	• Conduct mitigation as above. • Prepare baseline assessment plans for each tenure prior to commencement of production as per the Water Act. Prepare an underground water impact report including a water monitoring strategy including a spring impact management strategy for each tenure [B236].	Very Low	Low Significance (3)
Basalt	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
Clematis Sandstone (north)	Moderate	Moderate	Moderate Significance (9)		Very Low	Low Significance (3)

Table 14-19 Assessment of Other Impacts on Groundwater

Activity / Impact	Groundwater System	Unmitigated			Mitigation Measures	Residual (Mitigated) Impact Significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
Water quality impacts deterioration due to well installation, hydraulic stimulation, and sub-surface activities							
Incomplete or incorrect well installation results in interconnection of aquifers and consequential cross-contamination	Quaternary River Alluvium	Moderate	Low	Moderate Significance (6)	• Construct all CSG production wells in accordance with the standards described in the P&G Act and regulations to that Act [B249]. • Construct all monitoring wells in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (National Minimum Bore Specifications Committee, 2012) [B250].	Very Low	Low Significance (3)
	Tertiary Basalt	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	Clematis Sandstone (north)	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	CSG Groundwater System	Low	Low	Low Significance (4)		Very Low	Very Low Significance (2)
Lubricants, drilling fluids and other chemicals used in drilling process alter aquifers	Quaternary River Alluvium	Moderate	Low	Moderate Significance (6)	• Construct all CSG production wells in accordance with the standards described in the P&G Act and regulations to that Act [B249] • Construct all monitoring wells in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (National Minimum Bore Specifications Committee, 2012) [B250] Select drilling fluids to minimise potential groundwater impacts. Do not use oil-based drilling fluids [251]	Very Low	Low Significance (3)
	Tertiary Basalt	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	Clematis Sandstone (north)	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	CSG Groundwater System	Low	Low	Low Significance (4)		Very Low	Very Low Significance (2)

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Activity / Impact	Groundwater System	Unmitigated			Mitigation Measures	Residual (Mitigated) Impact Significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
Hydraulic stimulation fluid impacts	Target coal seams in the Blackwater Group and overlying Rewan Formation and underlying Back Creek Group:	Low	Low	Low Significance (4)	• Implement environmental hydraulic fracturing procedures to minimise risk of environmental impact. Including: — Following Arrow's Hydraulic Fracturing Execution Plan — Undertake groundwater monitoring before and after hydraulic stimulation, where required Compile a Risk Assessment and Stimulation Impact Monitoring Program	Very Low	Low Significance (3)
Spills at the well-pad drain or leak to the borehole leading to contamination of intercepted aquifers	Quaternary River Alluvium	Moderate	Low	Moderate Significance (6)	• Construct all CSG production wells in accordance with the standards described in the P&G Act and regulations to that Act [B249]. • Construct all monitoring wells in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (National Minimum Bore Specifications Committee, 2012) [B250].	Very Low	Low Significance (3)
Leaks and spills from sub- surface infrastructure (e.g. gathering lines) resulting in contamination of shallow groundwater resources	Quaternary River Alluvium	Moderate	Low	Moderate Significance (6)	• Consider local groundwater conditions when identifying sites for the installation of underground infrastructure (e.g. gathering lines). Install pipelines in accordance with relevant standards [252] • Consider local groundwater and surface water conditions when identifying sites for coal seam gas water storage dams, treated water facilities and associated brine storage facilities, production facilities and related storage areas [B353].	Very Low	Low Significance (3)
	Tertiary Basalt	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	Clematis Sandstone (north)	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)

Activity / Impact	Groundwater System	Unmitigated			Mitigation Measures	Residual (Mitigated) Impact Significance	
		Sensitivity	**Magnitude**	**Significance**		**Magnitude**	**Significance**
Deterioration in groundwater quality from associated water and waste storage, processing and distribution infrastructure activities							
Storage of chemicals, fuels, oils Leaching of spills resulting in contamination of groundwater system	Quaternary River Alluvium	Moderate	Low	Moderate Significance (6)	• Develop and implement emergency response and spill response procedures to minimise any impacts that could occur as a result of releases of hazardous materials or any loss of containment of storage equipment [B084].	Very Low	Low Significance (3)
	Tertiary Basalt	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	Clematis Sandstone (north)	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
Impacts to shallow, intermediate and coal seam groundwater systems from infrastructure footprints							
Installation of impervious surface coverings results in lower rainwater infiltration and reduced aquifer recharge	Quaternary River Alluvium	Moderate	Low	Moderate Significance (6)	• Avoid unnecessary impervious surface coverings; minimise land footprint, and vegetation clearing when designing facilities [253] • Consider local groundwater and surface water conditions when identifying sites for CSG water storage dams, treated water facilities and associated brine storage facilities, production facilities and related storage areas [B353].	Very Low	Low Significance (3)
	Tertiary Basalt	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	Clematis Sandstone (north)	Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
	CSG Groundwater System	Low	Very Low	Very Low Significance (2)		Very Low	Low Significance (3)
	Back Creek Group	Low	Very Low	Very Low Significance (2)		Very Low	Low Significance (3)

Activity / Impact	Groundwater System	Unmitigated			Mitigation Measures	Residual (Mitigated) Impact Significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
General impacts associated with installation of gas reticulation facilities and compressor stations	Quaternary River Alluvium	Moderate	Low	Moderate Significance (6)	• Store and manage all waste materials (domestic and industrial) in accordance with industry regulations and EHP EA conditions Use licensed waste management contractors. Conduct audits of disposal facilities, disposal permits and onsite operations to ensure adherence to regulations [B254].	Very Low	Low Significance (3)
	Tertiary Basalt	Moderate	Very Low	Low Significance (3)		Very Low	Low Significance (3)
	Clematis Sandstone (north)	Moderate	Very Low	Low Significance (3)		Very Low	Low Significance (3)
Impacts caused by associated water activities to shallow groundwater systems (alluvium and basalt)							
Impact to shallow groundwater caused by seepage of untreated CSG water from storage facilities		Moderate	Moderate	Moderate Significance (9)	• Design and construct new regulated dams (either raw water, treated water or brine dams) in accordance with the requirements of the most recent version of "Manual for Assessing Hazard Categories and Hydraulic Performance of Dams" and under the supervision of a suitably qualified and experienced person, and in accordance with relevant EHP schedule of conditions relating to dam design, construction, inspection and mandatory reporting requirements [B255].	Very Low	Low Significance (3)
Altered groundwater flow direction due to seepage of CSG water from storage facilities		Moderate	Low	Moderate Significance (6)		Very Low	Low Significance (3)
Impact to shallow groundwater caused by seepage of brine concentrate from storage facilities		Moderate	Moderate	Moderate Significance (9)		Very Low	Low Significance (3)
Unplanned discharge of untreated CSG water and brine to the land surface leading to groundwater impact		Moderate	Moderate	Moderate Significance (9)	• The number of monitoring wells and their location will take into account site-specific hydrogeology, preferential pathways, contaminants and potential receptors [B256] • Monitoring bores installed near dams will be used to monitor groundwater levels, electrical conductivity, pH, TDS, major cations and anions to	Very Low	Low Significance (3)

Activity / Impact	Groundwater System	Unmitigated			Mitigation Measures	Residual (Mitigated) Impact Significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
					allow preparation of piper plots and interpretation of results over time Further investigation will be considered where potential adverse impacts to groundwater quality are identified [B257]		

14.9 Monitoring and Management

The impact assessment (Section 14.7) allowed for the compilation of mitigation measures to reduce the impacts of the proposed Project and associated activities on groundwater environmental values. In order to assess the effectiveness of the mitigation measures, groundwater monitoring and management will be needed. In this section of the EIS, the ToR requirements are addressed with respect to the proposed monitoring and management strategy, including aims to (i) protect water quality during construction, operation and decommissioning of the Project; (ii) undertake a monitoring program; and (iii) define quantitative standards and indicators that can be recorded and audited.

14.9.1 Regional Baseline Monitoring

In this groundwater assessment initial bore inventory of the study area was carried out to identify bores registered in the NRM groundwater database that are located within the hydrogeological study area (Section 14.1). These data includes the origin, groundwater quality, and groundwater levels for each registered bore. These data will be updated regularly as additional bores are registered on the NRM database.

In 2011, Arrow compiled a Groundwater Monitoring and Investigation Strategy for the Surat Gas Project (Arrow 2011b). One of the main objectives of this document was to establish a framework for nominating groundwater monitoring sites for both baseline and impact monitoring. Arrow aims to implement a similar, Bowen Basin specific, strategy for the Project. This will involve installing groundwater bores to monitor pressure and groundwater quality in each major aquifer within the Project development area (both background and operation areas).

14.9.2 Numerical Groundwater Model

Arrow's commitment involves understanding, managing and mitigating potential impacts of CSG operations. This will involve a management plan that can adapt to CSG field development and monitoring results. As CSG field development continues, and groundwater monitoring programs expand, more information regarding the behaviour of regional groundwater will become available. A key element of the management plan is to use the monitoring data to validate and update the numerical groundwater model. The model will be recalibrated to reduce uncertainty in predictions and thereby provide information for improving the monitoring, management and mitigation measures [B258].

14.9.3 Trigger Actions for 'At-Risk' Bores

Trigger levels of 5 m drawdown for consolidated / confined aquifers and 2 m drawdown for unconsolidated / unconfined aquifers are defined in the Water Act (Table 14-2). The numerical groundwater model was developed to (see Groundwater Model Technical Report (Appendix M) of this EIS) predict groundwater drawdown patterns that have potential to exceed the trigger levels. These predictions have been mapped as 'Potential Impact Areas' for the duration of the Project (Figure

14-20) and areas that remain as Potential Impact Areas after 50 years post-closure (Long Term Affected Areas) (Figure 14-21).

The Potential Impact Areas provide an early warning system for ‘bores at risk’. The Potential Impact Areas are also to define and activate management measures to reduce the likelihood of impacts occurring to landholder bores and other environmental values. By placing new monitoring bores at key locations in the Project area, including at the tenement boundaries of the Project area, a groundwater monitoring program will be developed that can anticipate the spread of groundwater drawdown to stakeholder bores and environmental values within and beyond the tenement boundaries [B259].

Within the main depressurisation zone of the target coal seam, aquifers impacts are expected as shown in Table 14-14. For shallow unconfined aquifers (model Layer 1) above this zone predicted drawdown is less than 2 m. As a precautionary and conservative measure (to assess worst case scenario), the model predicted drawdowns in Layer 3 of the model were used to define the Potential Impact Areas in the shallow aquifers at cessation of operations and at 50 years beyond the Project life (Figure 14-20 and Figure 14-21). This was done as there is the potential, over time, for the drawdown to propagate to model Layer 1 units (the shallow groundwater resources) through induced flow. Induced flow can potentially occur above the depressurised zones in Layer 3. Subsequently the indirect impacts on shallow groundwater are conservatively defined by the 2 m drawdown contours in Layer 3 of the model.

Based on the Potential Impact Area, landholder bores that are ‘at risk’ can be identified. The following will apply to these existing bores [B260]:

- Preparation and development of Baseline Assessment Plans for each tenure prior to the commencement of production testing or production in accordance with the Water Act;
- Implementation of the Baseline Assessment Plan including assessment of each water bore in the tenure in accordance with the timetable contained in the plan;
- Collection of baseline data from each water bore including water level, water quality, bore construction and the type of infrastructure used to pump water from the bore;
- Supply of the collected data to the bore owner and regulator as required by the Water Act;
- Preparation of an UWIR including a Water Monitoring Strategy for each tenure in accordance with the Water Act;
- Identification of Immediately Affected Area Bores in the UWIR in accordance with the Water Act by undertaking groundwater modelling to identify areas in each aquifer where the bore trigger threshold will be exceeded within the subsequent three years;
- Completion of a bore assessment for each Immediately Affected Area Bore;
- Negotiation of a Make Good Agreement for each Immediately Affected Area Bore; and
- Installation and sampling of the network of monitoring bores identified in the Water Monitoring Strategy.

14.9.4 Data Management and Reporting Requirements

14.9.5 Groundwater Monitoring Program

It is considered that a structured database will host all the groundwater data (including groundwater levels and groundwater quality). Groundwater monitoring reporting will be conducted in accordance with the requirements of the administering authority. Reports will be submitted annually and will provide comment on [B261]:

- Changes (augmentation and alteration) to the groundwater monitoring network;
- Recent groundwater monitoring quality and water level results and trends;
- Comparison of background and baseline groundwater levels and modelled projected levels; and
- Recent model predictions of groundwater impacts.

14.9.5.1 Objectives

The objectives of the groundwater monitoring network and program are to:

- Establish background trends;
- Identify changes in aquifer conditions within and near areas of development;
- Identify changes in aquifer conditions near environmental values;
- Improve future groundwater flow modelling;
- Improve understanding of connectivity between aquifers;
- Develop an ‘early warning system’ that identifies areas potentially impacted by Project activities and allows early intervention (e.g. placement of monitoring bores in critical locations) [B267];
- To ensure that the impacts of groundwater drawdown on existing groundwater users and other identified environmental values is minimised through cause identification, response implementation, consultation and in the case of existing groundwater users, through the negotiation of alternative water supply agreements;
- Share information with regulatory authorities; and
- To provide flexibility to ensure the groundwater monitoring network can be modified or augmented over time, in line with the Project schedule, CSG plan changes, and CSG field expansion during the life of the Project.

14.9.5.2 Standards and Compliance

The groundwater monitoring program will demonstrate compliance with the requirements of the *Petroleum and Gas (Production and Safety) Act 2004*, EP Act, and Water Act. Important standards to comply with include:

- Monitoring and Sampling Manual – EPP (Water);
- Minimum Construction requirements for Water Bores in Australia;
- AS / NZ 5667.11: 1998 *Water Quality Sampling – Guidance on Sampling of Groundwater*; and
- Arrow Groundwater Sampling Procedures.

14.9.5.3 Regional Impact Monitoring

In order to fulfil the requirements of the legislation governing the CSG industry, and to mitigate potential adverse effects from CSG production on a regional scale, a groundwater monitoring program that includes a representative suite of bores in the shallow, intermediate and deep aquifers will be implemented. The major groundwater systems to be monitored include [B269]:

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

The monitoring program will provide groundwater level and groundwater quality data for these aquifers within and adjacent to the interpreted Potential Impact Areas. The monitoring program may use nested standpipe monitoring bores and vibrating wire piezometers in the aquifers vulnerable to groundwater drawdown. The nested sites will allow for both ongoing groundwater monitoring, assess induced flow, and allow discrete (aquifer) sampling [B270]. Some nested bores may also be installed at locations with negligible CSG impacts to provide ongoing background monitoring of climatic effects and/or resource developments that are independent of the proposed Project development [B271].

14.9.5.4 Site Impact Monitoring

Confirmed details of the Project field development will not be finalised until appraisal drilling programs are complete. These programs will be conducted progressively over the life of the Project. Thus the layout of CSG production wells and associated infrastructure, including associated water dams, facilities, gas and water gathering line networks have not yet been finalised and will be designed and implemented over time.

Monitoring will be conducted in compliance with relevant standards, but at a minimum, a suitable network of shallow (seepage) monitoring bores will be installed adjacent to water and waste storage facilities to ensure effectiveness of seepage mitigation designs. The number of monitoring wells and their location will take into account site-specific hydrogeology, preferential pathways, contaminants and potential receptors [B272].

Regular monitoring of groundwater levels, electrical conductivity values, pH, TDS, major cations and anions will be undertaken at monitoring bores installed near dams, to allow preparation of piper plots and interpretation of results over time [B273]. Table 14-20 outlines initial site impact monitoring strategies.

Table 14-20 Initial Site Impact Monitoring Strategies

Aquifer Monitored	Monitoring Sites	Parameters Monitored	Frequency of Monitoring	Purpose
Quaternary Alluvium and Quaternary Flood Plain Sediments	Adjacent to water and waste storage facilities, surficial and near surface infrastructure (i.e. gas gathering lines)	Water levels	A maximum of 12 hourly readings – electronic data loggers (VWPs)	To monitor background / baseline water levels / quality, and potential seepage from water and waste storage facilities and other surface / near surface infrastructure
		pH, EC, TDS (lab), cations, anions	EC – monthly; All other parameters bi-annually	
Tertiary Basalt and Sediments	Adjacent to water and waste storage facilities, surficial and near surface infrastructure (i.e. gas gathering lines)	Water levels	A maximum of 12 hourly readings – electronic data loggers (VWPs)	To monitor background / baseline water levels / quality, and potential seepage from water and waste storage facilities and other surface / near surface infrastructure
		pH, EC, TDS (lab), cations, anions	EC – monthly; All other parameters bi-annually	
Clematis Sandstone Outcrops	Clematis Sandstone Outcrops in northern Project area	Water levels	A maximum of 12 hourly readings – electronic data loggers (VWPs)	To monitor background / baseline water levels, and potential dewatering impacts, validate model predictions
Blackwater Group at Target CSG Depths	Adjacent to CSG wells, near structurally sensitive areas. Background bores outside of predicted zone of influence	Water levels	A maximum of 12 hourly readings – electronic data loggers (VWPs)	To monitor background / baseline water levels / quality, and potential dewatering / operational impacts. Obtain natural fluctuation data for comparison.
		pH, EC, TDS (lab), cations, anions	EC – monthly; All other parameters semi-annually	
Blackwater Group	Blackwater Group Subcrops	Water levels	A maximum of 12 hourly readings – electronic data loggers (VWPs)	To monitor background / baseline water levels / quality, and potential dewatering impacts
		pH, EC, TDS (lab), cations, anions	EC – monthly; All other parameters semi-annually	

14.10 Management of Potential Impacts

In this section of the EIS, the ToR requirements are addressed with respect to the description of key management strategy objectives to:

- Protect important local aquifers;
- Maintain sufficient quantity and quality of surface waters to protect existing beneficial downstream uses inclusive of maintenance of in-stream biota and the littoral zone; and
- Minimise impacts on flooding levels and frequencies both upstream and downstream of the Project.

The ToR further requests:

- A risk assessment, based on conservative assumptions, of uncontrolled emissions due to system or catastrophic failure including implications for human health and natural ecosystems; and
- A detailed assessment of mitigation measures to prevent, minimise, and contain the above impacts.

14.10.1 Management of Hydraulic Stimulation

The hydraulic stimulation memorandum, compiled by Arrow (see the Groundwater and Geology Technical Report (Appendix L) of this EIS) identified certain mechanisms by which hydraulic stimulation may result in exposure of people and ecological receptors to the approved chemicals used. The following protection measures will be implemented to reduce these risks:

- Worker training and hazard identification;
- Use of appropriate personal protective equipment;
- Flow back storage pond fencing to prevent entry of livestock;
- Installation of dam liners and routine dam inspections to prevent releases from flow back storage ponds; and
- Routine operational and security patrols to prevent trespassing.

Risks due to induced seismicity are considered low, however, environmental values can be further protected by constraining stimulation to areas avoid faults that are seismically active and/or have high groundwater pressure differentials across them.

Hydraulic stimulation is found to have a low potential of causing increased interconnection and blending of groundwater within the Permian aquitards above and below the target coal seams. Arrow will, however, undertake groundwater monitoring before and after hydraulic stimulation, where required, and undertake a risk assessment and subsequent stimulation impact monitoring program, as included in Table 14-19.

14.10.2 Trigger Actions for Make Good Commitments

If a landholder bore is 'at risk' of potential impacts and impaired capacity, or observes an impaired capacity in a bore due to CSG operations, then Arrow will undertake a bore assessment which will include the following [B274]:

- A field verification of groundwater levels in the nominated bore;
- Baseline bore information and groundwater data;
- A review and assessment of the available data; and
- Advice to the bore owner in writing of findings.

The bore owner would provide the following to Arrow:

- Bore details (e.g. total depth, screened intervals, stratigraphy);
- Groundwater usage data or metering data;
- Details of bore groundwater levels; and
- Details of groundwater pumping equipment and pump setting.

The bore assessment would consider:

- Drawdowns observed in the regional monitoring system;
- Local influences on groundwater conditions (e.g. other extractions such as irrigation use, town supply, industrial and climate);
- Bore specifics and bore metering data;
- Bore condition;
- Available drawdown for the bore;
- Use of the bore;
- Hydrogeological aspects; and
- Assess whether material impacts have occurred.

Following completion of a bore assessment of a bore 'at risk', and if it is confirmed that the capacity of the bore is impaired by the CSG operations, Arrow will negotiate a 'make good' agreement with the bore owner that will include documentation of the outcome of the assessment, identify any impacts or potential for impaired capacity, and identify appropriate 'make good' measures such as providing alternative water supplies, replacing pumps or deepening bores [B275].

14.10.3 Management of Associated Water

The 'beneficial use' of untreated associated water, in particular for irrigation purposes, can have potential to impact on land and the environment, primarily due to water quality (salinity) and may alter natural water balance equilibrium. Where beneficial use schemes are proposed for untreated associated water, a Land and Water EM Plan may be required to ensure the scheme is sustainable and does not result in land degradation, environmental impact and/or water resource impact [B276]. Any beneficial use scheme would be subject to meeting the criteria and investigation requirements as applicable to achieve EHP approval under the *Environmental Protection (Waste Management) Regulation 2000* and other relevant statutes.

Strategic monitoring of shallow groundwater at beneficial use sites is expected to be a requirement for such schemes. These requirements, and the design of monitoring plans and locations, will generally be site-specific and require individual assessment. This EIS assumes that the legislative framework to enable the beneficial use of CSG associated water under Arrow's water management strategy will be in place to facilitate third party use of the associated water.

14.10.4 Management of Cumulative Groundwater Impacts

Under the Water Act, a CMA may be declared where impacts of multiple independent CSG producers overlap. The northern Bowen Basin is not currently managed in this way because:

(i) It is not a significant groundwater resource area;

(ii) It does not have registered springs; and

(iii) It currently only has one major CSG project in operation (Arrow's Moranbah Gas Project).

It is anticipated that the Queensland Water Commission would be responsible for assessing cumulative impacts in the event that a CMA was established for the northern Bowen Basin. Arrow will offer the model results for inclusion in any possible regional cumulative groundwater model that may be developed in the future (similar to the Surat Basin modelling approach).

A variety of surface activities (e.g. hazardous materials storage) and subsurface activities (e.g. well installation, production and testing) have the potential to create cumulative impacts within one or multiple CSG well fields.

Monitoring programs conducted by all proponents will ensure that groundwater quality indicators are used to implement appropriate response actions in the event of leaks, spills, or inadequate well installations. It is also assumed that adherence to industry standards as they relate to the appropriate storage, handling, and disposal of hazardous materials and the drilling and installation of wells will mitigate cumulative potential impacts. Regular maintenance and well testing will also limit these potential impacts.

14.10.5 Management of Post-Closure Impacts

After CSG operations are completed, the groundwater system will equilibrate over the long term. However, due to relatively low rates of diffuse recharge into the Permian-Triassic outcrops (including the coal seams), the pre-development conditions appear to involve relatively low rates of regional groundwater flow through the deep aquifers, and effectively ‘zero’ regional flow through the deep aquitards. Consequently, post-closure recovery is likely to be relatively slow and the natural or base-line conditions are unlikely to be re-established. This interpretation is confirmed by numerical groundwater modelling (see Groundwater Model Technical Report (Appendix M) of this EIS) which shows limited recovery during the post-operations model scenarios. Further, the rate of groundwater recovery may be slowed even more by ongoing mining operations and other CSG operations within the northern Bowen Basin.

Based on the above interpretations, groundwater potentials in the confined coal seams (aquifers) appear unlikely to ‘rebound’ or ‘recover’ to their pre-development (‘natural’) conditions within a time frame meaningful to stakeholders. For this reason, it is acknowledged that the saline-sodic groundwater ‘resource’ within the coal seam ‘aquifers’ will be effectively ‘mined’. Cumulative impacts associated with other groundwater abstractions are also unlikely to influence the general long-term outcome although they may alter the magnitude of the long-term impacts.

A monitoring and management program for the post-closure impacts will involve a final modelling exercise that will include model calibration, model validation, long-term impact predictions, and long-term recovery predictions. These results will be considered in the final closure of the Project and hand-over to the governing authority with recommendations for long-term management.