7

GROUNDWATER

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SUPPLEMENTARY REPORT TO THE EIS

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7 Groundwater

The groundwater section summarises the findings of the supplementary groundwater assessment prepared by Coffey Environments Australia Pty Ltd (Coffey), and is included in Appendix E of the SREIS. The study supplements the Groundwater and Geology Technical Report (URS, 2012) presented in Appendix L of the EIS, the main groundwater findings of which are summarised in Section 14 of the EIS.

In addition to the study findings, a list of key issues raised in submissions along with responses to the issues is provided in the Submission Responses chapter (Section 21) of the SREIS. Reponses to submissions from EHP and DSEWPaC (which has since been superseded by the Department of the Environment) are presented in Section 22 and Section 23 of the SREIS, respectively. An updated list of commitments is also provided in Commitments Update (Appendix O) of the SREIS.

Groundwater also has recognised linkages with other environmental aspects related to the Project, including hydrology and geomorphology which is presented in the Hydrology and Geomorphology chapter (Section 9) of the SREIS. Arrow's updated CSG Water and Salt Management Strategy is presented in Appendix D of the SREIS.

7.1 Objectives

The objectives of the supplementary groundwater assessment were to:

- Identify any revisions to the project description with the potential to introduce new groundwater impacts, make previously identified impacts redundant or alter the significance of the potential impacts assessed;
- Present any additional information or changes to legislation since publication of the EIS; and
- Consider and where necessary, investigate queries or concerns for groundwater raised through public and government submissions made on the EIS.

7.2 Summary of Groundwater Studies for the EIS

This section provides an overview of the groundwater assessment completed for the Project EIS and the main conclusions from that assessment.

The groundwater impact assessment conducted for the EIS comprised a desktop review of available information that included geological and hydrogeological information. Information was sourced from relevant publications, government databases, published literature and reports of similar projects in the Bowen Basin to gain an understanding of the existing environment. The assessment conducted for the EIS also included the development of a numerical groundwater model presented in the Groundwater Technical Report (Appendix M) of the EIS to predict the groundwater drawdown response in aquifers as a result of CSG extraction. The groundwater model presented in the Groundwater Technical Report (Appendix M) of the EIS was prepared by Ausenco and the Norwest Corporation (Ausenco-Norwest, 2012).

The study area defined for the groundwater impact assessment extended beyond the Project area and included the outer geological and hydrogeological boundary of the Bowen Basin. The study area also encompassed the numerical groundwater model domain. The study area adopted for the groundwater impact assessment was larger than the area potentially impacted by groundwater drawdown as predicted by the EIS groundwater model.

7.2.1 Groundwater Systems

Based on the geological and hydrogeological characteristics of the study area, the existing groundwater environment was divided into three groundwater systems; shallow, intermediate and deep (coal seam) groundwater systems. The systems were defined primarily by their depth and relationship to the Blackwater Group, which is the target formation for CSG extraction in the Bowen Basin. The intrinsic characteristics of each groundwater system were assessed to define the sensitivity of each system to change resulting from CSG extraction.

A review of the characterisation of groundwater systems was conducted for the SREIS as discussed in Section 7.7.1.

7.2.2 EIS Groundwater Model

The EIS groundwater model was constructed using MODFLOW-SURFACT™ (version 4) software (developed by HydroGeoLogic Inc in 2011), and Groundwater Vistas (version 6) (developed by Environmental Simulations Inc in 2011) was used as the visual interface to the model. The model predicted the groundwater drawdown response in aquifers as a result of CSG extraction under two scenarios:

- **Scenario 1, Base Case.** This scenario included production extraction in accordance with Arrow's forecast CSG water extraction for the Project only (in isolation from other industrial developments); and
- **Scenario 2, Cumulative Case.** This scenario included extraction from the Project (the base case) together with extraction associated with the Moranbah Gas Project and by licenced groundwater users included in the Department of Natural Resources and Mines' (NRM) Water Management System database[1].

7.2.3 EIS Groundwater Impact Assessment

The groundwater impact assessment presented in the EIS considered the results of scenario 1. The groundwater drawdowns predicted by the model under scenario 2 were presented in the Groundwater

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

Technical Report (Appendix M) of the EIS, and the results were discussed in the Cumulative Impacts chapter (Section 31) of the EIS.

The potential groundwater related impacts identified as a result of the Project included reduced groundwater supply (including aquifer depressurisation) and altered groundwater quality. The mechanisms or activities through which these impacts could occur included both subsurface activities such as drilling and CSG extraction and surface based activities such as fuel, chemical and produced CSG associated water storage.

The assessment demonstrated that the implementation of the proposed mitigation measures for each of the identified impacts reduced the overall significance of residual impacts. The significance of residual impacts on each groundwater system reported in the EIS were as follows:

- Low for the shallow groundwater system;
- Low for the intermediate groundwater system; and
- Very low to low for the deep (coal seam) groundwater system.

Arrow committed to implement a number of avoidance, mitigation and management measures to reduce impacts on groundwater values in the Project area. These commitments were developed and presented in the EIS.

7.3 Regulatory Framework

Numerous updates have been made in relation to the legislative framework for CSG development since publication of the EIS. Some revisions, including changes to the Commonwealth framework, resulted in new requirements for petroleum tenure holders.

7.3.1 Queensland Government

Since the release of the EIS, Queensland's overarching regulatory framework for groundwater remains unchanged, primarily in relation to the following:

- *Petroleum and Gas (Production and Safety) Act 2004* (Qld) (P&G Act), and the definition of underground water rights and associated underground water obligations; and
- *Water Act 2000* (Qld) (Water Act), and the detailed information regarding the underground water obligations required to be met by proponents.

Changes to the Queensland regulatory framework related to management of groundwater and protection of groundwater values are discussed below within the context of a summary of the core components of Queensland's groundwater legislation.

7.3.1.1 *P&G Act*

Section 185 of the P&G Act, defines the underground water rights for petroleum tenures. Petroleum tenure holders 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, including CSG extraction.

On 22 November 2013, certain sections of the *Land Water and Other Legislation Amendment Act 2013* that amended the petroleum legislation (i.e., the *Petroleum Act 1923* and the P&G Act) commenced. Further discussion as to how the amendment affected the requirements for drilling water bores for the Project is discussed in Section 7.3.1.4, Codes and Standards for CSG Production Wells and Water Bores.

7.3.1.2 *Water Act*

The Water Act is the primary mechanism for management of groundwater resources in Queensland. Key aspects of the underground water obligations to be met by Arrow in relation to the Project are listed below:

- **Baseline Assessments**. The Water Act requires tenure holders to carry out baseline assessments of all third party bores within priority areas of tenures to identify the location, construction, groundwater level and groundwater quality of existing water bores before production of petroleum has commenced;
- Preparation of **Underground Water Impact Reports** (UWIRs);
- **Make good obligations** including the requirement to undertake a bore assessment for all bores located in an Immediately Affected Area (IAA) to determine whether the bore has, or is likely to start having, an impaired capacity; and
- **Make good agreements** with bore owners that document the outcome of the bore assessment, and defines make good measures for the bore to be undertaken by the responsible tenure holder.

Baseline Assessment Plan

In accordance with the Water Act, a baseline assessment plan must be developed for each tenure in which production of CSG, or production testing (during exploration) occurs. The baseline assessment plan includes a baseline assessment timetable that details when an assessment of each bore in the tenure will be undertaken. Assessments of bores in closest proximity to production of CSG or production testing are undertaken first.

UWIR

Each UWIR prepared under the Water Act must include the following:

- Description of the regional geology and hydrogeology;
- Existing and forecast petroleum and gas production rates;
- Prediction of groundwater drawdown as a result of the exercise of underground water rights, and
- Identification of areas for each aquifer in the tenure where groundwater drawdown is predicted to exceed the bore trigger thresholds (2 m for an unconsolidated aquifer and 5 m for a consolidated aquifer);
- Predicted drawdown in each aquifer that exceeds the relevant bore trigger threshold in the next three years (defined as the IAA), and at any time in the future (defined as the Long-term Affected Area (LAA)) for that aquifer;
- Identification of potentially affected springs, where drawdown is predicted to exceed the spring trigger threshold (defined in the Water Act as 0.2 m) at any time;

- Report obligations, including description of a Water Monitoring Strategy (WMS) and a Spring Impact Management Strategy (SIMS);
- Assignment of responsible tenure holder for report and make good obligations if the report is prepared for a cumulative management area (CMA); and
- Program for annual review.

7.3.1.3 *Supporting Queensland Groundwater Legislation*

The supplementary groundwater assessment revisited other components of Queensland's regulatory framework in light of revisions to the project description and improved understanding of the existing environment. New or revised components of the framework were also reviewed. Relevant legislative aspects identified during the reviews are discussed below.

Environmental Protection Act 1994

The objective of the *Environmental Protection Act 1994* (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. This is the primary piece of legislation underpinning the impact assessment for the Project.

In relation to the protection of groundwater values, the EP Act describes the assessment process for hydraulic stimulation through an EA application requirement. Under the EP Act, the EA application must include the following information in relation to hydraulic stimulation:

- Description of the environmental values potentially impacted by hydraulic stimulation activities, both on, and beyond the petroleum tenure where hydraulic stimulation activities are proposed;
- An assessment of sufficient detail to allow the administering authority to assess the application and issue appropriate conditions, which may include baseline and impact monitoring. If hydraulic stimulation activities are not planned, or the assessment is not supplied in the application, the EA may condition that hydraulic stimulation cannot be undertaken;
- Evidence that fluids used in stimulation will not include restricted stimulation fluids (as identified in Section 206 of the EP Act);
- Environmental protection commitments and objectives in relation to stimulation activities; and
- Control strategies to be implemented as part of the hydraulic stimulation event, e.g., details of monitoring to be undertaken prior, during and following each stimulation event.

The regulatory framework under the EP Act provides additional detail on the requirements of the assessment to be prepared by proponents and includes reference to the primary source of relevant guidance documents prepared by the American Petroleum Institute (API). Arrow currently prepares assessments in accordance with the relevant regulatory requirements.

Assessments prepared by Arrow have been approved by EHP, and the subsequent hydraulic stimulation event conducted in compliance with the relevant EA conditions.

Petroleum and Gas (Production and Safety) Regulation 2004

The Petroleum and Gas (Production and Safety) Regulation 2004 (P&G Regulation) details the requirements for petroleum tenure holders to provide a notice of intention to carry out hydraulic stimulation activities. The petroleum tenure holder must issue a notice of completion and lodge a report at the completion of hydraulic stimulation activities. The report requirements are further detailed in Subdivision 6 Sections 46A of the P&G Regulation.

Nature Conservation Act 1992

The *Nature Conservation Act 1992* (NCA) provides for the conservation of nature through the development of an integrated and comprehensive conservation strategy for the whole of Queensland. The NCA classifies species according to conservation status. The framework has been applied in the assessment of springs across the Surat CMA to identify biologically important springs. The Surat CMA incorporates the southern Bowen Basin, which includes Authority to Prospect (ATP) 1025, the southern-most tenement within the Project area.

Surat CMA UWIR

At the time the EIS was finalised, the Queensland Water Commission (QWC) was responsible for relevant activities including the preparation of UWIRs. The UWIR for the Surat CMA was endorsed by the Chief Executive of EHP in December 2012. The QWC ceased operation on 1 January 2013. The Office of Groundwater Impact Assessment (OGIA) took over responsibility for the storage of data collected by responsible tenure holders, assessment of cumulative groundwater impacts and establishment of integrated water management arrangements for the Surat CMA.

The UWIR is now a statutory instrument under the Water Act. Obligations for individual petroleum tenure holders for activities arising from the UWIR are now legally enforceable, and EHP is responsible for ensuring petroleum tenure holders comply with their obligations. The southern-most tenement within the Project area (ATP1025) is within the Surat CMA. Arrow also has other tenements within the Surat CMA, however, these do not form part of the Project.

The activities of multiple CSG proponents may cause drawdown observed in third-party bores or source aquifers to groundwater-dependent ecosystems. The UWIR assigns responsibility for monitoring and management strategies at those locations to one tenure holder.

The Water Act requires that the UWIR assigns responsible tenure holders to conduct certain activities within their own tenures and also within the IAAs and LAAs. The Surat CMA UWIR identifies the responsible tenure holder assigned to complete the following activities:

- **Baseline assessments**. In addition to the baseline assessments required of tenure holders under the Water Act, the Surat CMA UWIR also identifies those bores within the LAA for each aquifer requiring a baseline assessment, i.e., those with a predicted 1 m drawdown in the next 3 years. The tenure holder responsible for conducting baseline assessments in areas outside petroleum tenures is defined under the UWIR as the holder of the petroleum tenure within the production area that is closest to the location of the required baseline assessment.
- **Water Monitoring Strategy**. The UWIR identifies the responsible tenure holder assigned to each well in the regional monitoring network and the year in which they are required to complete installation of monitoring wells and commence recording groundwater level and quality monitoring data. Arrow is assigned to one monitoring well within ATP1025 under the Surat CMA UWIR.

- **Spring Impact Management Strategy**. The Surat CMA UWIR assigns a responsible tenure holder to each potentially affected spring. Arrow is not currently identified as a responsible tenure holder for any potentially affected springs defined in the Surat CMA UWIR.
- **Bore assessments and make good obligations**. The IAA defined in the Surat CMA UWIR does not intersect ATP 1025, and therefore Arrow does not currently have any obligation to complete bore assessments or enter into make good agreements with third-parties in this area. Future iterations of the Surat CMA UWIR will include production data provided by Arrow and other proponents. Any revisions to the extent of the IAA and associated responsible tenure holder obligations will presented when the updated UWIR is reissued.
- **Periodic reporting and review**. Responsible tenure holders are required to provide the OGIA with monitoring data and updates to production plans on an annual basis. Based on this information, the OGIA Surat CMA groundwater model will be re-run. Through this process, the OGIA will make predictions about future water levels and the defined IAAs and LAAs will be progressively refined.

The number of baseline assessments to be conducted by Arrow under the Surat CMA UWIR will be determined as the field development plan is progressed.

The UWIR will be revised and reissued by the OGIA every three years. The OGIA will maintain a database for data collected under monitoring plans carried out in accordance with monitoring programs in approved UWIRs. The database will also store baseline data collected by petroleum and gas operators as a part of their individual obligations under the Water Act. The OGIA is an independent body within NRM.

Great Artesian Basin Resource Operations Plan (2007)

The Great Artesian Basin Resource Operations Plan overlaps the Project area in the very south of ATP1025 near Blackwater. The plan was finalised in December 2006 and was amended on 16 November 2012 to streamline the process for release of unallocated water, as outlined in Chapter 2 of the plan.

On 30 May 2013, the chief executive of NRM commenced a process to release general reserve unallocated water from three management areas identified in the water resource plan. Up to a combined total of 7,200 ML of unallocated water has been made available from the Surat, Surat East and Surat North management areas. The Project area is not located within any of these management areas.

At the time of writing, the spring register provided under the operations plan was unavailable due to an open tendering process for the release of general reserve unallocated water in the three management areas. The supplementary groundwater assessment assumes that springs listed here would already be captured in the EHP (Qld Herbarium) register.

7.3.1.4 *Codes and Standards for CSG Production Wells and Water Bores*

Under the EP Act, all people have a duty to take reasonable and practicable measures to prevent or minimise the environmental harm resulting from their actions. This general environmental duty applies to all drilling activities. Further requirements on drilling activities are set through licencing and environmental authorities.

On 22 November 2013, the *Land Water and Other Legislation Amendment Act 2013* amended the *Petroleum Act 1923* and the P&G Act to permit the holder of an authority to prospect, a petroleum lease or a water monitoring authority to drill a water observation bore or water supply bore in the area of the respective authority or lease. The petroleum tenure holder must determine whether the bore will be drilled as per the requirements of the petroleum legislation, where there is significant gas hazard, or whether it is safe to drill the bore under the Water Act. If the bore is to be drilled under the petroleum legislation, there is no longer a need for the presence of a water bore driller to supervise drilling.

Minimum standards for the construction and reconditioning of water bores

A driller's licencing requirements under the Water Act ensures that all water bore drillers are properly skilled and that their work meets minimum standards.

All water bores (including groundwater monitoring bores) must be constructed in accordance with the Minimum Construction Requirements for Water Bores in Australia (NUDLC, 2012). Bores in artesian basins must also comply with Minimum Standards for the Construction and Reconditioning of Water Bores that intersect the sediments of artesian basins in Queensland (NRM, 2013), however for the Project this only relates to the small portion of the Project area where the southernmost tenement (ATP1025) overlaps with the Great Artesian Basin.

Code of Practice for Constructing and Abandoning CSG Wells in Queensland

The Code of Practice for Constructing and Abandoning CSG Wells in Queensland is intended to be enforceable in Queensland by being called up under the P&G Regulation as a "safety requirement".

The Code provides for the following outcomes, through establishment of minimum acceptable standards that dictate a consistent approach:

- Protection of the environment, in particular groundwater resources;
- Management of risks to public and CSG workers to a level that is as low as reasonably practicable;
- Compliance with regulatory and applicable Australian and international standards, as well as the operator's internal requirements;
- Effective management of a CSG well through all phases, including design, construction and decommissioning; and
- Implementation of appropriate monitoring programs during the life of the CSG well.

In November 2013, after the EIS was finalised, NRM released Version 2 of the Code of Practice. Version 2 includes information on CSG well control equipment and additional and alternative requirements for the construction of water bores by CSG tenure holders.

The requirements of the code have been taken into account in the SREIS and groundwater assessment.

7.3.2 Commonwealth Government

Changes to Commonwealth legislation related to management of groundwater and protection of groundwater values are discussed below.

7.3.2.1 *Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)*

The *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) provides for the protection of matters of national environmental significance (MNES), including the community of native species dependant on natural discharge of groundwater from the Great Artesian Basin, or listed threatened species that are reliant on springs.

Amendments to the EPBC Act became law on 22 June 2013, making 'water resources' a MNES in relation to CSG and large coal mining developments. The Department of the Environment prepared draft significant impact guidelines in June 2013 to assist proponents in their determination of whether a proposed CSG or large coal mining development has, or is likely to have a significant impact on a water resource (DSEWPaC, 2013). On 17 October 2013, the federal Environment Minister advised that 'water resources' is a controlling provision for the Project.

7.3.3 Non-statutory Mechanisms

The guideline on application requirements for an environmental authority (EA) or an amendment to an EA on petroleum tenures, including CSG activities was prepared by EHP in March 2013 (EHP, 2013a). The document includes guidance on the content of the application in relation to hydraulic stimulation activities and waste management. Arrow will use the guideline in preparing its application for, or amendment to, an EA.

Use of the guideline when preparing the application document will assist the administering authority in determining the most appropriate set of conditions to be set out in the EA.

7.4 Project Description Changes Relevant to Groundwater

The revised project description is detailed in the project description (Section 3) of the SREIS. Aspects relevant to groundwater and / or with the potential to change or refine the assessment of potential groundwater impacts as presented in the EIS, are described below with respect to the following aspects:

- Field development sequence;
- Well design and associated water extraction rates; and
- Additional details on the hydraulic stimulation process.

7.4.1 Indicative Field Development Sequence

Comparison of the indicative development sequence presented in the EIS with that presented in the SREIS shows that a similar Project phasing is anticipated. The order in which drainage areas commence production reflects the timing of groundwater extraction across the Project area. Initial development and groundwater extraction will be focussed along the western extent of the Project area, followed by areas in the east, with the last expected phases of development anticipated near Blackwater to the south.

To maximise gas recovery over the life of the Project, the SREIS development case presents a greater number of drainage areas (i.e., 33) each with a reduced radius of influence (i.e., 6 km) in comparison with the EIS, which presented a total of 17 drainage areas with a 12 km drainage radius (see Figure 3-1, Project Description chapter (Section 3) of the SREIS).

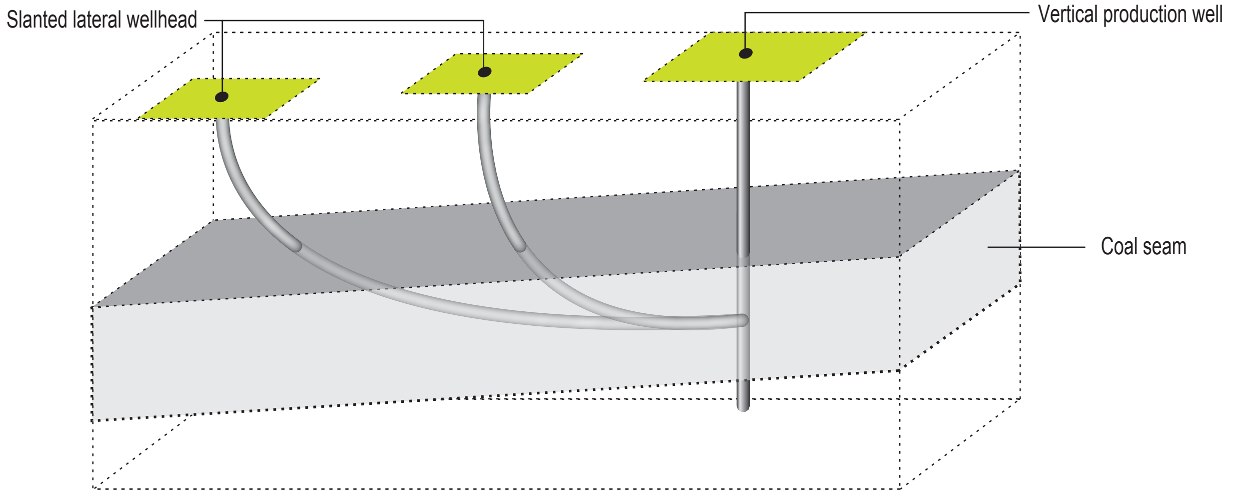
7.4.2 Production Well Design and CSG Associated Water Extraction

The EIS included the surface-in-seam chevron well design in a dual lateral configuration and the multi-seam hydraulically stimulated vertical well design (see Project Description (Section 3) of the SREIS). Multi-seam hydraulically stimulated vertical wells remain a production well design for the SREIS, however the dual lateral configuration has been superseded by multi-branch lateral wells (Figure 7-1). The multi-branch lateral well configuration reduces the surface disturbance footprint area, as it does not require two dedicated horizontal wells.

Another new design option, will allow the co-location of multiple wells, with up to six multi-branch lateral wells positioned together. This co-location could see a multi-well pad comprising 12 well heads on a single pad (i.e., 6 vertical production conduits and 6 lateral wells), which significantly reduces the overall number of well pads and disturbance across the Project area.

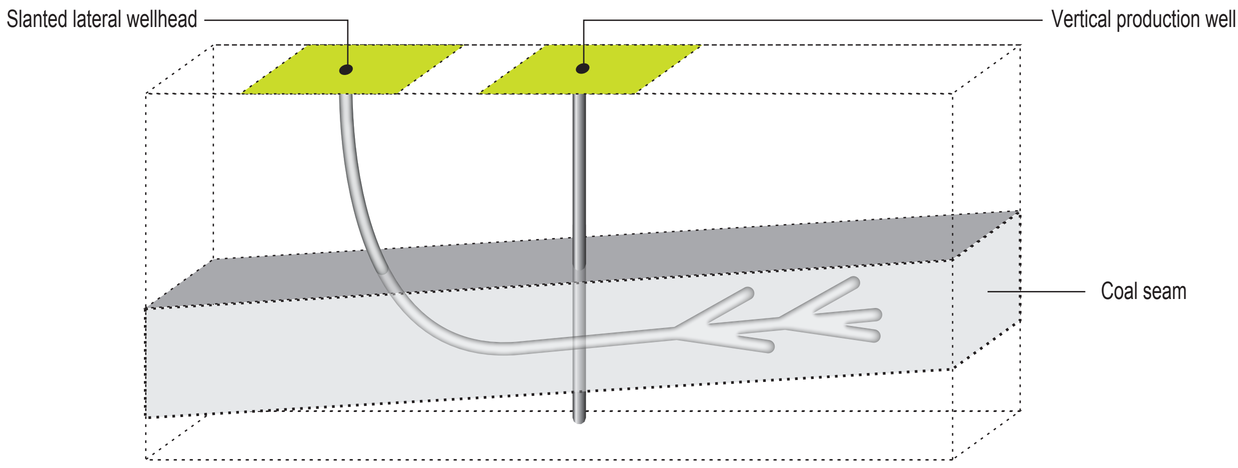
Introduction of the multi-well pad design means that the overall number of production wellheads at the surface has reduced from up to 6,625 proposed in the EIS, to approximately 4,000 presented in the SREIS. Furthermore, the use of multi-branch lateral wells also means that the same “in-coal” well spacing can be achieved with a reduced number of wellheads, given that each lateral branch will be terminated in different sections of the coal seam to enhance gas recovery.

Production well design presented in the EIS



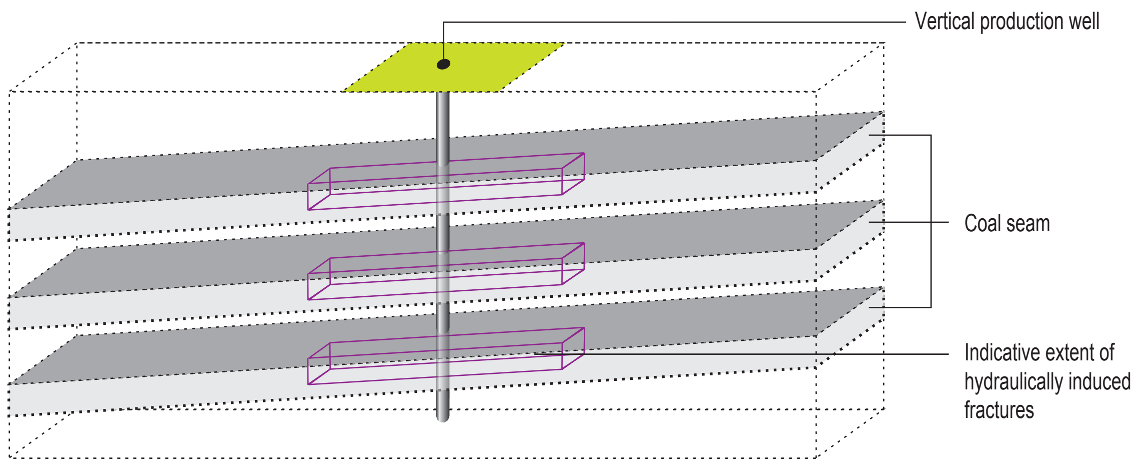
Surface-in-seam chevron well

Production well design presented in the SREIS



Multi-branch lateral well

Production well design presented in both the EIS and SREIS



Multi-seam hydraulically stimulated vertical well

Source: Reproduced from schematics provided by Arrow Energy

coffey	Date: 17.04.2014	Arrow Energy Limited	arrow energy go further	Typical schematics of production well designs presented in the EIS and SREIS	Figure No: 7.1
	File Name: 7043_03_F07.01_GL	Bowen Gas Project			

Progression of the field development plan has included more effective well placement to target areas of high gas yield. Furthermore, refinement to the reservoir modelling shows lower water extraction rates are expected from the production wells. The combination of improved well placement, the requirement for fewer wells through well design, and lower extraction rates has resulted in a significant reduction in the anticipated overall water production. It is anticipated to decline from 264 GL presented in the EIS (and used as the basis for the numerical groundwater model), to 153 GL over the life of the Project in the SREIS. The revised CSG associated water production profile is shown in Figure 7-2. Based on the revised indicative development sequence, average CSG associated water production is estimated at 4 gigalitres per annum (GL/a), with peak production estimated at 10 GL/a, a reduction from the average (7 GL/a) and equivalent to the peak (also 10 GL/a) production estimates reported in the EIS.

7.4.3 Hydraulic Stimulation Process

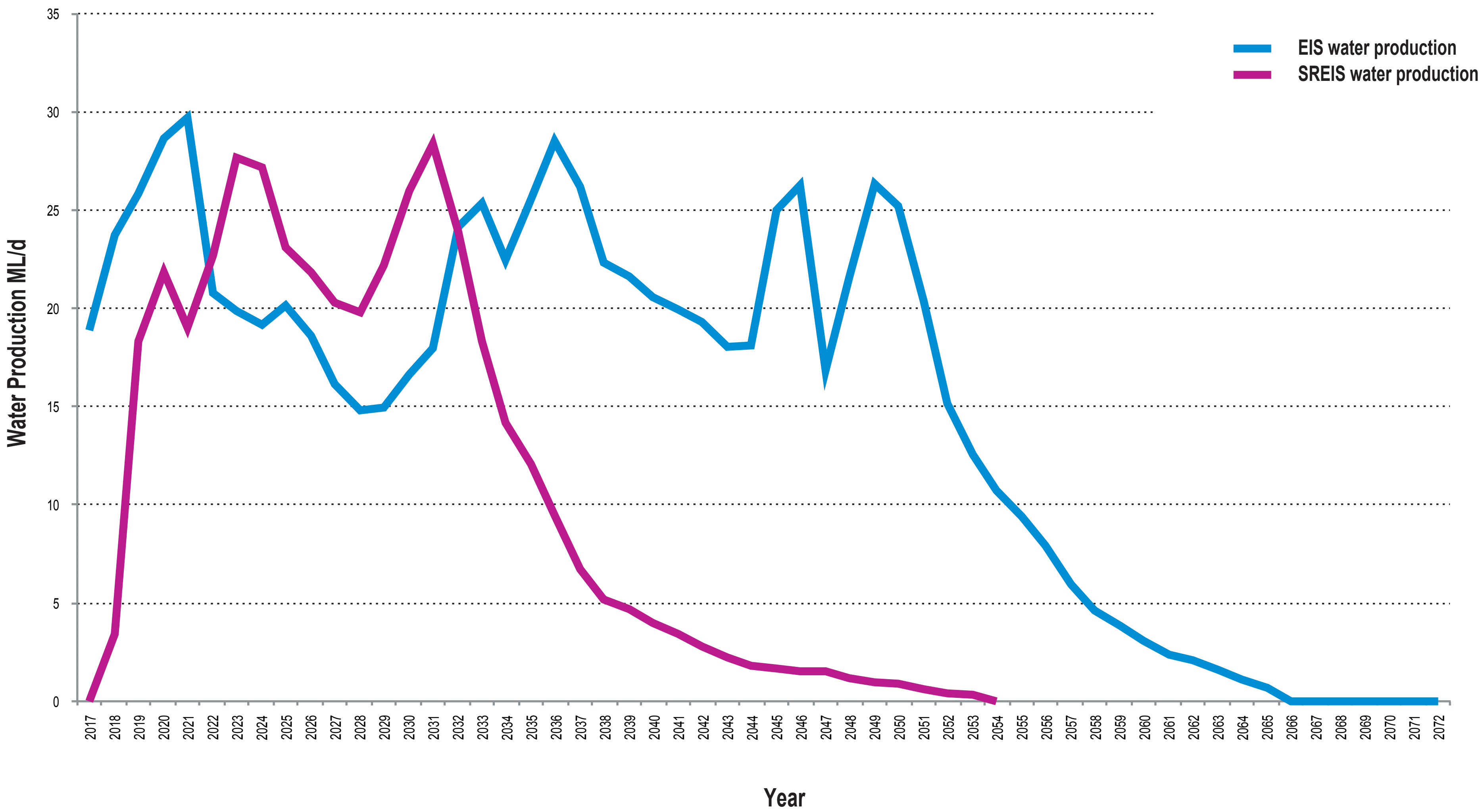
The process of hydraulic stimulation was described in the EIS and included a discussion on why it is potentially required in the Project area and the additives commonly used in the stimulation fluid. The EIS also presented a summary of the results of a hydraulic stimulation assessment (contained in the Groundwater and Geology Technical Report (Appendix L) of the EIS).

The SREIS retains the option to hydraulically stimulate up to 25% of all CSG production wells if required. The other key characteristics of hydraulic stimulation have also been retained for the SREIS, specifically, that approximately 99.5% of the material pumped into the well during hydraulic stimulation is made up of water and sand. The remaining 0.5% consists of additives commonly found in many household products. A list of the additives was provided in Appendix G of the Groundwater and Geology Technical Report (Appendix L) of the EIS.

Information on the hydraulic stimulation process relevant to the groundwater assessment additional to that presented in the EIS include the following:

- Further information on the varying positive high hydraulic pressures required to physically fracture the coal matrix (ranging from approximately 7,000 kPa to 30,000 kPa).
- Further information on fluid pumped into perforations within the production casing, and into the targeted CSG formation including the size of the perforations created in the steel casing pipe and surrounding cement seal (approximately 5 mm to 15 mm diameter holes). This information allows an understanding of the relationship between types of fluids used during a hydraulic stimulation event and the extent of fracturing.

Additional information on the process and associated management controls related to groundwater are presented in the Supplementary Groundwater Assessment (Appendix E) of the SREIS and discussed in Section 7.5.1.6 below.



Source:
Water production data provided by Arrow Energy

coffey

Date: 17.04.2014

File Name: 7043_03_F07.02_GL

Arrow Energy Limited

Bowen Gas Project

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Indicative water production presented in the EIS and SREIS

Figure No: 7.2

7.5 Study Method

The supplementary groundwater assessment methods closely align with those described in the EIS and include the following:

- **Review of additional information**. Information made available since preparation of the EIS included government and industry research and studies and field data provided by Arrow. Some information sources considered in the EIS were re-visited in light of the new information available.
- **Numerical groundwater modelling**. Additional numerical groundwater simulation was conducted using a refined model to investigate the effect of faults on groundwater drawdown predictions. A peer review and uncertainty analysis were also conducted on the EIS groundwater model to verify the suitability of the model and better understand any model limitations.
- **Validation of the EIS impact assessment.** The adequacy of the potential impacts identified in the EIS were assessed in light of the revised project description. The review considered whether the identified impacts in the EIS were redundant or whether additional impacts could result and if so, how this affected the assessment of significance of impacts. In light of the findings, the adequacy of the mitigation and management measures identified in the EIS was assessed and updates made, where necessary.

Each study method of the supplementary groundwater assessment is explained in further detail below.

7.5.1 Review of Additional Information

Additional sources of information that were identified following finalisation of the EIS were reviewed within the context of the Project area and the broader EIS groundwater model domain. Such information included technical data, operational procedures and operating guideline documents provided by Arrow.

The review focussed on the following areas to inform the supplementary groundwater assessment:

- Regional geology;
- Regional hydrogeology;
- Groundwater-dependent ecosystems;
- Sites of Indigenous cultural and spiritual significance;
- Groundwater quality;
- Subsidence; and
- Seismicity.

7.5.1.1 *Regional Geology*

The regional geology presented in the EIS was revisited and additional review and research undertaken to provide further understanding and characterisation of the Bowen Basin structure, stratigraphy, stress regime, faulting, and fault hydraulic behaviour. This information was reviewed with a focus to describe the role faulting and folding has on the movement of groundwater and how the drawdown associated with depressurisation of the target coal seams may be influenced by these structural features.

Regional information available from Esterle et al (2002), CSIRO (2008) and Sliwa (2011) was used as the primary basis for confirming the geological and geophysical data available in the Bowen Basin, specifically the target coal seams and interbedded units (the interburden and overburden). The information in these regional models describes the distribution and nature of faults, folds and igneous intrusions across the Bowen Basin. The interpretation presented in Sliwa (2011) describes and characterises fault types within the northern Bowen Basin, and results from other studies conducted in the Bowen Basin were used to characterise the hydraulic behaviour of these faults based on the stress regime (Hillis et at, 1999) and the thermal and fluid flow history (Uysal et al, 2000) of the Bowen Basin. Field data and observations were used to assist in this characterisation. Where relevant, analogous examples of faults and published models of fault damage zones in Australia and internationally were used to further conceptualise the behaviour of faults in the Bowen Basin.

The regional geology review also identified areas where the shallow alluvial aquifers may be directly underlain by target coal formations without the presence of a confining layer such as the Rewan Formation, and as a result there is the potential for increased hydraulic connectivity between groundwater systems. The Sliwa (2011) investigation combined with stratigraphic information provided by Arrow was used to provide additional detail on this element of the existing environment.

7.5.1.2 *Regional Hydrogeology*

The aquifer parameters adopted for the EIS groundwater model were reviewed as part of the supplementary groundwater assessment. The review considered the process presented in Ausenco-Norwest (2012) and the referenced data sources, parameters adopted for the OGIA Surat CMA groundwater model (GHD, 2012), and the results of field hydraulic testing associated with the Moranbah Gas Project (Arrow, 2013).

7.5.1.3 *Groundwater-Dependent Ecosystems*

Information on springs and groundwater-dependent ecosystems relied on the findings of the SKM (2009a and 2009b) reports utilised in the EIS, which provided a detailed conceptualisation of groundwater systems in the Isaac-Connors catchment. Additional characterisation of the types of groundwater-dependent ecosystems potentially present within the Project area and immediate surrounds, their potential connectivity to various aquifer units, groundwater chemistry characteristics and ecological values were determined from the following information sources:

- The Australian groundwater-dependent ecosystem toolbox assessment framework (Part 1) (Richardson et al., 2011a) and assessment tools (Part 2) (Richardson et al., 2011b). These tools detail a framework for defining and identifying different types of groundwater-dependent ecosystems in a landscape, and provide tools to quantify their level of groundwater dependence.
- The National Atlas of Groundwater Dependent Ecosystems, administered by the Bureau of Meteorology (BOM, 2013). This online mapping tool presents the current ecological and hydrogeological understanding of known and potential groundwater-dependent ecosystems across

Australia. The supporting report, prepared by Sinclair Knight Merz (SKM, 2012) contains information on the methodology used to develop the atlas.

- The EPBC Act protected matters online search function for nationally important wetlands. This online resource was used to provide information on the location of nationally important wetlands. The supporting report (Environment Australia, 2001) provides a description of each listed wetland including ecological and hydrological characteristics. The potential dependence of a wetland on groundwater can be assessed through the application of this information in conjunction with other sources.
- Studies conducted by Halcrow (2012 and 2013) in the Surat CMA following the release of the UWIR. The findings of these studies are applicable to the understanding of potential groundwater-dependent ecosystems in the vicinity of ATP1025 (located within the Surat CMA).

7.5.1.4 *Groundwater Quality*

The groundwater quality information presented in the EIS was sourced primarily from studies completed by Raymond and McNeil (2011) and Pearce and Hansen (2006). Since the release of the EIS, water quality data for the northern Bowen Basin has been collated and assessed in Ausenco-Norwest (2013a). This study was based on 211 samples collected from 110 Arrow production wells and 1,239 samples collected from 547 individual bores contained within the NRM water entitlements database. In addition, Worley Parsons (2012) has completed a study that collated basin-wide groundwater quality data and provides additional information to supplement data specific to the Project area. The findings of the comparison between the latest data with that reviewed for the EIS is discussed in Section 7.6.1.4.

7.5.1.5 *Subsidence*

The potential for CSG extraction activities to cause surface subsidence was identified in the EIS impact assessment. Since the release of the EIS, a ground motion study of the Moranbah Gas Project area was conducted on behalf of Arrow (Altamira Information, 2013). The study analysed historical ground motion using satellite interferometry data from December 2006 to January 2011 collected across the tenements that make up Arrow's existing Moranbah Gas Project, which commenced CSG production in 2003. The Moranbah Gas Project area and the activities undertaken are considered to be a reasonable analogue of the Project area and the Project activities.

Other information sources relevant to the mechanisms of subsidence, include a report prepared by Geoscience Australia that summarises advice on the potential impacts of CSG extraction in the Surat and Bowen basins (Geosciences Australia and Habermehl, 2010), an analysis of CSG production and natural resource management in Australia (Williams, 2012) and an assessment of subsidence associated with the Powder River Basin coal-bed methane Project in Wyoming, USA (Grigg, 2012).

7.5.1.6 *Natural and Induced Seismicity*

Natural seismicity in the Bowen Basin was considered as part of the review of information presented in Geoscience Australia (2013). The review of natural seismicity included consideration of the spatial pattern for the April 2011 earthquake and aftershocks located near Bowen, approximately 100 km north of the Project area and interpreted by Mathews et al (2011).

Clark et al, (2011) and Hillis et al, (1999) were reviewed with respect to the seismicity and current tectonic regime in Queensland and the Bowen Basin, and comparisons were made between the Sydney Basin which has both similarities and differences to the northern Bowen Basin.

Seismicity that has resulted from human activities is known as induced seismicity, and may be associated with changes to the mass loading of the earth (for example by large open cut mining, or by filling of reservoirs), by underground mining, or by injection of fluids into the sub-surface. Hydraulic stimulation, which is sometimes undertaken at CSG wells, releases energy in the sub-surface when a target formation is fractured. The review looked at the potential for this process to release energy in the form of low intensity seismic events based on the experience both in Australia and elsewhere in the world, with references to reliable sources such as Geoscience Australia, Kansas Geological Survey and the British Geological Survey to help establish the potential impacts that may result from induced seismicity.

Since publication of the EIS, microseismic mapping was undertaken during the hydraulic stimulation of vertical CSG wells located 38 km north of Moranbah. A total of 11 hydraulic stimulation treatment stages were stimulated for production and mapped by Pinnacle (2013), a company that specialises in this field. The results were used to understand the extent, complexity and geometry of fractures generated during well hydraulic stimulation events.

7.5.2 Numerical Groundwater Model

A numerical groundwater model was prepared in the EIS groundwater model to predict groundwater drawdown in response to the Project. This model also presented cumulative drawdown predictions that included groundwater extraction associated with the Moranbah Gas Project and third-party groundwater entitlements contained in the NRM water entitlements database.

Standard industry practice is for groundwater models to undergo a process of continual review, update and recalibration as new data and information becomes available. The results of these investigations are included in the supplementary groundwater assessment. The additional work included:

- An independent review of the EIS groundwater model conducted by NTEC Environmental Technology (NTEC). The review referred to the draft Australian Groundwater Modelling Guidelines (Barnett et al, 2012). Arrow subsequently engaged CDM Smith Australia Pty Ltd (CDM Smith) in 2013 to prepare a report (Appendix D of the Supplementary Groundwater Assessment (Appendix E) of the SREIS summarising the previous NTEC review stages (CDM Smith acquired NTEC in early 2013).
- An assessment of the level of predictive error or uncertainty associated with the initial EIS groundwater model parameters. This work was undertaken by Ausenco-Norwest to better understand the model limitations and to identify data gaps. A report was prepared (see Appendix E of the Supplementary Groundwater Assessment (Appendix E) of the SREIS) to present the initial assessment findings.
- Additional groundwater modelling was undertaken by Arrow to simulate the effect of faults, simulated as preferential pathways for groundwater flow between aquifers, and to consider how the

effect of such changes to aquifer interconnectivity would influence the potential drawdown impacts caused by the Project. In the initial EIS groundwater model faults were represented as barriers to groundwater flow, based on the existing understanding and field experience. These additional model simulations used a method known as Telescopic Mesh Refinement (TMR) to create a refined model within a subregion of the EIS groundwater model where faults were modelled to behave as pathways for groundwater flow (as opposed to acting as a barrier). This model is referred to herein as the TMR groundwater model.

7.5.3 Review and Update of the EIS Impact Assessment

The groundwater impact assessment prepared for the EIS adopted a significance assessment approach, whereby the significance of potential impacts to the groundwater systems was determined through the establishment of environmental values and their sensitivity to change, and consideration of the magnitude of potential impacts on those values.

7.5.3.1 *Groundwater Characterisation Update*

The findings of the review of additional information, modelling and investigations provided a technical basis that underpinned a review of the groundwater impact assessment presented in the EIS.

An initial outcome of the review of the environmental values resulted in a minor refinement to the characterisation of the deep groundwater systems. In the EIS, the target coal seams of the Blackwater Group and the underlying aquifers of the Back Creek Group were combined into the ‘coal seam groundwater system’. To separate direct impacts on the target coal seams from indirect impacts to the underlying aquifers, the Back Creek Group has been separated into a discrete ‘deep groundwater system’.

7.5.3.2 *Supplementary Assessment Method*

The method used to meet the objectives of the supplementary groundwater assessment included:

- Review and verification of the groundwater environmental values to be protected or enhanced. This included reclassification of the groundwater systems presented in the EIS to enhance the clarity of the assessment of impacts (direct and indirect) on the deep groundwater;
- Detailing any changes to the sensitivity rankings applied to groundwater environmental values;
- Verifying whether potential impacts identified in the EIS remain relevant. Identify any new impacts, or impacts that no longer apply to the Project;
- Re-assessing the magnitude rankings applied prior to implementation of mitigation measures to determine the pre-mitigation impact significance;
- Reviewing mitigation and management measures where required, in light of the revised impact assessment. Addition to, or revision or omission of, mitigation and management measures developed during the EIS that are necessary to address the supplementary assessment findings; and
- Re-assessing magnitude rankings applied with consideration for successful implementation of the mitigation measures to determine the residual impact significance.

7.6 Updates to EIS Findings

This section describes the improved understanding of the existing environment in the Project area and the broader model domain. This section also presents the findings of the peer review and uncertainty analysis conducted on the EIS groundwater model. Results of the additional scenarios simulated by the TMR groundwater model are also described below.

7.6.1 Existing Environment Updates

The characterisation of the existing environment presented in the EIS is supported by the outcomes of the information review completed for the supplementary assessment. Areas where additional information has improved the understanding of the existing environment relate primarily to aspects of the regional geology, in particular the faults present in the Bowen Basin and their hydraulic behaviour. New information has also allowed a more detailed description to be presented of groundwater-dependent ecosystems present in the Project area.

The following sections describe these updated aspects of the existing environment.

7.6.1.1 *Regional Geology*

Stratigraphy in the Bowen Basin is well characterised largely through the focus in this area on petroleum, coal and mineral resource exploration and development. The EIS presented a detailed characterisation of the regional geology, describing the evolution of the Bowen Basin, structural controls (for example, faults and folds), and a description of the geological formations, including the target coal seams. Further information is presented below on the influence of the tectonic stress regime on seismic activity, the characteristics of faults in the Bowen Basin and the hydraulic behaviour of these faults.

Stress Regime

A more detailed understanding of the regional stress regime in the Bowen Basin allows a more comprehensive assessment to be made of how structural features in the Bowen Basin have developed, and how these processes can be correlated with seismic activity and the hydrogeological behaviour of faults.

In structural geology, stresses refer to the forces acting on the rocks and sediments that form the earth's crust, such as horizontal forces caused by crust or plate movements, or vertical downward forces caused by the mass of the rocks and sediments.

The stress regime of a geological basin relates to relative stress magnitudes in the horizontal and vertical direction. If a basin is in a compressive state, the horizontal stress magnitude is found to be greater than the vertical stress magnitude. Conversely, where an extensional state exists, the vertical stress magnitude is found to be greater than the horizontal stress magnitude.

A regional assessment of the stress regime in eastern Australia was completed by Hillis et al (1999) using over 1,000 individual stress measurements. Data for the Bowen Basin indicates that horizontal stress forces have a greater influence on the overall stress in the basin than vertical stress forces (Hillis et al, 1999), and therefore indicates that the Bowen Basin is in a compressive state.

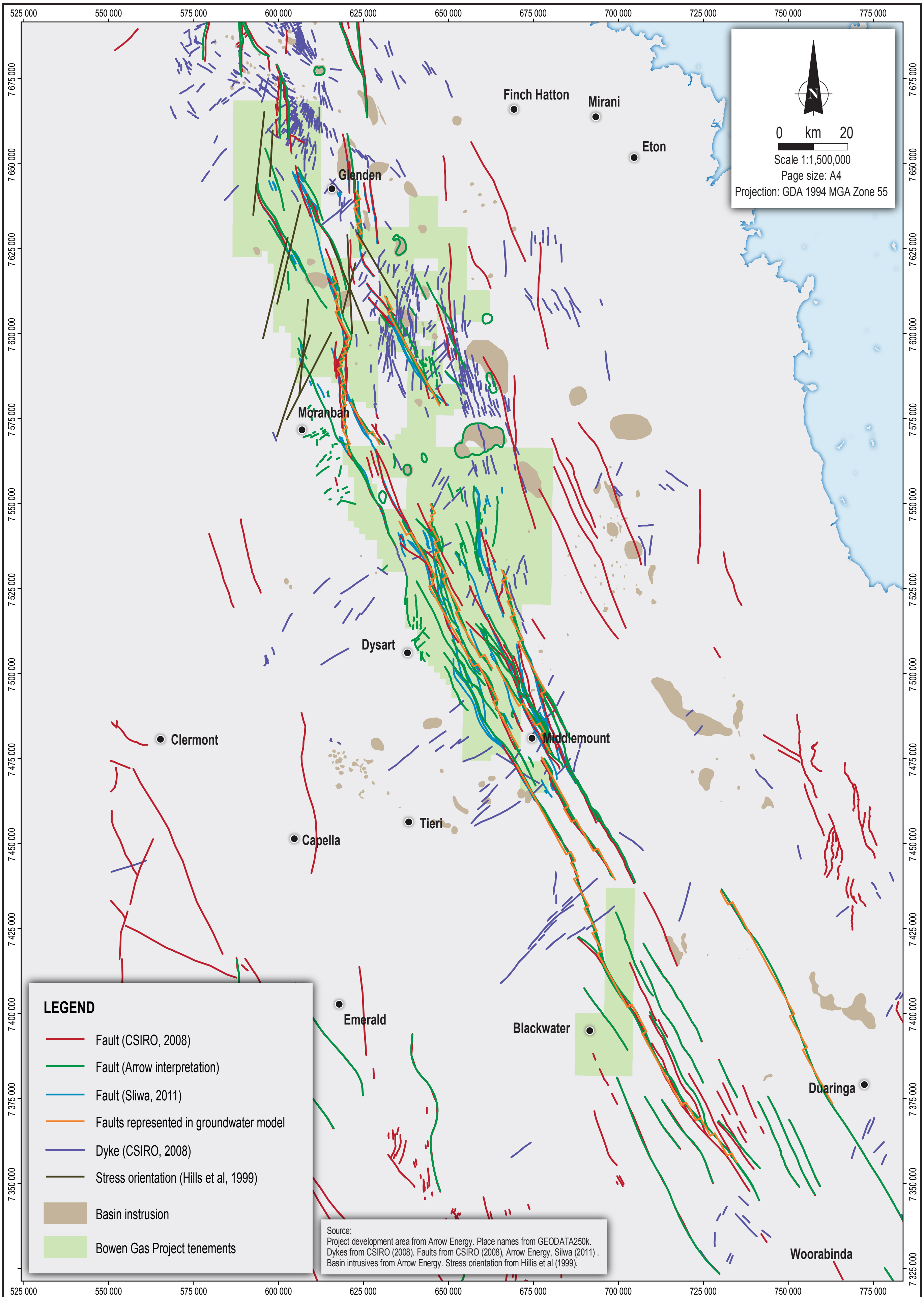
Fault Types, Occurrence and History

The EIS presented maps and cross sections of the Bowen Basin showing the location and geometry of faults. The EIS also described the history of faulting in the Bowen Basin. Faulting patterns show that early in its geologic history the Bowen Basin underwent an episode of mild extension, followed by a later compressional episode (Esterle & Sliwa, 2002). The initial period of extension resulted in development of normal faults, where fault blocks are displaced downwards, a common response under an extensional stress regime. During the more recent compressive episode, thrust (reverse) faults developed, whereby the faulted block is displaced upwards.

The initial episode of extension experienced by the Bowen Basin is interpreted to have occurred in the Early Permian (approximately 300 million years ago). The target coal seams in the Bowen Basin formed during this time period. During the subsequent compressive period, the thrust faults are reported to be related to the regional-scale Jellinbah Thrust Belt system. This thrust fault system propagated into the Bowen Basin during the Mid Triassic (approximately 240 million years ago). Other extensional events that affected Australia are reported in the Late Triassic (approximately 225 million years ago) and the Late Jurassic – Early Cretaceous (approximately 145 million years ago) (Uysal et al, 2000). Groundwater flow through geological formations is interpreted during these events, especially during the Late Triassic. Heat and groundwater flow is likely to have resulted in mineralisation, reducing permeability and porosity of rocks within the Bowen Basin (Uysal et al, 2000).

In more recent geological times (from 65 million years ago to the present), the compressional regime has persisted in the Bowen Basin (Hillis et al, 1999) and faulting activity has been limited (Clark et al, 2011).

An updated map showing the location of known and potential faults, igneous intrusions and the stress orientation in the Project area is presented in Figure 7-3. This map incorporates fault mapping generated by Hillis et al (1999), CSIRO (2008), Sliwa (2011) and Arrow. The Sliwa (2011) assessment provides a detailed analysis of available geophysical information from the Bowen Basin to define structural zones based on different compressive deformational characteristics.



coffey	Date: 17.04.2014 MXT: 7043_03_GIS027_v1_1 File Name: 7043_02_F05.01_GIS_GL	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Known and potential faults, dykes, igneous intrusions and stress orientation for the Northern Bowen Basin	Figure No: 7.3

Rewan Formation Extent

Another important aspect of Bowen Basin regional geology relates to the presence or absence of the Rewan Formation. The Rewan Formation is the key confining layer positioned above the target coal seams in the Bowen Basin. In part, understanding the propagation of groundwater drawdown from the target coal seams to overlying aquifers is informed by the understanding of the distribution of the Rewan Formation.

The EIS acknowledged that the Rewan Formation is absent in some portions of the Project area, as represented in the geological model that underpins the EIS groundwater model. The geological model represented the extent of the Rewan Formation based on information in the Bowen Basin structural geology map (CSIRO, 2008) as shown in Figure 7-4.

A review of the mapping produced by CSIRO (2008) was conducted by Sliwa (2011) to revise the mapped extent of the Rewan Formation. The revised mapping indicates that overall the extent of the Rewan Formation presented in the CSIRO (2008) and the Sliwa (2011) revision was similar. However in some areas, particularly in the south of the Project area, the Rewan Formation confining layer is more extensive than previously mapped.

7.6.1.2 *Regional Hydrogeology*

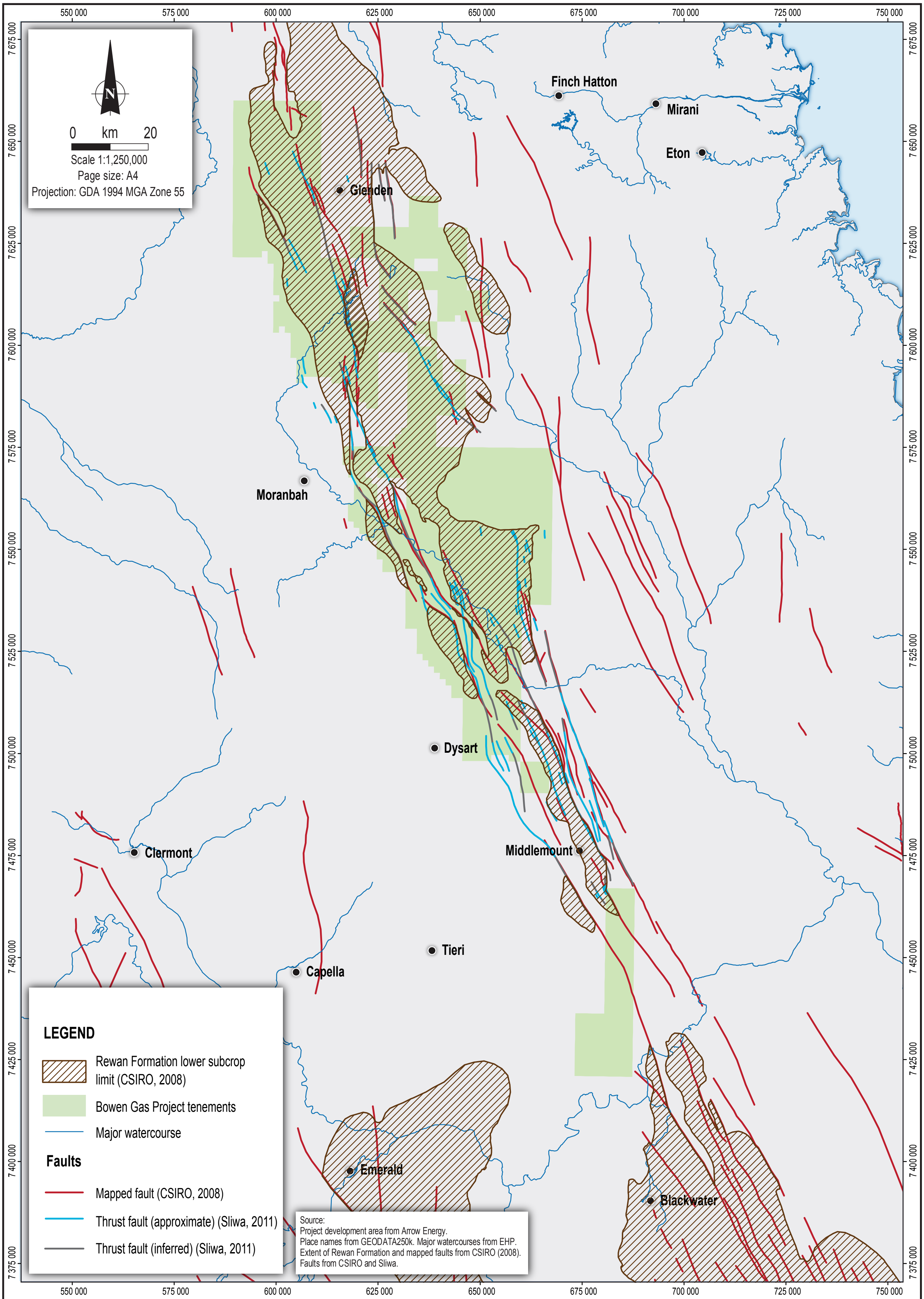
The characterisation of the Project area hydrogeology considers the movement of groundwater through and between aquifers, as well as the direction and velocity of groundwater flow. The understanding of regional hydrogeology presented in the EIS has been further developed, based on additional information and reconsideration of existing information. This further consideration has confirmed that the assumptions underpinning the EIS groundwater model remain valid.

The updated understanding of the regional hydrogeology is presented in this section. In particular, the factors that influence the movement of groundwater in the Bowen Basin are described in terms of:

- Aquifer parameters (hydraulic conductivity and storage).
- Faults and their hydraulic behaviour (i.e. whether they influence groundwater flow across or between geological formations).
- Stratigraphy (i.e. the distribution of confining layers).

Aquifer Parameters

A parameterisation process was applied to the EIS groundwater model whereby aquifer properties were compiled from literature, government databases and in-house Arrow data (URS, 2012). During model calibration, aquifer parameters that characterise the capacity of an aquifer to release and transmit groundwater, are adjusted to fit the predicted groundwater levels in the model with observed groundwater levels. This approach provides a realistic representation of groundwater regimes that are based on field or published data for the geology of the rock and unconsolidated formations that occur in the Bowen Basin.



coffey	Date: 17.04.2014 MXT: 7043_03_GIS023_v1_1 File Name: 7043_03_F07.04_GIS_GL	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Extent of Rowan Formation

Figure No: 7.4

Information available since finalisation of the EIS has been used in a comparative process to verify the calibrated aquifer parameters adopted by the EIS groundwater model. The OGIA Surat CMA groundwater model (GHD, 2012) includes information for a portion of the Bowen Basin, and the results of hydraulic testing conducted by Arrow in the Moranbah Gas Project area (Arrow, 2013) are also available.

Comparison of the calibrated parameters established in the EIS groundwater model (Ausenco-Norwest, 2012) with the OGIA Surat CMA groundwater model shows that hydraulic conductivity values are within the same range for comparable rock types. Calibrated values for specific storage presented for confined aquifers in the EIS groundwater model are also within the typical range of storage values adopted by the OGIA Surat CMA groundwater model.

Analysis of field data collected from monitoring wells within the Moranbah Gas Project area allows minimum, maximum and average hydraulic conductivity values to be determined for four different geological units; the Quaternary sediments, Tertiary sediments, weathered Tertiary basalts, and weathered Fort Cooper Coal Measures.

The EIS groundwater model uses an average parameter value to represent the hydraulic conductivity. The adequacy of this value was confirmed in a review of published information and the results of field tests.

Hydraulic Behaviour of Faults

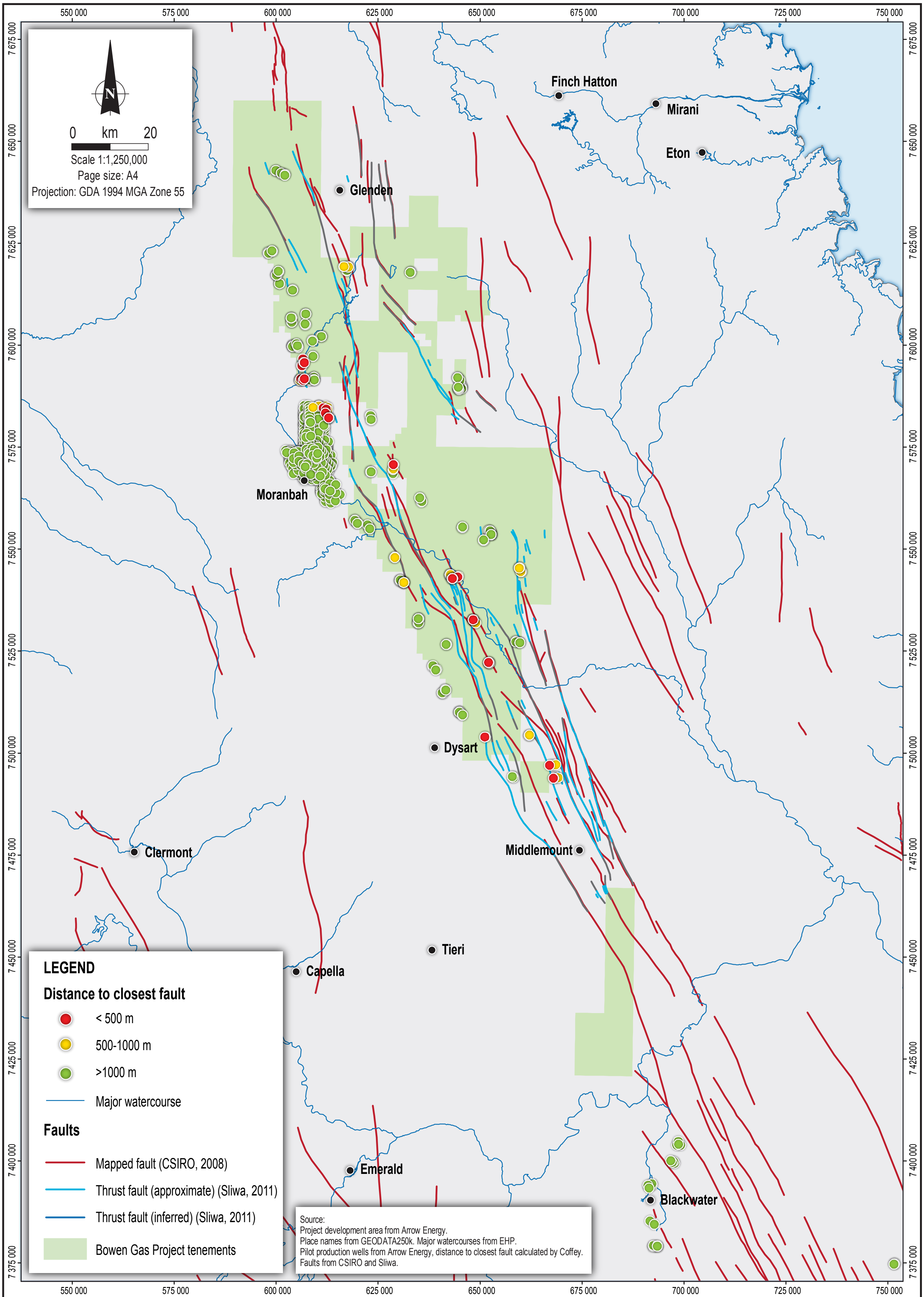
Figure 7-5 shows Arrow pilot production wells together with mapped major faults. In some cases wells have been drilled and installed within a few hundred metres of known faults, although these are generally avoided where possible. In some cases minor faults have been encountered in drilling; however no significant loss or gain of water has been observed during drilling through these structures. This provides field evidence which supports a hypothesis of limited connectivity within faults.

In addition it is considered that the presence of faults, if permeable across formations, may over time lead to the loss of gas from coal seams due to migration. Therefore, the presence of gas within the target seams (as observed in the field) provides supporting evidence that pathways for migration are not present or limited.

The hydraulic behaviour of faults can be determined from field-based data and also conceptualised based on multiple lines of evidence.

A study presented by Kinnon (2010) for a CSG Project in the northern Bowen Basin correlated structural information with CSG production rates and groundwater chemistry data from wells installed in different fault blocks. The results showed that the fault blocks in the study area were compartmentalised as indicated by different gas production rates and groundwater quality characteristics on either side of faults. This evidence of limited connectivity was reflected in the EIS.

Since publication of the EIS, additional investigation has been undertaken to establish an improved understanding of faults within the Project area. Regional information from the Bowen Basin and other Australian and international examples were considered in conjunction with field observations from Arrow to develop a conceptual understanding of the hydraulic behaviour of faults.



coffey	Date: 17.04.2014 MXT: 7043_03_GIS028_v1_1 File Name: 7043_03_F07.05_GIS_GL	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Pilot and production well proximity to known faults	Figure No: 7.5

Several models are available for use in predicting fault permeability, as presented in Flodin et al (2001) and Jourde et al (2002). Faults are known to act as either barriers to groundwater flow or conduits to flow, or a combination of both (Flodin et al, 2001). The behaviour of faults can also be complex, sometimes varying in different locations and at different times during their development (Jourde et al, 2002).

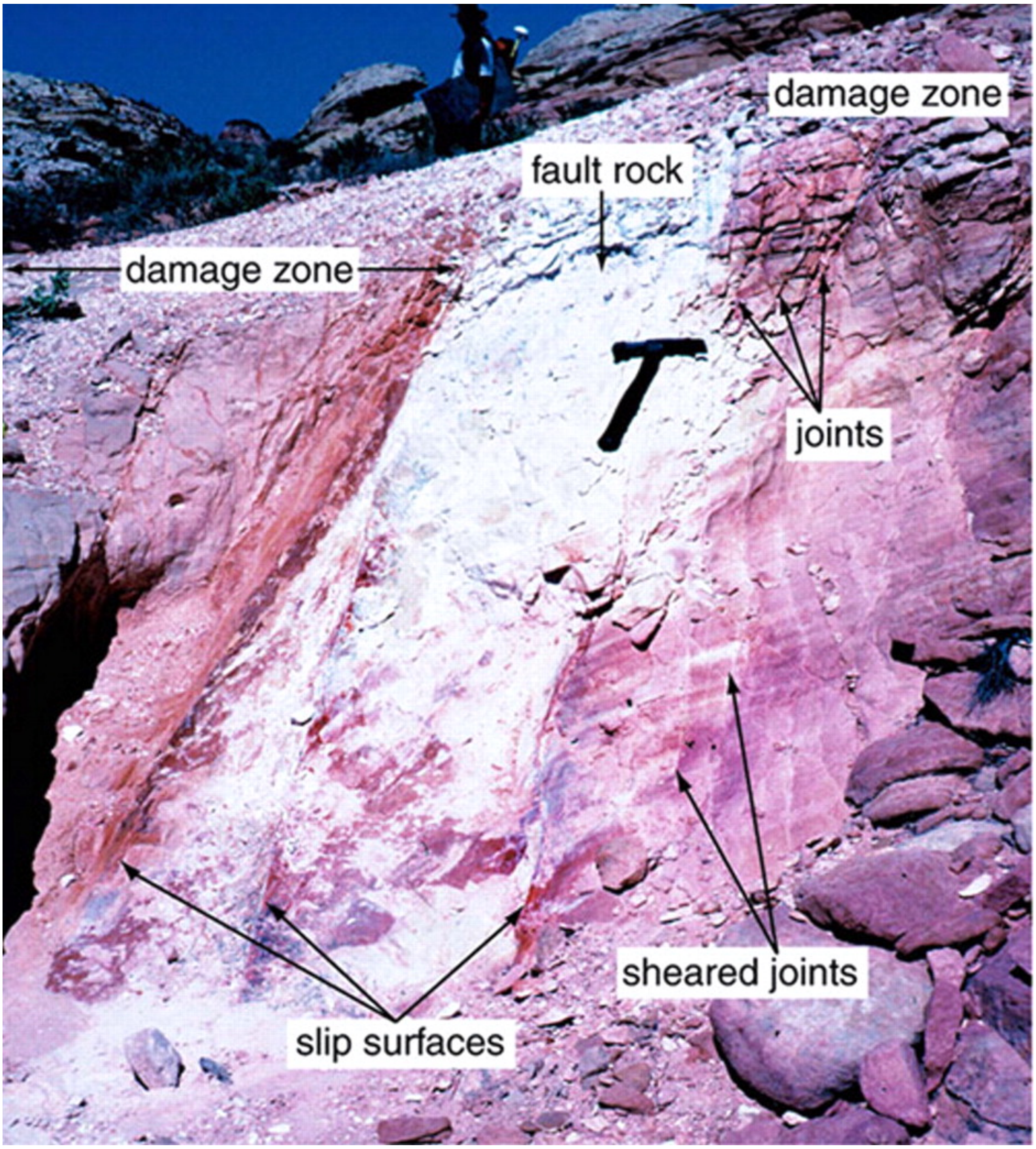
The example used by Flodin et al (2001) and Jourde et al (2002) focussed on a faulted sandstone aquifer. The results of the Flodin et al (2001) study showed a relationship between fault slip (the measured displacement along the fault plane) and fault permeability. Jourde et al (2002) found that permeability varied relative to the direction from the fault plane, with enhanced permeability parallel to the fault plane, and reduced permeability perpendicular to the fault plane.

Faults usually contain a number of different zones, with variable hydraulic characteristics. A general fault zone structure includes a central fault core containing fine-grained fault rock and breccia, with a damage zone either side, and un-faulted host rock beyond that (Plate 7-1). The damage zone can contain attendant structures related to the growth of the fault, such as fractures and joints (Flodin et al 2001).

A number of lines of evidence indicate that the faults in the Project area, and the Bowen Basin more broadly, have limited permeability and are more likely to behave as barriers to groundwater flow as opposed to conduits. A summary of key points supporting each line of evidence is provided below:

- **Field Evidence and Observations.** Based on Arrow's field experience, including drill stem tests from the Bowen Basin, including the Moranbah Gas Project, water losses through structure have either not occurred or not been significant.
- **Gas Production Rates and Groundwater Quality.** Differing gas production rates either side of faults together with varied groundwater chemical compositions indicate limited connectivity across fault boundaries (Kinnon, 2010).
- **Age of Faults and Faulting History.** Faulting activity in the Bowen Basin primarily occurred during the Triassic and Jurassic period (approximately 250 to 140 million years ago) (Esterle & Sliwa 2002 and Sliwa, 2011). These faults are considered to be inactive in the present day based on the lack of recent tectonic activity in the Bowen Basin (Clark et al, 2011). Increased permeability parallel to fault zones is more likely to occur in geological settings where faults are currently active (Paul et al, 2009).
- **Thermal Activity.** Groundwater flow causing alteration and mineralisation described in Uysal et al (2000) has resulted in reduced porosity and permeability of formations in the Bowen Basin, including within fault zones.
- **Basin Stress Regime.** The current compressive stress regime in the Bowen Basin (Hillis et al, 1999) is likely to 'close' fractures and faults, causing barriers to groundwater flow.
- **Low Permeability Fault Core Rock.** The presence of low hydraulic conductivity core rock within faults is normally developed between host rock damage zones. Permeability perpendicular to the fault may be two orders of magnitude less than the host rock permeability (Jourde et al, 2002). This indicates faults act as barriers to horizontal groundwater flow regardless of whether mineralisation of associated damage zones has occurred or not.

Plate 7-1 Photograph of a Fault from the Valley of Fire State Park Showing Characteristic Structural Features of the Fault Core (Fault Rock, and Slip Surfaces) and the Surrounding Damage Zone (Joints and Sheared Joints)



(Photo source: Figure 4 of Jourde et al. (2002).

Influence of Stratigraphy

Areas where the Rewan Formation is mapped as absent (Figure 7-4) indicate where the target coal seams could be in direct contact with the overlying Quaternary and Tertiary aquifers of the shallow groundwater system. In these areas, the regional confining layer is absent, and drawdown impacts could more readily propagate to the aquifers of the shallow groundwater system.

The results of the mapping conducted by Sliwa (2011) generally align with the distribution of the Rewan Formation presented by CSIRO (2008), showing the following areas where the confining layer is absent:

- Western parts of ATP742, ATP1103 and ATP1031;
- Most of ATP749 and ATP759;
- Northern parts of ATP1031; and
- Small parts of ATP1025 to the north and north west.

The distribution of the Fort Cooper Coal Measures also influences the regional hydrogeology, where present. The interburden of the Fort Cooper Coal Measures includes shale and sandstone of low permeability. As such, these measures function as a regional confining unit between the Moranbah Coal Measures and overlying aquifers of the shallow and intermediate groundwater systems.

7.6.1.3 *Groundwater-Dependent Ecosystems*

Groundwater-dependent ecosystems were identified and discussed in the groundwater impact assessment prepared for the EIS. A 50 km buffer zone surrounding the Project area has been adopted to define the study area for the assessment of groundwater-dependent ecosystems as part of the supplementary groundwater assessment.

New information has allowed the types of groundwater-dependent ecosystems present within the study area to be identified in a manner consistent with the classification system adopted in the Australian groundwater-dependent ecosystem toolbox assessment framework (Richardson et al., 2011a and 2011b). The classification is as follows:

- Ecosystems dependent on the surface expression of groundwater including:
  - Springs (including spring wetlands and spring fed watercourses).
  - Groundwater discharge to watercourses and wetlands.
- Ecosystems dependent on the subsurface presence of groundwater, including where plant roots access shallow groundwater.

The National Groundwater-dependent Ecosystem Atlas (BoM, 2013) is a published tool used for the identification of potential groundwater-dependent areas, including where groundwater may discharge to watercourses and wetlands, or where plants may access groundwater. Throughout most of the study area the level of actual groundwater dependency has not been verified through field investigations.

A summary of the updated information related to groundwater-dependent ecosystems in the study area in the Bowen Basin is provided in the sections below. Further details are provided in Appendix E, Supplementary Groundwater Assessment.

Known Springs and Spring-fed Watercourses

A spring (or spring vent) is a point where there is a surface expression of groundwater. Springs may be either recharge or discharge springs. Recharge springs are supplied by groundwater from an aquifer in the vicinity of the spring that is not confined, and discharge springs are supplied by groundwater from a confined aquifer.

A spring-fed watercourse occurs where the natural land surface has been eroded sufficiently to intersect the water table and groundwater is discharged to a watercourse (also known as stream or river baseflow).

Figure 7-6 shows the location of known springs and watercourse springs within the study area, including the conservation status of each known spring (where available). The conservation status of springs are ranked from highest importance (ranking of 1) to lowest importance (ranking of 5) based on the biological importance of each spring.

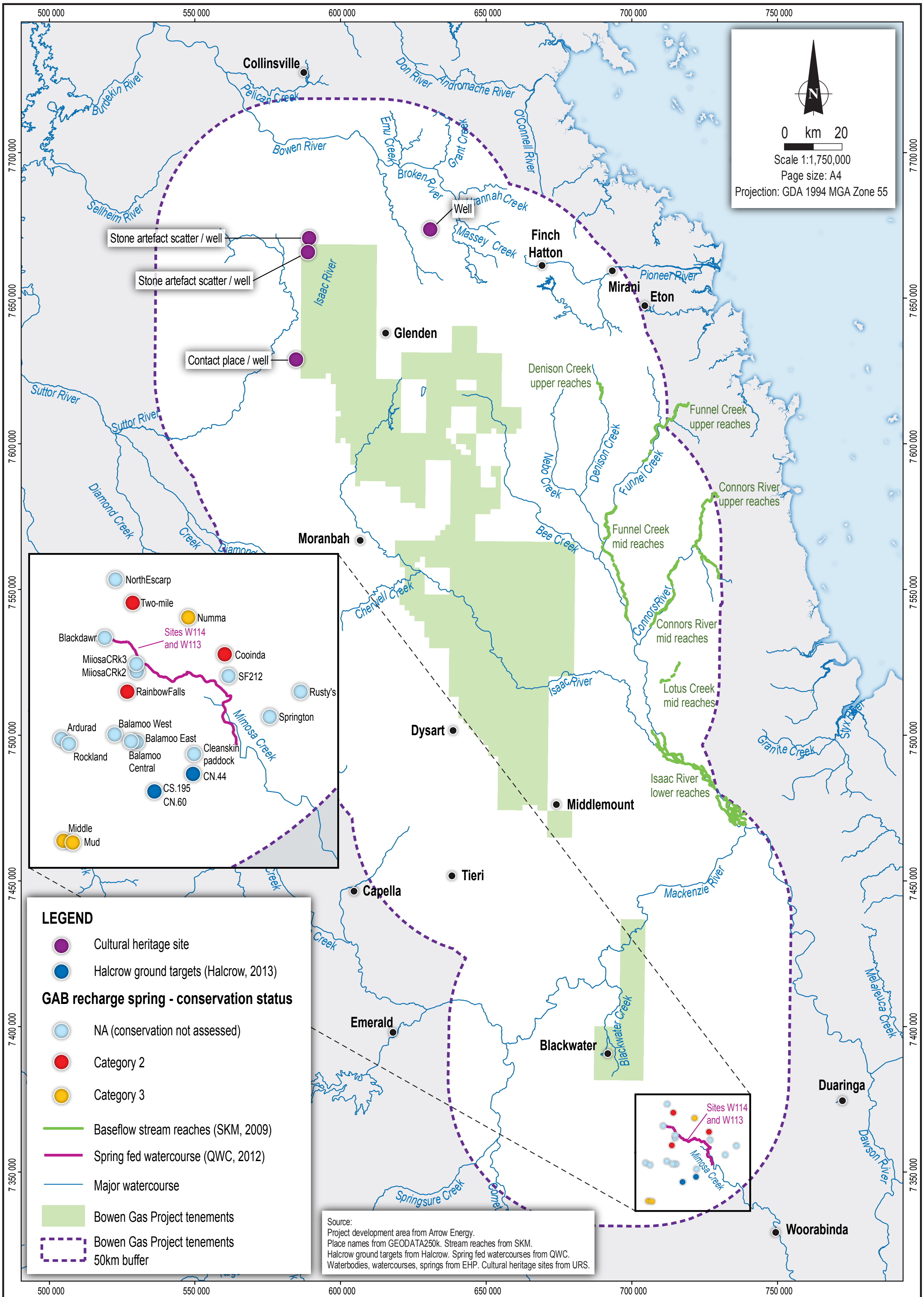
No known springs or watercourse springs are located within the Project area. A total of 19 known spring vents and 9 watercourse springs are located outside the Project area but within the broader study area (50 km buffer from the Project area).

The 19 known spring vents are considered to be recharge springs and they are all located to the south of Blackwater in the Blackdown Tableland. The surface geological unit present at these locations is interpreted to represent the source aquifer given that they are all recharge springs and therefore supported by groundwater from a nearby unconfined aquifer. The interpreted source aquifer for these springs is primarily the outcropping Rewan Formation or Clematis Sandstone, as well as Precipice Sandstone and single instances of younger Tertiary sandstone and Quaternary sediments. No EPBC or NCA listed species or communities have been identified at these locations based on the information in the Queensland Springs Dataset (maintained by EHP). A conservation status ranking is not available for most of these springs, however those with a ranking range from category 2 to category 3 represents moderate biological importance.

In addition to the known springs presented in Figure 7-6, a further two potential spring vent sites within the study area have been identified through remote sensing, thematic mapping and aerial validation studies (Halcrow, 2012 and 2013). The two potential spring sites have been earmarked for ground validation by Halcrow as part of a detailed study commissioned by Santos Ltd.

Two of the nine known watercourse springs are also located to the south of Blackwater in the Blackdown Tableland and occur where groundwater discharges to Mimosa Creek and a tributary of Mimosa Creek.

The remaining seven creek and river reaches identified as receiving baseflow (SKM, 2009a) are located to the east of the Project area and are shown on Figure 7-6. These watercourses are associated with the Isaac-Connors Catchment.



coffey	Date: 22.04.2014 MXT: 7043_03_GIS010_v1_1 File Name: 7043_03_F07.06_GIS_GL_2	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Mapped spring vents, water course springs and sites of Indigenous spiritual and cultural importance	Figure No: 7.6

Potential Groundwater Discharge to Watercourses, Lakes and Wetlands

The National Atlas of Groundwater-dependent Ecosystems (BOM, 2013) presents a wide range of landscapes that potentially contain ecosystems dependent on the surface expression of groundwater for some or all of their water requirements.

These areas of potential interaction are typically distributed across the study area along watercourses, where depth to groundwater is expected to be at its shallowest. Within and in the vicinity of the Project area the landscapes are typically classified as watercourse or riverine systems along floodplains and swamps.

The potentially groundwater-dependent landscapes that have been assigned a high potential for interaction with the surface expression of groundwater, or where the ecosystems have been identified as part of a previous study, are considered to represent actual groundwater-dependent ecosystems for the purpose of this assessment. These areas are shown in Figure 7-7, and within the Project area this includes:

- Reaches of Kangaroo, Suttor, Anna, Hail, Bee, Phillips and Cherwell creeks;
- Isaac River (Upper and Mid reaches); and
- Burton Gorge Dam.

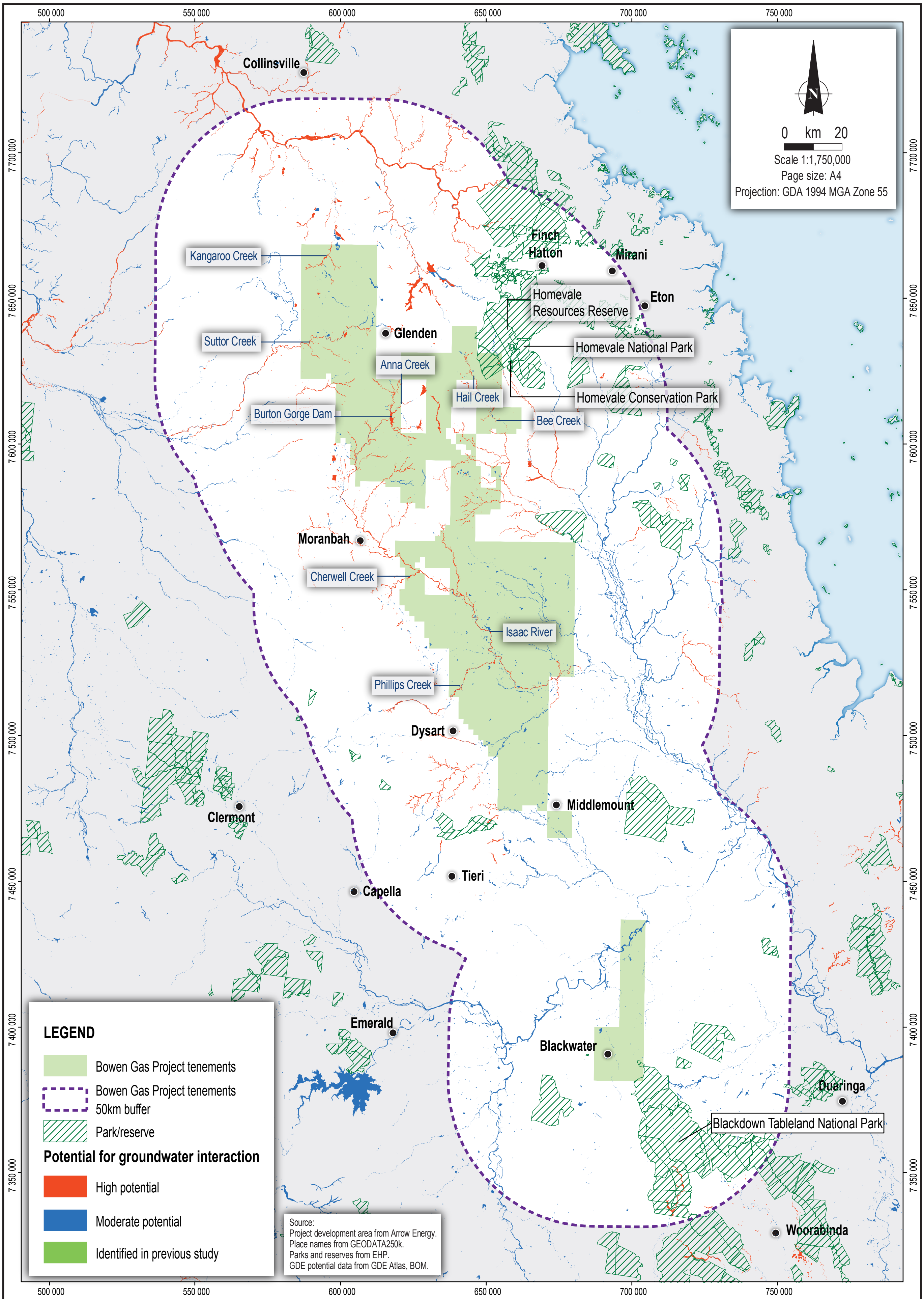
Other unnamed surface water features, including tributaries of the creeks and rivers listed above, are also mapped as having a high potential for interaction with groundwater, particularly in the north of the Project area. In addition, Lake Elphinstone, located immediately outside the Project area is mapped as having a high potential for interaction with the surface expression of groundwater. Lake Elphinstone is a nationally important wetland and is discussed further below.

Groundwater-dependent ecosystems mapped as being potentially dependent on the surface expression of groundwater coincide with areas of national and conservation parks in the proximity of the Project area, including Homevale National and Conservation Park in the northeast, and the Blackdown Tableland National Park in the south.

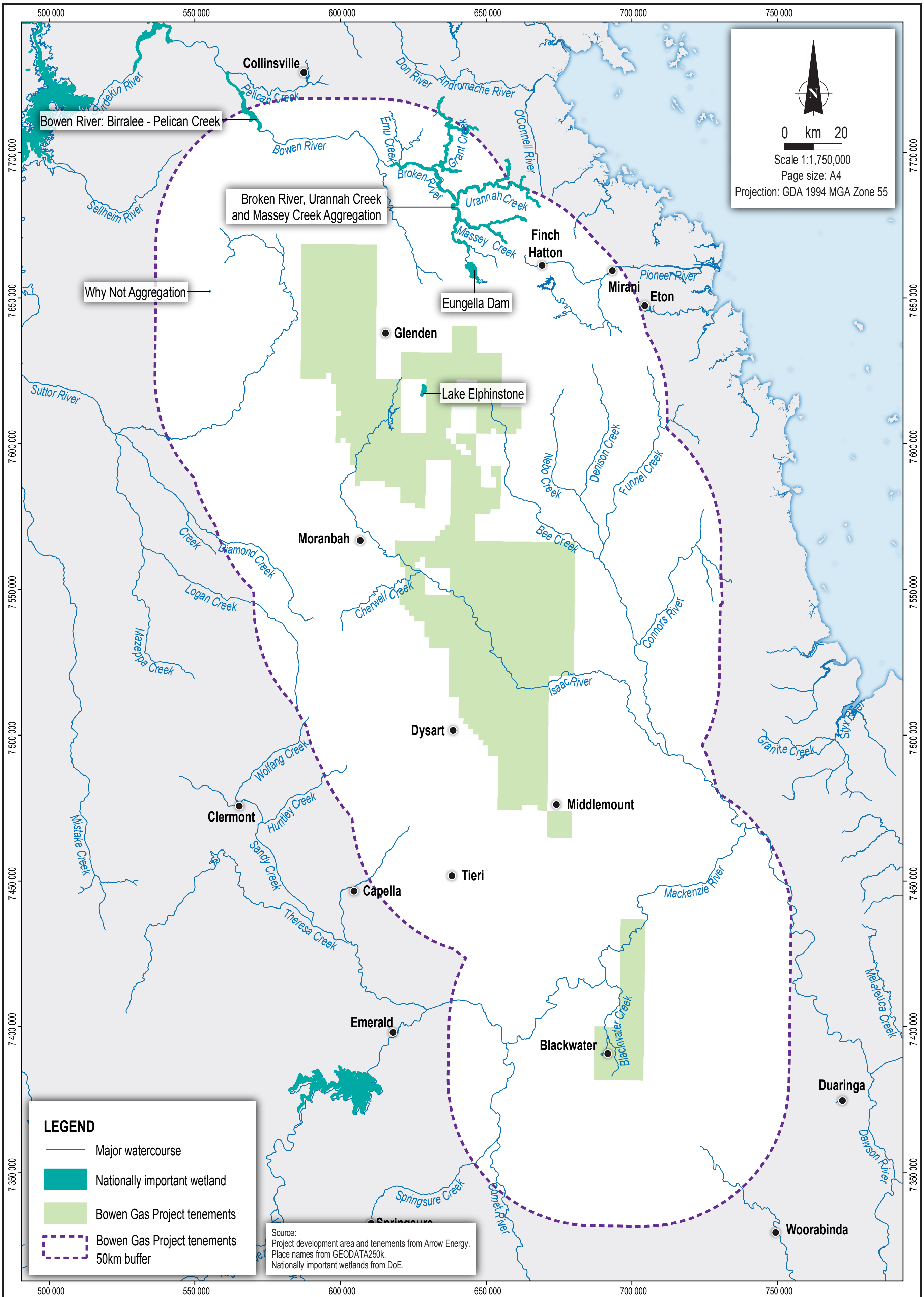
Nationally Important Wetlands

Wetlands may receive groundwater discharge and can therefore support groundwater-dependent ecosystems. A search of the EPBC Act 'Protected Matters: Nationally Important Wetlands' (DoE, 2013) directory identified five wetlands within the study area (Figure 7-8). None of these wetlands occur within the Project area. The closest wetland is Lake Elphinstone, located adjacent to the Project area.

The Directory of Important Wetlands in Australia (Environment Australia, 2001) was used to provide an interpretation of the potential for each wetland to be supported by groundwater, and therefore provide suitable conditions for groundwater-dependent ecosystems. A summary is provided in Table 7-1.



coffey	Date: 22.04.2014 MXT: 7043_03_GIS031_v1 File Name: 7043_03_F07.07_GIS_GL_2	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Mapped GDEs potentially dependent on the surface expression of groundwater	Figure No: 7.7



coffey	Date: 22.04.2014 MXT: 7043_03_GIS030_v1 File Name: 7043_03_F07.08_GIS_GL_2	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Nationally important wetlands	Figure No: 7.8

Table 7-1 Summary of Nationally Important Wetlands within the Study Area

Wetland Name	Wetland Category and Location	Potential to Support Groundwater-Dependent Ecosystems (Environment Australia, 2001)
Lake Elphinstone	Inland wetland located adjacent to the Project area.	Water supply to the lake is noted to be sourced from runoff and stream flow from the local catchment. The lake may have some groundwater dependence. Lake levels fluctuate seasonally and water is semi-permanent.
Why Not Aggregation	Human-made wetlands located approximately 35 km to the west of the Project area.	An artificial impoundment located on a drainage depression and filled by local runoff rather than a stream. Not dependent on groundwater.
Eungella Dam	Inland wetland and human-made wetlands located approximately 15 km to the north of the Project area.	The wetland has been created by damming a valley of the Broken River. Water supply to the wetland is listed as being stream flow and runoff from the catchment. Not groundwater dependent.
Bowen River: Birralee – Pelican Creek	Inland wetland located approximately 44 km to the north of the Project area.	Stream reaches could receive groundwater baseflow and therefore represent a groundwater-dependent ecosystem. The central part of the feature is described as a large permanent clear water hole with rapids, sand, rock or rubble bars, terraces and small waterholes at the upstream and downstream ends. Most of this section of the river has cut into volcanic rocks and has a bedrock bed, which has been partially covered by sheets and banks of sand, gravel and pebbles.
Broken River, Urannah Creek and Massey Creek Aggregation	Inland wetland located approximately 30 km to the north of the Project area.	An upper perennial and intermittent riverine wetland. Water is transported from the high rainfall upper catchment to the lower rainfall western side of the site providing a reliable source of water. Not groundwater dependent.

Ecosystems Dependent on the Subsurface Presence of Groundwater

Ecosystems dependent on the subsurface presence of groundwater occur in areas where groundwater levels are near the ground surface or where the root systems of vegetation are able to access deeper groundwater systems. The National Atlas of Groundwater-dependent Ecosystems (BOM, 2013) defines these systems as groundwater-dependent ecosystems that potentially rely on the subsurface presence of groundwater, and presents a range of landscapes that may rely on the subsurface presence of groundwater for some or all of their water requirements.

Figure 7-9 shows the mapped location of ecosystems potentially dependent on the subsurface presence of groundwater. Areas mapped with a high potential for interaction with subsurface groundwater are often distributed along watercourses where depth to groundwater is typically shallowest. This distribution is similar to the distribution of ecosystems potentially dependent on the surface expression of groundwater. Areas mapped with a moderate potential for interaction with subsurface groundwater generally correlate with regions of relatively high vegetation density in comparison to surrounding land, for instance north and south of Glenden.

The potentially groundwater-dependent landscapes that have been assigned a high potential for interaction with the subsurface presence of groundwater, or where the ecosystems have been identified as part of a previous study, are considered likely to represent groundwater-dependent ecosystems for the purpose of this assessment. Within the Project area this constitutes predominantly riparian vegetation along the Isaac and Mackenzie rivers, and Stephens, Phillips, Harrow and Kangaroo creeks, as well as other minor creeks throughout the northern parts of the Project area. Depth to groundwater is not known across much of the study area. Data from registered groundwater bores in the area and previous studies indicate depth to groundwater typically ranges from 5 m to 20 m below ground level. These depths indicate the potential for groundwater to be within plant rooting depths (typically <10 m), particularly along watercourses where depth to groundwater is typically shallower.

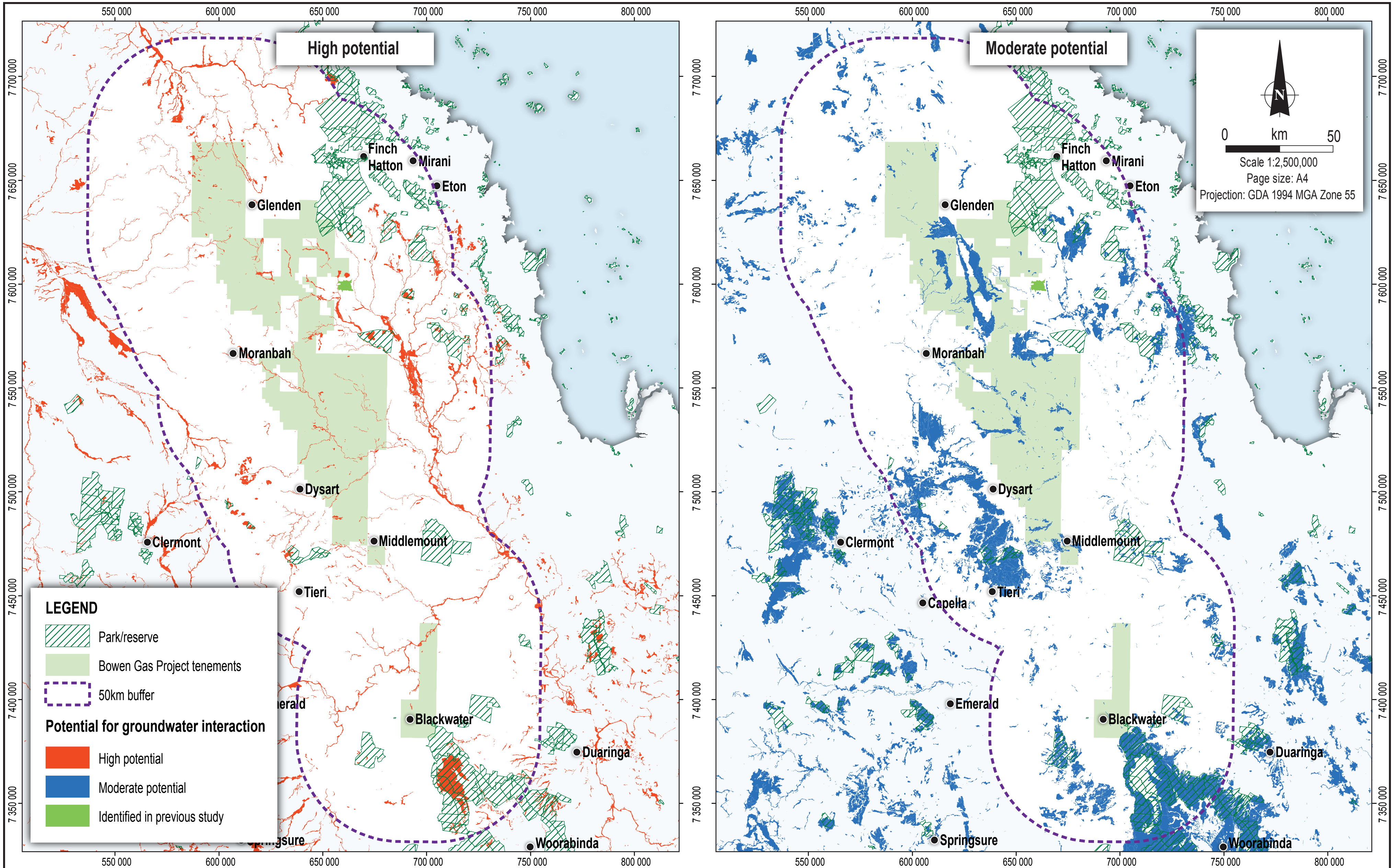
Areas with a moderate potential for interaction with the subsurface presence of groundwater coincide with areas of national and conservation parks in proximity of the Project area, including Homevale National and Conservation Park in the north east, and the Blackdown Tableland National Park in the south. No field investigations have been carried out in these parks. The actual dependency of these vegetated areas on groundwater is unconfirmed.

The vegetation communities in these areas are mapped as regional ecosystems 11.7.5 and 11.5.4 which have been identified in the Terrestrial Ecology chapter (Section 11) of the SREIS as areas of low sensitivity not of conservation interest under the EPBC Act and *Vegetation Management Act 1999* (Qld).

Summary of Groundwater-Dependent Ecosystems

No known springs or watercourse springs identified in the study area are located within the Project area. There are no known nationally important wetlands dependent on groundwater supply within the Project area. Nationally important wetland Lake Elphinstone borders the Project area and is potentially reliant on groundwater.

Several areas identified by the National Atlas of Groundwater Dependent Ecosystems within the Project area are mapped as having a high potential for interaction with groundwater; both the surface expression of groundwater and the subsurface presence of groundwater. Typically these areas are associated with watercourses where depth to groundwater is expected to be shallowest. Groundwater typically ranges from 5 to 20 m below ground level in these areas, which is within typical plant rooting depths (typically <10 m). These areas are therefore likely to represent conditions that may support ecosystem interaction with the surface expression and subsurface presence groundwater.



Source:
Project development area from Arrow Energy.
Place names from GEODATA250k.
Parks/reserves from EHP.
GDE potential data from GDE Atlas, BOM.

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Date: 17.04.2014
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File Name: 7043_03_F07.09_GIS_GL

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Mapped GDEs potentially using the subsurface presence of groundwater

Figure No: 7.9

Ecosystems mapped as having a moderate potential for interaction with the surface expression or subsurface presence of groundwater are present within the Project area and are typically associated with watercourses or significant stands of vegetation. No field investigations have been carried out in areas mapped with a moderate potential for interaction with the subsurface presence of groundwater. The actual dependency of these vegetated areas on groundwater is unconfirmed. For the purposes of this impact assessment, conditions in these areas are assumed to have the potential to support interaction with subsurface groundwater.

7.6.1.4 *Groundwater Quality*

The EIS presented groundwater quality information sourced primarily from studies completed by Raymond and McNeil (2011) and Pearce and Hansen (2006). Since the release of the EIS, water quality data for the northern Bowen Basin has been collated and assessed in Ausenco-Norwest (2013a), and basin-wide water quality was assessed in Worley Parsons (2012). These additional data sources were reviewed to provide an updated assessment on water quality.

Groundwater within key aquifer units has been classified by its groundwater quality composition, based on major ion composition, total dissolved solids (TDS) and pH and are summarised in Table 7-2. The geological formations presented in the table represent key formations within the Project area. The dominant water quality composition categories presented in the Supplementary Groundwater Assessment (Appendix E) of the SREIS are generally consistent with those identified in the EIS.

The assessment of groundwater quality presented in the EIS, as well as that documented in Ausenco-Norwest (2013a) highlight that groundwater quality across the study area, within each aquifer assessed, is moderately to highly variable. There is no apparent correlation between salinity with respect to depth or location within the Bowen Basin within a geological formation or between formations (Ausenco-Norwest, 2013a). Likewise there appears to be no trend in spatial distribution of major ion data and major ion data cannot be used to definitively characterise an aquifer. The new available data supports the characterisation of groundwater quality presented in the EIS.

Arrow commissioned microseismic mapping (Pinnacle, 2013) to be conducted when hydraulic stimulation activities took place for the drilling of three vertical CSG wells into the Moranbah Coal Measures. The mapping measured the potential for fracture propagation as a result of hydraulic stimulation. One aspect of the mapping looked at the potential for fracture propagation to increase hydraulic conductivity between aquifers, which if shown to occur, could lead to cross-contamination of aquifers.

The mapping of hydraulic stimulation activities (Pinnacle, 2013), demonstrated that fractures in formations within the Bowen Basin, occur along the horizontal plane of the target formation with a maximum vertical extent of 32 m and that most fractures are contained within their target interval. The network of lateral fractures mapped due to hydraulic stimulation ranged from 29 m to 53 m, showing that vertical hydraulic conductivity in the overlying and underlying formations is not likely to be enhanced by hydraulic stimulation activities.

Table 7-2 Summary of Groundwater Chemistry by Aquifer

Groundwater System	Formation	Number of Samples	Dominant Groundwater Composition	Median TDS concentration (mg/L)	Mean TDS concentration (mg/L)	Median pH	Comments
Shallow groundwater system	Quaternary Alluvium	216[1]	Sodium-chloride and sodium bicarbonate	520	1782	7.7	Groundwater chemistry is within the range of concentrations presented in the EIS.
	Tertiary Basalt	132[1]	Sodium-chloride to sodium bicarbonate and magnesium bicarbonate	896	1663	8.1	
	Tertiary Sediments	28[1]	Sodium-chloride	1940	3280	8.0	
Intermediate groundwater system	Triassic Sediments	14[1]	Sodium-chloride	1931	2401	8.0	Limited information is presented in the EIS for comparison due to limited data available for these formations.
	Clematis Sandstone	266[2]	Sodium-bicarbonate to sodium-bicarbonate-chloride	387	383	7.9	
	Rewan Formation	63[2]	Sodium-chloride to sodium-chloride-bicarbonate	1490	3571	7.8	
Coal seam groundwater system	Blackwater Group	186[1]	Sodium-chloride to sodium bicarbonate	4256	5301	7.9	Groundwater chemistry consistent with that presented in the EIS.
	Blackwater Group interburden	160[2]	Sodium-bicarbonate and sodium-chloride	1767	3149	7.9	Groundwater chemistry for coal measure interburden units is not presented in the EIS.

Groundwater System	Formation	Number of Samples	Dominant Groundwater Composition	Median TDS concentration (mg/L)	Mean TDS concentration (mg/L)	Median pH	Comments
Deep groundwater system	Back Creek Group	81[1]	Sodium-bicarbonate to sodium-bicarbonate-chloride	1925	3191	7.9	Groundwater chemistry is consistent with that presented in the EIS.

Data Source: 1: Ausenco-Norwest (2013a)
2: Worley Parsons (2012)

7.6.1.5 *Sites of Indigenous Cultural and Spiritual Significance*

The Indigenous cultural and heritage study presented in the Indigenous Cultural Heritage Technical Report (Appendix W) of the EIS identified uncommon and culturally important places listed in the Queensland Indigenous cultural heritage register and database. Four of these sites are assigned a classification that includes the description as a 'well'. All four sites are located in the northern portion of the Project area (Figure 7-6). Based on the classification of these sites as 'wells', there is the potential for the Indigenous cultural and spiritual values at these sites to rely on the presence of groundwater.

Information on the status of each site i.e., whether intact or destroyed, and their characteristics, i.e. size and dimensions, are unavailable. The classifications assigned to these features in the database cannot be confirmed. Surface geology mapping available from NRM (2012a) has been combined with the information from the Queensland Indigenous cultural heritage register and database to identify the following characteristics at each site:

- Two sites are identified as 'stone artefact / well' sites and are located approximately 15 km southwest of Glenden. The surface geology at these locations is mapped as unconsolidated river sediments.
- A single site is identified as a 'contact place / well' and is located along the Isaac River approximately 28 km north of Moranbah. The surface geology at this location is mapped as unconsolidated river sediments.
- A single site is identified as a 'well' and is located approximately 32 km southeast of Glenden. The surface geology at this location is mapped as the Fair Hill Formation which correlates to the Fort Cooper Coal Measures.

7.6.1.6 *Subsidence*

The link between CSG extraction and the potential for surface subsidence has been an area of further study since finalisation of the EIS. A report prepared for the Australian Council of Environmental Deans and Directors in October 2012 (Williams, 2012), reflects the general understanding across the industry that subsidence within a landscape will occur to some degree following extraction of water from aquifers.

A report commissioned by DSEWPaC, and undertaken by Geosciences Australia in 2010 (Geosciences Australia and Habermehl, 2010), also notes that groundwater extraction may cause some aquifer compaction that is likely to result in a degree of subsidence. The structural integrity of aquifers however, in relation to their ability to transmit water, is unlikely to be significantly impacted by groundwater extraction associated with CSG production.

Additional information in relation to historical ground movement observed during groundwater extraction at the Moranbah Gas Project CSG field is provided below. The processes that influence subsidence and how they can be used to predict the degree of ground movement are also described.

Historical Ground Movement

A ground motion study of the Moranbah Gas Project (Altamira Information, 2013) was undertaken to determine the amount of settlement over the period from December 2006 to January 2011, during which CSG associated water was extracted by Arrow. The study determined that ground motion during the period was minimal. During the monitoring period approximately 3,300 ML of groundwater was extracted from the Moranbah Gas Project area petroleum leases.

The study found considerable variability across the Project area with both areas of uplift and subsidence identified. The uplift arises from seasonal factors (swelling of soils) and subsidence occurs from settling of manmade structures such as railway embankments. The results showed the bulk of the area monitored was subject to a rate of movement of less than 8 mm/year over the monitoring period which Altamira Information (2013) defined as “stable” (i.e. below the measurement threshold; see also Figure 7-10).

Isolated locations with greater rates of movement were identified. Some such areas showed localised upward movement of up to 60 mm/year, which was reportedly associated with changes in soil moisture and subsequent swelling of reactive clays following heavy rainfall after a prolonged period of drought.

Localised downward movement coincided with surface processes and activities such as erosion, compaction associated with road and rail infrastructure, and excavations associated with the construction of infrastructure. The degree of downward movement in these localised areas ranged between 60 mm/year to 130 mm/year, consistent with the performance of engineered earthen structures which experience initial high rates of settlement before stabilising.

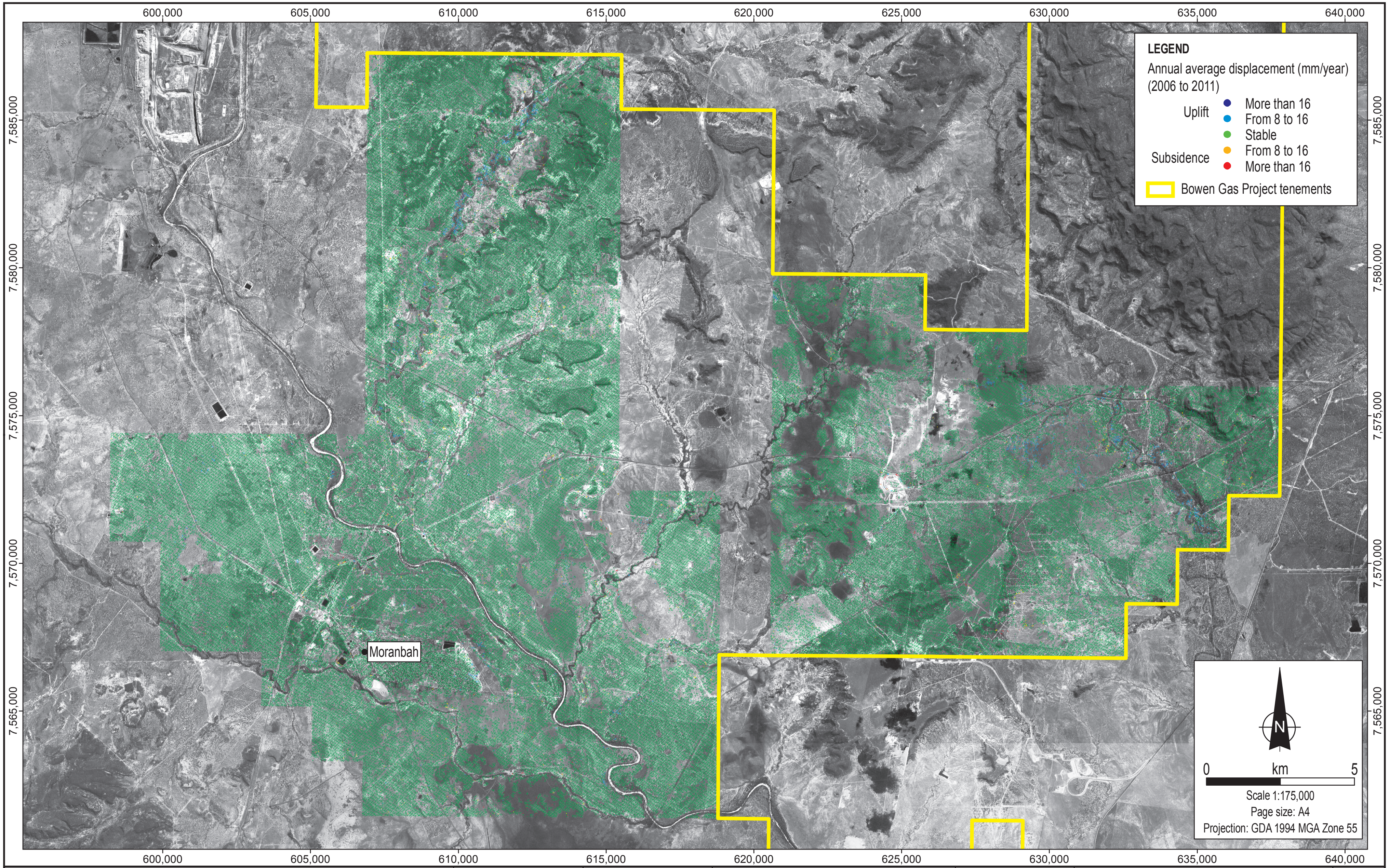
Coffey conducted a review of the Altamira (2013) ground motion study (Appendix B of Appendix E of the SREIS) to determine whether regional settlement had occurred for the monitoring period (2006 to 2011). The review found:

- Interpreted ground motion over most of the study area was determined to be less than 10 mm (uplift or subsidence).
- Isolated locations with a greater rate of movement were identified and found to be consistent with site surface features in most cases.
- Average downward vertical movement in the range 10 to 20 mm was identified in one area that approximately correlates with both CSG extraction and coal mining activities.

Estimated Future Ground Movement

Subsidence associated with CSG extraction can occur from the following two processes:

- Shrinkage of the coal seam due to gas extraction; and
- Compression of the coal seam and overlying formations due to reduced groundwater pressures.



Source:
Project development area from Arrow Energy.
Annual average displacement from Altamira Information (2013),
Vertical movement from Altamira (2013)
Imagery from SPOT.

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Ground movement results from the Altamira baseline study for the Moranbah Gas Project

Figure No: **7.10**

For the Moranbah Gas Project, the assessment calculated shrinkage in the coal measures from gas extraction to be in the order of 10 mm (with a range of 5 mm to 15 mm) and settlement due to reduced groundwater pressure to be in the order of 30 mm (with a range of 10 to 60 mm), resulting in overall settlement of 40 mm (with a range of 15 mm to 75 mm).

The calculated range of 15 mm to 75 mm was found to be:

- Greater than the rates of regional ground movement reported in the Coffey review of the ground motion study (Appendix B of Appendix E of the SREIS), which is likely to reflect the conservatism adopted in the calculation; and
- Less than localised rates of ground movement due to natural swelling in reactive clays reported in the ground motion study (Altamira, 2013).

The assessment of subsidence potential and observed effects show that the magnitude of potential subsidence resulting from CSG development in the Moranbah Gas Project area is substantially less than that arising from longwall coal mining, where subsidence is typically greater than 1 m. For example, the vertical subsidence predicted for an underground coal mine in central Queensland is anticipated to be 3.2 m (Hansen Bailey, 2013).

The subsidence interpreted from satellite interferometry indicates that the magnitude of the surface ground movement associated with CSG extraction in the Moranbah Gas Project is:

- Small;
- Within the lower range of calculations used to estimate subsidence; and
- Significantly less than expected for longwall coal mining.

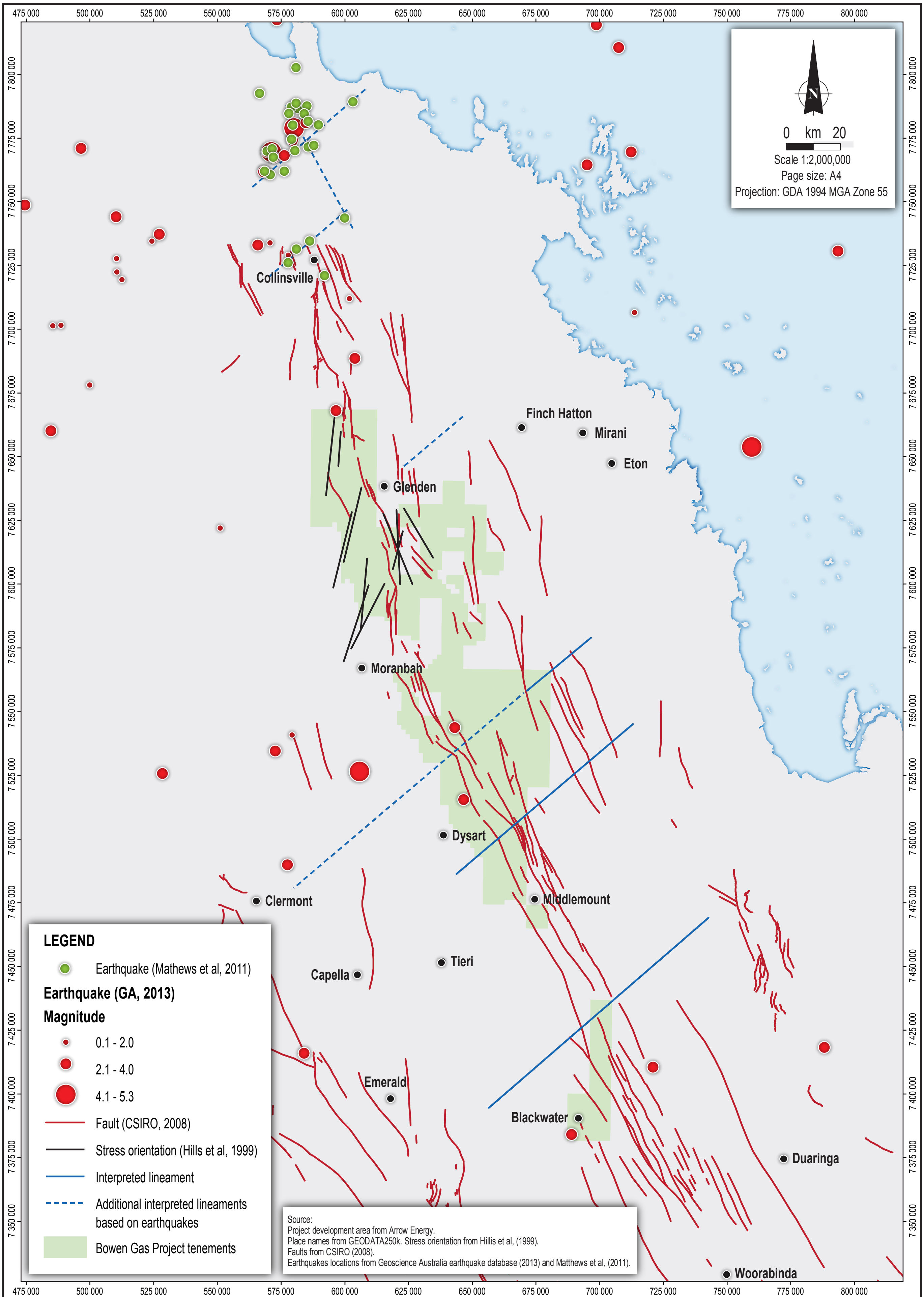
It is concluded that these outcomes will also apply to the Project because the Moranbah Gas Project area and the activities undertaken are considered to be a reasonable analogue of the Project area and the Project activities. In addition it is noted that any subsidence resulting from CSG development would be broadly distributed and that differential subsidence would not occur, further reducing the risks of surface impacts arising.

Additional details on the assessment of future subsidence rates are provided in Appendix E of the SREIS.

7.6.1.7 *Natural and Induced Seismicity*

Figure 7-11 shows the location and magnitude of earthquakes recorded by Geoscience Australia between 1950 and 2013 in the vicinity of the Project area. Figure 7-11 also shows the location of an earthquake, known as the Bowen earthquake, and associated aftershocks that occurred in April 2011 approximately 100 km north of the Project area (Mathews et al, 2011). The primary tremor associated with the Bowen earthquake registered a magnitude of 5.7 and was followed by aftershocks with magnitudes ranging from 3.2 to 4.1.

Despite the 2011 Bowen earthquake, the Bowen Basin is considered to be relatively aseismic (i.e. of low earthquake activity) with the exception of a few small events (Hillis et al, 1999). In addition, few structural features have been generated in the Bowen Basin during recent geological times, reflecting limited tectonic activity in the current setting (Clark et al, 2011).



coffey	Date: 17.04.2014 MXT: 7043_03_GIS035_v1_1 File Name: 7043_03_F07.11_GIS_HU	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Approximate location of registered earthquakes in the study area between 1950 and 2013	Figure No: 7.11

Subsurface activities such as underground mining or fluid injection into reservoirs can also induce low magnitude earthquakes. In relation to the Project, hydraulic stimulation may be required to increase the permeability of coal seams to optimise CSG recovery. Completion of a hydraulic stimulation event involves fluid injection into the target seam at depth.

How formations respond including the extent of the fracture propagation when hydraulically stimulated, can be used to understand the potential for this activity to result in induced seismicity. As discussed in Section 7.6.1.4, Arrow commissioned microseismic mapping (Pinnacle, 2013) in response to hydraulic stimulation activities conducted at three vertical CSG wells drilling into the Moranbah Coal Measures. The network of fractures produced by the hydraulic simulation event were constrained within the formation targeted by the hydraulic stimulation event, within the range of 29 m to 53 m of lateral penetration. A relationship between pumping rate and the vertical extent of the fractures was not identified, however, the complexity of fracture networks appeared to increase as the viscosity of the injected fluid decreased (i.e. the viscosity of injection fluid decreases as the volume of additives such as clay and silica gel is reduced).

The average magnitude of micoseismic events measured during the hydraulic stimulation events ranged from -3.07 to -3.91 moment magnitude (Mw) and were measured up to 253 m away from the central vertical bores. These are negative magnitude values that equate to events that can only be detected by sensitive recoding equipment and are not perceptible to the human senses at the surface.

7.6.2 Groundwater Modelling Update

The EIS groundwater model is a regional model used to predict groundwater drawdown in response to CSG extraction (Ausenco-Norwest, 2012). Findings of additional work related to numerical groundwater drawdown modelling conducted since the finalisation of the EIS are described below.

7.6.2.1 *Independent Peer Review*

An independent review of the EIS groundwater model was conducted by NTEC. The review referred to the Australian Groundwater Modelling Guidelines (Barnett et al, 2012). Arrow subsequently engaged CDM Smith in 2013 to prepare a report summarising the previous NTEC review stages (CDM Smith acquired NTEC in early 2013). A copy of the report is contained in the Supplementary Groundwater Assessment (Appendix E) of the SREIS.

The checklist provided in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012) was used to assess the suitability of the EIS groundwater model. The peer review was conducted progressively during development of the model and associated documentation, and deemed the model appropriate for estimating regional groundwater impacts created by the Project, and that it:

- Conforms to best industry practice;
- Is fit for purpose; and
- Fulfils the appropriate criteria of the Australian Groundwater Modelling Guidelines.

7.6.2.2 *Uncertainty Analysis*

Additional modelling was undertaken by Ausenco-Norwest to assess the level of uncertainty associated with the model parameters adopted for the EIS groundwater model (Ausenco-Norwest, 2013b). The findings are contained in Appendix E of the Supplementary Groundwater Assessment (presented in Appendix E of the SREIS).

A null space Monte Carlo method (a probabilistic uncertainty analysis method) was used to assess the level of uncertainty. The *uncertainty analysis* technique was described by QWC (2012) as requiring *"specialised skills, significant computer capacity and time. The technique involves using multiple sets of parameters, all of which are physically realistic and all of which calibrate the model, to make a large number of predictions. These are then statistically analysed to provide a measure of uncertainty in model."*

The assessment derived an 'envelope' of potential groundwater drawdown magnitudes and extents based on the range of parameters adopted for the model.

Results from the uncertainty analysis show that groundwater drawdown predicted by the base case scenario (scenario 1) in the EIS groundwater model, in terms of degree and extent, is conservative, in that the parameters used in the model result in drawdowns close to the 'worst case' predicted drawdown in the uncertainty analysis.

With regard to the adequacy of the aquifer parameters modelled, it is therefore concluded that the parameters modelled predict a plausible, conservative assessment of groundwater drawdown arising from the Project production supported by review of published information and field test results (see Section 7.6.1.2), and also in light of the uncertainty analysis findings.

7.6.2.3 *Simulation of Faults*

Assumptions associated with the presentation of faults in the EIS groundwater model, and subsequent modelling undertaken by Arrow to refine these assumptions are discussed below.

EIS Groundwater Model

In the EIS groundwater model, simulations were conducted both without fault representation, and with faults that were represented as barriers to groundwater flow. This fault/barrier conceptualisation is consistent with low permeability faults, with restricted connection across or between faulted aquifers, under a compressive stress regime. There were 14 major faults incorporated into the EIS groundwater model and these structural features were represented as horizontal flow barriers (HFB) using the MODFLOW HFB modelling package. The HFBs were assigned a thickness of 1 m and a hydraulic conductivity of 1×10^{-9} m/day.

The model outputs generated by the scenario incorporating HFBs were compared with the outputs generated by the scenario excluding HFBs to demonstrate little variation in the predicted drawdown between the two conceptualisations.

TMR Groundwater Model

Major faulting within the model domain simulated in the EIS groundwater model via the Modflow HFB package, was consistent with the adopted conceptualisation of faults presenting barriers to horizontal flow. For completeness, a separate study has been undertaken to consider a scenario where faults or other conduits such as weathered dykes behave as pathways to groundwater flow. If these features were sufficiently permeable, it might be assumed that they could influence the movement of groundwater in response to CSG production.

These additional model simulations, conducted since the submission of the EIS, have been undertaken to determine the model sensitivity to permeable faults using TMR to create a more refined model within the subregion of the EIS groundwater model. The aim of the study was to test two hypotheses:

- Hypothesis 1: closed faults or conduits act as barriers to groundwater flow along and across faults near a CSG well.
- Hypothesis 2: CSG production from a well in proximity to an open fault or conduit will increase flow along the fault plane or conduit towards the pumping zone, resulting in aquifer connectivity.

The TMR groundwater model is a subset of the EIS groundwater model, with grid cells refined from 1.5 km grid cells in the regional groundwater model, to 100 m grid cells in order to better represent the faults. Hydraulic conductivity zones were also varied to account for increased permeability. The outcomes of this study provided a theoretical scenario to enable an assessment of the significance of flow along permeable features in the model.

TMR Fault Modelling Conclusions

The results of the study were found to be in support of Hypothesis 1 – that faults or conduits will act as barriers to groundwater flow along and across faults near a CSG production well. This was supported by the following key findings:

- Drawdown impacts are constrained to the target aquifer and do not propagate into the overlying or underlying aquifers;
- Flow direction on each side of the closed fault suggests compartmentalisation of the groundwater, due to the fault acting as a barrier to groundwater flow; and
- Groundwater flux for the modelled fault is low, ranging from ~0.01 m^3/day to 0.015 m^3/day, in comparison to modelled well production rates of 57 m^3/day.

An assessment of the opposite scenario where faults or other conduits behave as pathways to groundwater flow showed that drawdown and flow direction on each side of the fault indicated that the fault can act as a preferential vertical pathway for flow, however groundwater flux for the fault remains low, ranging from 0.05 m^3/day to 0.09 m^3/day.

While this result partially supports Hypothesis 2, the study showed that the fault can only play a minor role in the migration of drawdown impacts, which remain low as demonstrated by the small change in total flux along the fault zone between a production case and no-production case of only 0.003 m^3/day.

Based on the findings, the study concluded that:

- Faults in the Bowen Basin behave as barriers to groundwater flow along and across fault planes near CSG wells; and
- In the event that a fault zone or weathered dyke represents an existing preferential pathway for flow, the fault or dyke will only play a minor role in propagation of drawdown impacts across formations.

7.6.3 Submission Responses

Submissions on the EIS raised a range of issues relating to groundwater. The issues fall in to broad topics which are listed below.

- Aquifer connectivity, specifically in areas where the Rewan Formation is absent;
- Potential for hydraulic stimulation activities to induce seismic events;
- Chemicals and additives used in hydraulic stimulation activities.
- Potential for fractures created by hydraulic stimulation activities to connect aquifers;
- Arrow's obligations under the P&G Act and the Water Act;
- Interactions between surface water and groundwater;
- Springs and groundwater-dependent ecosystems;
- Groundwater monitoring requirements;
- Implementation and enforcement of make good measures;
- Management of cumulative impacts;
- Management of groundwater drawdown impacts;
- Potential for CSG extraction to cause subsidence;
- Protection of groundwater quality for a variety of uses;
- Relationship between Arrow and the OGIA; and
- Uncertainty associated with the groundwater model.

The topics list is provided to give an idea of the types of issues that have been raised in relation to groundwater and for which responses have been provided under the heading 'Groundwater' in Submission Responses chapter (Section 21), EHP Submission Responses chapter (Section 22) and DSEWPaC Submission Responses chapter (Section 23).

7.7 Review and Update of the EIS Impact Assessment

The updates made to the EIS impact assessment are detailed below and are based on the updates to the description of the existing environment and the results of the model review and TMR groundwater model simulations.

7.7.1 Confirmation of Environmental Values

The EIS presented a comprehensive assessment of groundwater environmental values, and was based on the framework defined in the EPP (Water). Based on a refined understanding of the existing environment, the groundwater environmental values have been revisited to ensure alignment with new information available and to facilitate review of the impact assessment.

The outcome of the review of the environmental values associated with the groundwater systems was mainly limited to a refinement of the characterisation of the deep groundwater system (see Section 7.5.3.1) and is summarised below in terms of the four groundwater systems identified; shallow, intermediate, coal seam and deep. Subsequent to the summary, Table 7-5 presents the findings in terms of the biological values, consumptive and productive uses and the cultural and spiritual values.

7.7.1.1 *Shallow Groundwater System*

This groundwater system contains a number of discontinuous unconfined (water table) aquifers dominated by Quaternary sediments and Tertiary basalts within the Project area. Quaternary sediments are predominately associated with watercourses throughout the Project area and also include sediments deposited in floodplains adjacent to watercourses. The Tertiary basalts within the shallow groundwater system have a limited extent within the Project area, and are commonly weathered and fractured with clayey horizons. In addition, Tertiary sediments including the Suttor Formation and Duaringa Formation may act as local aquifers where gravelly or sandy lenses are present. These areas will be of limited extent.

Indigenous cultural and spiritual values were identified on review of the information provided in the Non-Indigenous Cultural Heritage Technical Report (Appendix X) of the EIS. Three of the four sites listed as being wells of Indigenous cultural significance identified in the Project area are assumed to be associated with the shallow groundwater system based on outcrop geology mapping.

With the understanding that the intrinsic characteristics of the Quaternary sediments, the Tertiary basalts and Tertiary sediments differ, the system was allocated an overall moderate sensitivity ranking based on the following key features:

- **Quaternary Sediments.** Comprises Quaternary floodplain alluvium and sediments and Quaternary river alluvium. These units have variable water quality with typically moderately saline groundwater suitable for stock water, mining and industrial purposes. In some areas fresher quality (lower salinity) lenses of groundwater exist and a wide range of beneficial uses may apply. However in the Project areas these fresher lenses are considered to be limited in extent and not continuous. The EIS identified the potential for Quaternary sediments (primarily Quaternary river alluvium) to interact with surface water features in some areas, providing support to ecological communities. Where the Quaternary sediments are connected to surface water features, they can receive local recharge via steam flow, with increased rates of recharge during flood events. Where the Quaternary sediments are separated from the target coal seams in the Blackwater Group by the Rewan Formation, the system can be resilient to change resulting from coal seam depressurisation.
- **Tertiary Basalts**. Tertiary basalts have variable groundwater quality with low yields and few licensed users. Recharge of these units is limited by the clay-rich weathered horizons which impact on the storage capacity of the aquifer and its permeability. Where the Tertiary basalts are separated from the target coal seams in the Blackwater Group by the Rewan Formation, the system can be resilient to change resulting from coal seam depressurisation.
- **Tertiary Sediments**. Tertiary sediments have variable water quality with typically low yield. Much of the Tertiary sequence is concealed by overlying Quaternary alluvium and colluvium.

7.7.1.2 *Intermediate Groundwater System*

The intermediate groundwater system comprises the Clematis Sandstone and Rewan Formation. Across the study area these formations are both confined aquifers and unconfined where they outcrop. In the study area the Clematis Sandstone is poorly characterised. Groundwater quality is variable, however good quality groundwater is known to exist within the formation. Few licensed users access the aquifer for productive or consumptive uses due to the limited extent within the Project area, however the aquifer is characterised by moderate to good permeability and porosity.

The Clematis Sandstone is sensitive to change based on limited recharge mechanisms and moderate recovery rate following disturbance. This groundwater system was assigned an overall moderate sensitivity ranking.

The Rewan Formation is classified as a regional aquitard, however where it is weathered or fractured at outcrop it has the potential to contain productive groundwater.

7.7.1.3 *Deep Groundwater Systems*

In the EIS, the target coal seams of the Blackwater Group and the underlying aquifers of the Back Creek Group were combined into the deep (coal seam) groundwater system.

To separate direct impacts on the target coal seams (the Blackwater Group) from indirect impacts to the underlying aquifers, the Back Creek Group has been separated into a discrete ‘deep groundwater system’ for the purpose of the supplementary groundwater assessment.

Coal Seam Groundwater System

The Blackwater Group contains the coal seams within the confined aquifers targeted for gas production as part of the Project, the Rangal Coal Measures and the Moranbah Coal Measures. The Fort Cooper Coal Measures are also part of the Blackwater Group. The coal seams within this sub-unit are not currently targeted for gas production as part of the Project. In limited areas, the formations outcrop and form the water table aquifer.

The system was allocated an overall low sensitivity ranking based on the key features described as follows:

- The coal seams within the Blackwater Group contains variable groundwater quality. In general, the groundwater is unsuitable for productive or consumptive uses due to high salinity values, but may have potential to support small-scale primary industry uses;
- Recharge rates are slow due to the separation of the coal seams from outcropping recharge beds and the regional groundwater flow rates;
- The coal seams are widespread and common throughout the Project area; and
- One groundwater-dependent site identified for its cultural and spiritual value, is assumed to be associated with the outcrop geology which correlates to the Fair Hill Formation / Fort Cooper Coal Measures. Therefore anthropomorphic values of the coal seam groundwater system are considered to be present in isolated areas.

Deep Groundwater System

The deep groundwater system includes the Back Creek Group, which underlies the Blackwater Group and acts as the hydraulic basement below the coal seam groundwater system. The system was allocated an overall low sensitivity ranking based on the key features described below:

- The groundwater quality within these deep, confined aquifers is generally poor, with limited consumptive or productive uses as indicated by low numbers of registered bores accessing this formation within the Project area; and
- The Back Creek Group outcrop along the east and extensively along the west margins of the study area and there is the potential for interaction with groundwater-dependent ecosystems where the water table is sufficiently shallow. Some potential for groundwater-dependent ecosystems also exist in the vicinity of Homevale National Park and Conservation Park.

As indicated, the revised environmental values carried forward through the supplementary groundwater assessment are summarised in Table 7-3 below.

Table 7-3 Summary of Groundwater Environmental Values

Groundwater System	Geological Formation(s)	Revisions and Updates		
		Biological Value	Consumptive and Productive Use Values	Cultural and Spiritual Values
Shallow groundwater system. Unconfined (water table) aquifers.	Quaternary alluvium (river and floodplain) and Tertiary basalts and Tertiary sediments	Quaternary alluvial aquifers are known to support slightly to moderately disturbed wetlands and riparian vegetation within the Project area. Tertiary basalts outcrop in the Homevale National Park, an area of pristine biological integrity located in the northeast of the Project area. Tertiary sediments support some recharge springs to the south of Blackwater, which have high ecological importance. Groundwater from Quaternary alluvial aquifers may support Lake Elphinstone, the largest natural freshwater body in central Queensland and a drought refuge and likely breeding site for a range of fauna. The lakebed consists of unconsolidated Quaternary alluvial sediments (Environment Australia, 2001).	Groundwater salinity varies within this groundwater system. Lenses of fresher groundwater (low salinity) exist where sand and gravel dominate the alluvium. Where these areas of fresher water exist a wide range of productive and consumptive uses is possible, however the areas are limited in spatial extent. More common across the Project area is moderately saline groundwater that is suitable for agricultural use e.g., stock watering. Yield is also variable and typically highest in the alluvium and basalt.	The review of additional information identified four sites of Indigenous cultural and spiritual significance within the Project area that are potentiality reliant on groundwater. Three of these sites are assumed to be associated with the shallow groundwater system based on the mapped geology outcropping at those locations (Quaternary alluvial sediments). In the absence of additional information, the local surface geology present at these sites is interpreted to be the source of any groundwater supply to these features.
Intermediate groundwater system. Confined to unconfined	Clematis Sandstone and Rewan Formation.	Recharge springs present to the south of ATP1025 are associated with outcropping Clematis Sandstone and Rewan Formation. The springs source water from local flow systems, disconnected from the underlying target coal seams, however	Where groundwater quality information is available for the Clematis Sandstone, it indicates the potential for consumptive and productive uses. While the Rewan Formation generally acts	Unlikely to be present within the Project area.

Groundwater System	Geological Formation(s)	Revisions and Updates		
		Biological Value	Consumptive and Productive Use Values	Cultural and Spiritual Values
aquifers located above the target coal seams.		have high ecological importance. In the north of the Project area the aquifers of the intermediate groundwater system (where present) are generally considered to be moderately disturbed. Where present in the south they are generally considered to be near pristine or slightly disturbed due to conservation as a national park. Groundwater from the Rewan Formation may support Lake Elphinstone. While the lakebed itself consists of Quaternary alluvial sediments of the shallow groundwater system, the lake rests on an area of outcropping Rewan Formation. Lake Elphinstone is an area of high ecological value.	as a regional aquitard in the Project area, water quality information indicates the potential for consumptive and productive uses in some areas.	
Coal seam groundwater system. Confined aquifers within the target coal seams.	Blackwater Group: • Rangal Coal Measures • Fort Cooper Coal Measures • Moranbah Coal Measures	The coal seam groundwater system has limited biological value as it is not associated with pristine stands of vegetation. There is the potential for some interaction between this groundwater system and groundwater-dependent ecosystems where the formations outcrop and form the water table aquifer. Also, some pockets of fresher groundwater may occur in the	Limited yields of poor quality groundwater result in limited potential for productive and consumptive uses. There is the potential for small scale primary industry use in some areas.	The review of additional information identified four sites of Indigenous cultural and spiritual significance within the Project area that are potentiality reliant on groundwater. One of these sites is assumed to be associated with the coal seam groundwater system based on the mapped geology outcropping at that location (the Fair Hill Formation, which correlates to the

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Groundwater System	Geological Formation(s)	Revisions and Updates		
		Biological Value	Consumptive and Productive Use Values	Cultural and Spiritual Values
		outcrop or shallow subcrop areas where direct rainfall recharge occurs.		Fort Cooper Coal Measures). In the absence of additional information, the local surface geology present at this site is interpreted to be the source of any groundwater supply to this feature.
Deep groundwater system. Confined aquifers underlying the target coal seams.	Back Creek Group	The Back Creek Group outcrop extensively in the west of the study area and there is the potential for interaction with GDEs where the water table is sufficiently shallow. In some areas the Back Creek Group outcrop in national and conservation parks and GDEs in these areas will have high ecological importance, however this is limited in extent.	Limited yields of typically poorer quality groundwater result in limited potential for productive and consumptive uses. Some areas of lower salinity may provide for small scale primary industry use.	Unlikely to be present within the Project area.

7.7.2 Overall Sensitivity Rankings

The overall sensitivity rankings assigned to the shallow and intermediate groundwater systems remain unchanged from those presented in the EIS. While individual scores assigned to the components that make up the overall sensitivity score were reviewed and in some cases revised, the new overall score did not result in a material change to the ranking.

The overall sensitivity of the coal seam groundwater system has increased from low to moderate based primarily on the potential for the system to support a site of Indigenous cultural and spiritual importance and the limited recharge potential. The coal seam groundwater system may also support small scale industrial uses in some areas.

The newly defined deep groundwater system has a low overall sensitivity due to poor groundwater quality and limited potential for the system to support consumptive or productive uses or areas of biological importance.

Details on the sensitivity ranking system applied to the groundwater systems are set out in the supplementary groundwater assessment (Appendix E).

7.7.3 Potential Impacts and Pre-mitigation Magnitude Rankings

All potential impacts identified in the groundwater impact assessment prepared for the EIS remain relevant to the supplementary assessment. Some additional potential impacts were identified, and as such, all potential impacts were reviewed to account for:

- Additional information that updates the understanding of the existing environment and definition of environmental values and associated sensitivity rankings.
- Separation of the Back Creek Group into its own groundwater system (the deep groundwater system), with an individual set of environmental values and overall sensitivity ranking.
- Changes to the project description, specifically Arrow's revised indicative development sequence and groundwater extraction profile that could result in a varied impact profile by way of location (spatial extent) or timeframe, and the potential requirement for new mitigation measures to be implemented to manage these impacts.
- Findings of the model reviews and additional outputs.

Potential impacts were grouped in the EIS, and for consistency the same grouping is applied to the supplementary assessment, as follows:

- Direct impacts on the coal seam groundwater system caused by coal seam depressurisation (Table 7-4).
- Indirect impacts on the shallow, intermediate and deep groundwater systems caused by coal seam depressurisation (Table 7-5).
- Impacts caused by field and infrastructure development, operation and decommissioning (Table 7-6). The activities identified in this table have the potential to impact on different groundwater systems based on an understanding of what systems could be intersected:

  - Activities related to the installation of production wells have the potential to impact on the shallow, intermediate and coal seam groundwater systems. The deep groundwater system is unlikely to be intersected by production wells.
  - Activities related to the installation of monitoring bores have the potential to impact on all groundwater systems. Monitoring bores may be installed into all aquifer units within the Project area.
  - Hydraulic stimulation activities have the potential to impact on all groundwater systems.
  - Activities associated with installation and operation of gathering lines and other supporting sub-surface infrastructure have the potential to impact on all groundwater systems. All groundwater systems outcrop in the Project area, or are located close to the surface in places.
  - Activities associated with installation and operation of surface infrastructure have the potential to impact on all groundwater systems. All groundwater systems outcrop in the Project area, or are located close to the surface in places.
  - Disturbance footprints associated with surface infrastructure have the potential to impact on all groundwater systems. All groundwater systems outcrop in the Project area, or are located close to the surface in places.

- Impacts caused by surface management and storage of CSG water (Table 7-7). These activities have the potential to impact on all groundwater systems. All groundwater systems outcrop in the Project area, or are located close to the surface in places.
- Cumulative impacts caused by this and other projects requiring the dewatering (mining activities) and depressurisation of the target coal seams are presented in Section 7.8.

The potential impacts and pre-mitigation magnitude rankings are presented in Table 7-4 to Table 7-7 below.

Table 7-4 Direct Impacts Caused by Coal Seam Depressurisation

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
Groundwater drawdown resulting in reduced supply to existing or future groundwater users.	Coal seam groundwater system	This potential impact was identified in the EIS.	High	The high pre-mitigation magnitude ranking reflects the severity, extent and duration of the drawdown impacts in the Blackwater Group, as indicated by the EIS groundwater model outputs: • Drawdown greater than 5 m is predicted in the coal seam groundwater system over extensive parts of the Project area at the end of CSG production. • In some areas drawdown greater than 5 m extends beyond the Project area. • Limited recovery is observed in the 50 years after the cessation of CSG production.
Groundwater drawdown resulting in reduced supply to groundwater-dependent ecosystems supported by the target coal measures		This is a new potential impact based on additional information on groundwater-dependent ecosystems.	Moderate	A moderate magnitude ranking has been determined based on the following additional information presented in the SREIS: • A single spring vent (site name North Escarp) is located within the 10 km buffer beyond the 0.2 m drawdown contour for the Leichhardt seam, however, this is a recharge spring with the source aquifer considered to be associated with the shallow groundwater system. No drawdown impact is predicted at this location in the aquifers overlying the Leichhardt seam therefore this spring is not considered to be directly impacted by depressurisation of the coal seam groundwater system. • The coal measures outcrop within the extent of 0.2 m predicted drawdown and the 10 km buffer zone. In some limited areas this coincides with mapped potential groundwater-dependent ecosystems. In these areas the coal measures form the water table aquifer and may support groundwater-dependent ecosystems where groundwater is sufficiently shallow. • Based on available water level information groundwater in the coal measures, where they outcrop, water level is typically greater than 10 m below ground

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
				surface, which is generally considered to be beyond the rooting depth of vegetation. There may however be some isolated areas, in particular where surface drainage channels coincide with outcropping coal measures, that groundwater may support ecosystems reliant on the subsurface presence or surface expression of groundwater. The coal measures are not expected to support large areas of GDEs due to typically poor quality groundwater and limited yield. • The extent of potential impact from groundwater drawdown extends beyond the Project area, and limited or no recovery is observed in the 50 year period after cessation of CSG production.
Groundwater drawdown resulting in reduced supply to groundwater-dependent Indigenous sites of cultural and spiritual importance supported by the target coal measures		This is a new potential impact based on additional information on sites of Indigenous cultural and spiritual importance.	Moderate	A moderate magnitude ranking has been determined based on the following additional information presented in the SREIS: • A site of cultural significance associated with the Fort Cooper Coal Measures is located within the 10 km buffer zone of the 0.2 m drawdown contour for that formation (Groundwater model Layers 8, 9 and 10 in the EIS groundwater model). • The site is located beyond the mapped extent of the Rewan Formation (based on both CSIRO (2008) and Sliwa (2011) mapping). • Potential drawdown impacts remain 50 years after the cessation of CSG production.

Table 7-5 Indirect Impacts Caused by Coal Seam Depressurisation

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
Inter-aquifer flows between adjacent aquifers above and below the target coal seams causing groundwater quality impacts.	Shallow groundwater system	This potential impact was identified in the EIS.	Very Low	A very low pre-mitigation magnitude ranking is determined. Depressurisation of the target coal seams will induce groundwater flow from aquifers above the target formations and increase flux into the coal measures from underlying aquifers. This will reduce the potential for contamination of overlying or underlying aquifers from the coal measures which contain typically poorer quality water than surrounding aquifers. Therefore impact magnitude will be very low as any inter-aquifer flows caused by depressurisation of the coal measures will not involve flow of poor quality water into higher quality aquifers.
	Intermediate groundwater system		Very Low	
	Deep groundwater system		Very Low	
Groundwater drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined and reflects potential impaired capacity of existing and future groundwater users. The duration and extent of impact is minor, however the impact exceeds the bore trigger threshold for some existing registered groundwater bores in the north of the Project area. The EIS groundwater model predicts greater than 2 m of drawdown in isolated areas for the shallow groundwater system, including two isolated instances outside of the Project area. This drawdown coincides with some areas of alluvial outcrop and represents areas of potential impairment for existing and future groundwater users. The alluvial aquifer system is dynamic with several recharge mechanisms. Due to the close connection between surface recharge processes and the shallow groundwater system it is expected that the groundwater system will recover over time when groundwater extraction associated with CSG production ceases.

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
	Intermediate groundwater system		Very Low	A very low pre-mitigation magnitude ranking is determined. Modelling predicts greater than 5 m drawdown in isolated areas in aquifers associated with the intermediate groundwater system, however no registered groundwater bores screening the intermediate groundwater system are predicted to be impacted. Modelling predicts that 50 years after the cessation of gas production the extent of drawdown in the intermediate groundwater system will have increased in comparison to the drawdown extent at the cessation of gas production. While this indicates continued propagation of depressurisation impacts from the coal seam groundwater system into the overlying intermediate groundwater system, the areas of drawdown in excess of 5 m remains in isolated areas, and no existing users are predicted to be impacted in excess of the bore trigger threshold.
	Deep groundwater system		Very Low	A very low magnitude ranking has been determined. No drawdown greater than 5 m is predicted in the deep groundwater system as a result of the depressurisation of the Rangal and Moranbah Coal Measures.
Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent ecosystems.	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined due to the availability of new information on the distribution of springs and groundwater-dependent ecosystems within the Project area, and within a further 50 km buffer zone of the Project area that identified: • Two springs (site names North Escarp and Middle) located within the 50 km buffer zone (south of ATP1025 near Blackwater) are interpreted to be supported by groundwater from the shallow groundwater system. Modelling predicts that these springs are located beyond the 10 km buffer zone of the 0.2 m drawdown for aquifers in the shallow groundwater system. The springs are located in an area where the Rewan Formation is present at depth. The Rewan Formation is considered to be a regional aquitard and will act to limit

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
				the potential for the effects of coal seam depressurisation to propagate to the spring source aquifer. • Lake Elphinstone is a nationally important wetland potentially supported by groundwater from the shallow groundwater system (and directly underlain by the Rewan Formation associated with the intermediate groundwater system). Lake Elphinstone is situated immediately outside the Project area, within the 10 km buffer zone of the 0.2 m drawdown contour for Layer 3 of the EIS groundwater model (the layer used to represent potential drawdown in shallow aquifers). Modelling predicts some reduction in drawdown 50 years after the cessation of gas production. • The Bowen River: Birralee – Pelican Creek reach is a nationally important wetland associated within the shallow groundwater system. It is located approximately 44 km north of the Project area and is not predicted to be impacted by any groundwater drawdown associated with Project activities. • Groundwater-dependent ecosystems potentially reliant on the surface expression and subsurface presence of groundwater are mapped as being present throughout the study area, including areas of predicted drawdown in the shallow groundwater system. • The shallow groundwater system forms the water table aquifer across most of the study area and may support groundwater-dependent ecosystems in some areas. The extent of where this may occur is considered to be restricted to watercourse and drainage lines where the water table is sufficiently shallow. Available water level information indicates that the depth to groundwater is typically beyond the rooting depth of plants, however along the mid-reaches of the Isaac River there may be some potential for groundwater interaction. The Groundwater and Geology Technical Report (Appendix L) of the EIS indicates that the main channels of the Isaac and Mackenzie Rivers are incised around 3

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
				to 5 m below the floodplain. Tributaries to the Mackenzie, Suttor and Bowen Rivers also have channels incised 3 to 5 m into the floodplain. This reduces the potential for the surface expression of groundwater to occur because the depth to groundwater is typically greater than 10 m below ground level. • Further south there are fewer mapped potential groundwater-dependent ecosystems, and depth to groundwater remains in the order of 10 to 20 m below ground level, which is typically beyond the rooting depth of plants (<10 m).
	Intermediate groundwater system		Moderate	A moderate pre-mitigation magnitude ranking is determined due to the availability of new information on the distribution of springs and groundwater-dependent ecosystems within the Project area, and within a further 50 km buffer zone of the Project area that identified: • A total of 17 springs located within the 50 km buffer area (south of ATP1025 near Blackwater) are assumed to rely on groundwater from the intermediate groundwater system. The springs are recharge springs, fed by local groundwater flow systems, disconnected from the underlying groundwater system of the target coal seams. Modelling predicts that the springs are located beyond the 10 km buffer zone of the 0.2 m drawdown for aquifers in the intermediate groundwater system. All springs are located in an area where the Rewan Formation is present or outcrops. The Rewan Formation is considered to be a regional aquitard and will act to limit the potential for effects of coal seam depressurisation to propagate to the spring source aquifer. • Lake Elphinstone is a nationally important wetland potentially supported by groundwater from the intermediate groundwater system (both shallow and intermediate groundwater systems potentially support the Lake). Lake Elphinstone is situated immediately outside the Project area, within the 10 km

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
				buffer zone of the 0.2 m drawdown contour for Layer 4 of the EIS groundwater model (the layer used to represent potential drawdown in intermediate aquifers). Modelling predicts some reduction in drawdown 50 years after the cessation of gas production. • Groundwater-dependent ecosystems potentially reliant on the surface expression and subsurface presence of groundwater are mapped as being present throughout the study area, including areas of predicted drawdown in the intermediate groundwater system. • There is limited groundwater level information available to inform a determination of the potential for this system to support ecosystems potentially reliant on the surface expression or subsurface presence of groundwater. In the absence of this information it is assumed that the intermediate groundwater system could support groundwater-dependent ecosystems in areas where aquifers in this groundwater system outcrop, and mapped potential groundwater-dependent ecosystems coincide. In the north of the study area mapped potential groundwater-dependent ecosystems coincide with areas of intermediate groundwater system outcrop, primarily along watercourses. Some of these areas fall within the 0.2 m drawdown contour or the 10 km buffer zone. In the south of the study area, where there is drawdown impact predicted in the intermediate groundwater system either the intermediate groundwater system does not outcrop, or there are no mapped potential GDEs.
	Deep groundwater system		Very low	A very low magnitude ranking has been determined based on the following additional information presented in the SREIS: • No springs or surface water features are identified as relying on groundwater from the deep groundwater system. • Groundwater-dependent ecosystems potentially reliant on the surface

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
				expression and subsurface presence of groundwater are mapped as being present throughout the study area. • The deep groundwater system outcrops in isolated areas where it may represent the water table aquifer, however, where this occurs the groundwater is expected to be too deep to support groundwater-dependent ecosystems.
Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent sites of Indigenous cultural and spiritual importance	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined based on the following additional information presented in the SREIS: • Three sites of cultural significance are potentially associated with the shallow groundwater system. One of these sites is located within the 10 km buffer zone of the 0.2 m drawdown contour for the shallow groundwater system aquifers. The site is located beyond the mapped extent of the Rewan Formation (based on both CSIRO (2008) and Sliwa (2011) mapping). • Impact severity reduces 50 years after the cessation of gas production however the site is still within the 10 km drawdown buffer zone.
	Intermediate groundwater system		Very low	A very low pre-mitigation magnitude ranking is determined due to the absence of known culturally significant sites associated with this groundwater system.
	Deep groundwater system		Very low	A very low pre-mitigation magnitude ranking is determined due to the absence of known culturally significant sites associated with this groundwater system.
Groundwater drawdown in adjacent aquifers due to leakage	Shallow groundwater system	This potential impact was identified in the EIS.	Low	The magnitude rankings are determined to be low and consider information on groundwater quality and inter-aquifer flows: • Potential inter-aquifer flows that would be caused by the failure rate of a small percentage of wells is not considered to be hydrologically significant compared
	Intermediate		Low	

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
through CSG wells (well failure) causing groundwater quality impacts from inter-aquifer flows.	groundwater system			to inter-aquifer flows through confining layers over large regional areas. • Inter-aquifer flows that occur locally due to failed wells are expected to decline rapidly, as pressure equilibrium is approached between the formations in the vicinity of the wells. • In the longer term as aquifer pressures recover after the cessation of CSG water extraction, modelling shows that pressure differences observed between to formations reduce, further limiting the potential for adverse impact.
	Deep groundwater system		Low	
Inter-aquifer flows between adjacent aquifers above and below the Blackwater Group causing subsidence and loss of aquifer structural integrity.	Shallow groundwater system	Additional information is available on baseline conditions and the mechanisms for CSG extraction to result in subsidence.	Very low	The magnitude of impact to the structural integrity of depressurised formations which might occur due to the physical effects of subsidence is considered to be very low. The loss of an aquifer's structural integrity would require significant levels of subsidence to occur on a localised scale, at differing rates. Results of the baseline ground movement study (Altamira Information, 2013) show that conditions have remained stable in the area of CSG production from the Moranbah Gas Project. As subsidence is not expected to be significant and is expected to be widespread, differential movement is not expected. It is noted that subsidence at ground surface has the potential to impact on surface water values (primarily hydrology). These impacts are discussed in the Hydrology and Geomorphology sections (Section 9 and Appendix G respectively) of the SREIS.
	Intermediate groundwater system		Very low	
	Deep groundwater system		Very low	

Table 7-6 Impacts Caused by Field and Infrastructure Development, Operation and Decommissioning

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
Production Well Installation				
Production well installation and potential aquifer cross-contamination.	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined based on the following: • Potential impacts would be contained within the Project area or localised around each production well. • Impact severity is minor when considering regional hydrogeological inter-aquifer flows. • Impact duration would be limited to the period of well drilling and installation. If a well is incorrectly installed and allows on-going cross-contamination, impact duration will be for the life of the production well, ceasing when the well is decommissioned.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
Production well installation and potential aquifer contamination by the sub-surface drilling process.	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined based on the following: • Potential impacts would be contained within the Project area or localised around each production well. • Impact severity would be minor when considering regional hydrogeological processes and the materials used by Arrow during drilling of production wells (water and salt-based drilling muds). • Impact duration would be limited to the period of well drilling and installation.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
Production well installation and potential aquifer	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined based on the following: • Potential impacts would be contained within the Project area or localised

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
contamination by the surface drilling process (e.g. drilling fluid storage and the operation of the drilling rig and ancillary equipment).	Intermediate groundwater system		Low	around each production well. • Impact severity would be minor due to the materials used by Arrow during installation of production wells (water and salt-based drilling muds) and implementation of standard procedures to reduce the potential for impact. • Impact duration would be limited to the period of well drilling and installation.
	Coal seam groundwater system		Low	
Monitoring Bore Installation				
Monitoring bore installation and potential aquifer cross-contamination.	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined based on the following: • Potential impacts would be localised around each monitoring bore. • Impact severity is minor when considering regional hydrogeological inter-aquifer flows. • Impact duration would be limited to the period of bore drilling and installation. If a bore is incorrectly installed and allows on-going cross-contamination, impact duration will be for the life of the monitoring bore, ceasing when the well is decommissioned.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
	Deep groundwater system		Low	
Monitoring bore installation and potential aquifer	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined based on the following: • Potential impacts would be localised around each monitoring bore.

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
contamination by the sub-surface drilling process.	Intermediate groundwater system		Low	• Impact severity would be minor when considering regional hydrogeological processes and the materials used by Arrow during drilling of monitoring bores (water and salt-based drilling muds). • Impact duration would be limited to the period of bore drilling and installation.
	Coal seam groundwater system		Low	
	Deep groundwater system		Low	
Monitoring bore installation and potential aquifer contamination by the surface drilling process (e.g. drilling fluid storage and the operation of the drilling rig and ancillary equipment).	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined based on the following: • Potential impacts would be localised around each monitoring bore. • Impact severity would be minor due to the materials used by Arrow during installation of monitoring bores (water and salt-based drilling muds) and implementation of standard procedures to reduce the potential for impact. • Impact duration would be limited to the period of bore drilling and installation.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
	Deep groundwater system		Low	
Hydraulic Stimulation Activities				
Hydraulic stimulation and	Shallow groundwater	This potential impact was identified in the	Low	A low pre-mitigation magnitude ranking is determined based on the following:

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Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
potential aquifer contamination by surface processes (e.g., chemical storage, operation of pumping systems and management of flowback water).	system	EIS.		• Potential impact would be contained within the Project area and localised around each production well. • Impact severity would be minor due to the predominantly water based fluids used in hydraulic stimulation events and implementation of standard procedures to manage flowback water. • Impact duration would be limited to the period of well drilling and installation.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
	Deep groundwater system		Low	
Hydraulic stimulation and potential aquifer cross contamination due to fracture propagation across confining units.	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined based on the following: The aquitard formations (mudstones and siltstones) of the Rewan Formation, coal measure interburden and the Back Creek Group that predominantly separate the target coal seam from the developed aquifer formations typically behave elastically, and are therefore expected to respond to applied stresses through ductile deformation (stretching and folding) rather than brittle fracturing. Therefore these confining layers are expected to resist fracture propagation beyond the target coal seam, with any fractures truncating at the top or bottom of a coal seam.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
	Deep groundwater system		Low	
Hydraulic stimulation and	Shallow groundwater	This potential impact was identified in the	Low	A low pre-mitigation magnitude ranking is determined based on the following:

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
potential for events to induce earthquakes and alter the structural integrity of aquifers.	system	EIS.		Preliminary research on hydraulic stimulation induced seismicity in Australia indicates that induced earthquakes release less energy than naturally occurring earthquakes of similar size (Geoscience Australia, 2013). Field evidence demonstrates that microseismic events due to fracturing are low, and not perceptible at the surface other than with sensitive seismology equipment.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
	Deep groundwater system		Low	
Installation of Supporting Sub-surface Infrastructure				
Contamination of groundwater systems from leaks and spills from of other sub-surface infrastructure (e.g. gathering lines and underground storage tanks)	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined based on the following: • Potential impact would be contained within the Project area and localised around sub-surface infrastructure such as gathering lines or underground storage tanks. • Impact severity would be minor due to the small proportion of sub-surface infrastructure in comparison with the extent of groundwater systems across the Project area. Standard procedures associated with the methods of fuel and chemical storage, handling and disposal will be implemented. • In the event sub-surface infrastructure was incorrectly installed or on-going leaks and spilled occurred, potential groundwater contamination would continue over the operational life of the infrastructure, ceasing when the component of infrastructure was decommissioned and residual contamination.
	Intermediate groundwater system		Low	
	Coal seam groundwater system		Low	
	Deep groundwater system		Low	
Installation of Supporting Surface Infrastructure and Waste Management				

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
Contamination of groundwater systems from leaks or spills from surface storage of chemicals, fuels, oils.	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined. Spills or leaks of stored chemicals, fuels and oils may enter the groundwater systems that form the water table aquifer and migrate to other groundwater systems, impacting water quality, impairing consumptive and productive uses and groundwater-dependent ecosystems. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be moderate for the shallow groundwater system
	Intermediate groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the intermediate groundwater system.
	Coal seam groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the coal seam groundwater system.
	Deep groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the deep groundwater system.
Contamination of groundwater systems from leaks or spills from surface waste	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined. Leakage of stored waste may enter the aquifers that form the shallow groundwater system and migrate to other groundwater systems, impacting water quality, impairing consumptive and productive uses and groundwater-dependent ecosystems.

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
generation and storage.				Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be moderate for the shallow groundwater system
	Intermediate groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the intermediate groundwater system.
	Coal seam groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the coal seam groundwater system.
	Deep groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the deep groundwater system.
Contamination of groundwater systems from leaks or spills from surface waste water storage and sanitation processes.	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined. Leakage of effluent may enter the groundwater systems that form the water table aquifer and migrate to other groundwater systems, impacting water quality, impairing consumptive and productive uses and groundwater-dependent ecosystems. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be moderate for the shallow groundwater system
	Intermediate groundwater		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
	system			outcrop) impact magnitude is considered to be low for the intermediate groundwater system.
	Coal seam groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the coal seam groundwater system.
	Deep groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Based on the potential area for impact to occur (i.e. area of groundwater system outcrop) impact magnitude is considered to be low for the deep groundwater system.
Disturbance Footprints associated with Surface Infrastructure				
Reduced aquifer recharge due to placement of impervious surface coverings.	Shallow groundwater system	This potential impact was identified in the EIS.	Low	A low pre-mitigation magnitude ranking is determined. Direct rainfall recharge to the water table aquifer may be reduced in the areas where impervious surfaces are installed. Under the current project description, the total area of Project tenements is 8,000 km^2 and the total footprint of Project components (assumed to represent the area of impervious surfaces) is less than 100 km^2. Taking into consideration the overall area available for potential aquifer recharge in comparison to the expected reduction in surface area due to the installation of impervious surface coverings, the impact magnitude is considered to be low in the shallow groundwater system
	Intermediate groundwater system		Very low	A very low pre-mitigation magnitude ranking is determined taking into consideration the overall area available for potential aquifer recharge in comparison to the expected reduction in surface area due to the installation of impervious surface coverings.

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
	Coal seam groundwater system		Very Low	A very low pre-mitigation magnitude ranking is determined taking into consideration the overall area available for potential aquifer recharge in comparison to the expected reduction in surface area due to the installation of impervious surface coverings.
	Deep groundwater system		Very Low	A very low pre-mitigation magnitude ranking is determined taking into consideration the overall area available for potential aquifer recharge in comparison to the expected reduction in surface area due to the installation of impervious surface coverings.
General impacts associated with installation of facilities	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined based on comparison of the potential area for impact to occur (i.e. area of groundwater system outcrop) to the total footprint of facilities.
	Intermediate groundwater system		Low	A low pre-mitigation magnitude ranking is determined based on comparison of the potential area for impact to occur (i.e. area of groundwater system outcrop) to the total footprint of facilities.
	Coal seam groundwater system		Low	A low pre-mitigation magnitude ranking is determined based on comparison of the potential area for impact to occur (i.e. area of groundwater system outcrop) to the total footprint of facilities.
	Deep groundwater system		Low	A low pre-mitigation magnitude ranking is determined based on comparison of the potential area for impact to occur (i.e. area of groundwater system outcrop) to the total footprint of facilities.

Table 7-7 Impacts Caused by Management and Storage of CSG Water

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
Altered groundwater quality due to seepage of untreated CSG water from surface storage facilities.	Shallow groundwater system	This potential impact was identified in the EIS.	Very Low	A very low pre-mitigation magnitude ranking is determined. Proposed storage facilities are not associated with areas of the shallow groundwater system.
	Intermediate groundwater system		Moderate	A moderate pre-mitigation magnitude ranking is determined. Proposed storage facilities are associated with areas where the Rewan Formation outcrop. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation of untreated CSG water storage.
	Coal seam groundwater system		Moderate	A moderate pre-mitigation magnitude ranking is determined. Proposed storage facilities are associated with areas where the Blackwater Group outcrop. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation of untreated CSG water storage.
	Deep groundwater system		Very Low	A very low pre-mitigation magnitude ranking is determined. Proposed storage facilities are not associated with areas of the deep groundwater system.
Altered groundwater flow direction due to seepage of CSG water from surface storage facilities.	Shallow groundwater system	This potential impact was identified in the EIS.	Very Low	A very low pre-mitigation magnitude ranking is determined. Storage facilities are not proposed where the shallow groundwater system represents the water table aquifer(s).
	Intermediate groundwater system		Low	A low pre-mitigation magnitude ranking is determined. Proposed storage facilities are associated with areas where the Rewan Formation outcrop and seepage from CSG water storage facilities may result in localised groundwater mounding and radial flow. The impact is minor, localised and will experience rapid recovery at the cessation of CSG water storage.
	Coal seam		Low	A low pre-mitigation magnitude ranking is determined. Proposed storage facilities

Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
	groundwater system			are associated with areas where the Blackwater Group outcrop and seepage from CSG water storage facilities may result in localised groundwater mounding and radial flow. The impact is minor, localised and will experience rapid recovery at the cessation of CSG water storage.
	Deep groundwater system		Very Low	A very low pre-mitigation magnitude ranking is determined. Storage facilities are not proposed where the deep groundwater system represents the water table aquifer(s).
Altered groundwater quality due to seepage of brine from surface storage facilities.	Shallow groundwater system	This potential impact was identified in the EIS.	Very Low	A very low pre-mitigation magnitude ranking is determined. Storage facilities are not proposed where the shallow groundwater system represents the water table aquifer(s).
	Intermediate groundwater system		Moderate	A moderate pre-mitigation magnitude ranking is determined. Proposed storage facilities are associated with areas where the Rewan Formation outcrop and brine seepage from storage facilities may alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation of brine storage.
	Coal seam groundwater system		Moderate	A moderate pre-mitigation magnitude ranking is determined. Proposed storage facilities are associated with areas where the Blackwater Group outcrop and brine seepage from storage facilities may alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation of brine storage.
	Deep groundwater system		Very Low	A very low pre-mitigation magnitude ranking is determined. Storage facilities are not proposed where the deep groundwater system represents the water table aquifer(s).

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Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
Altered groundwater quality due to unplanned discharge of CSG water to the land surface from surface storage facilities or infrastructure installed for distribution of CSG water to end users.	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined based on the overall extent of where the shallow groundwater system forms the water table and may therefore be impacted. Unplanned discharge of untreated CSG water to the land surface may enter the water table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation production.
	Intermediate groundwater system		Moderate	A moderate pre-mitigation magnitude ranking is determined based on the overall extent of where the intermediate groundwater system forms the water table and may therefore be impacted . Unplanned discharge of untreated CSG water to the land surface may enter the water table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation production.
	Coal seam groundwater system		Low	A low pre-mitigation magnitude ranking is determined based on the overall extent of where the coal seam groundwater system forms the water table and may therefore be impacted. Unplanned discharge of untreated CSG water to the land surface may enter the water table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation production
	Deep groundwater system		Low	A low pre-mitigation magnitude ranking is determined based on the overall extent of where the deep groundwater system forms the water table and may therefore be impacted. Unplanned discharge of untreated CSG water to the land surface may enter the water table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend

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Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
				beyond the area of activity or Project footprint, and may persist beyond the cessation production.
Altered groundwater quality due to unplanned discharge of brine to the land surface from surface storage facilities.	Shallow groundwater system	This potential impact was identified in the EIS.	Moderate	A moderate pre-mitigation magnitude ranking is determined based on the overall extent of where the shallow groundwater system forms the water table and may therefore be impacted. Unplanned discharge of brine to the land surface may enter the water table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation of brine storage.
	Intermediate groundwater system		Moderate	A moderate pre-mitigation magnitude ranking is determined based on the overall extent of where the intermediate groundwater system forms the water table and may therefore be impacted. Unplanned discharge of brine to the land surface may enter the water table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation of brine storage.
	Coal seam groundwater system		Low	A low pre-mitigation magnitude ranking is determined based on the overall extent of where the coal seam groundwater system forms the water table and may therefore be impacted. Unplanned discharge of brine to the land surface may enter the water table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems. The impact may extend beyond the area of activity or Project footprint, and may persist beyond the cessation of brine storage.
	Deep groundwater system		Low	A low pre-mitigation magnitude ranking is determined based on the overall extent of where the deep groundwater system forms the water table and may therefore be impacted. Unplanned discharge of brine to the land surface may enter the water

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Activity and Potential Impact	Potentially Affected Groundwater System	Status of Potential Impact in the EIS	Pre-mitigation magnitude Ranking - SREIS Assessment	Summary and Comparison
				table aquifer, alter groundwater quality and impair consumptive and productive uses and groundwater-dependent ecosystems.

7.8 Cumulative Impacts

Cumulative impacts are the successive, incremental and combined impacts of an activity on society, the economy and the environment. Cumulative impacts are most often raised in the context of multiple resource operations in the same basin or geological province. The groundwater related cumulative impacts in the Bowen Basin have been assessed.

7.8.1 Cumulative Groundwater Impacts Presented in the EIS

The assessment of cumulative impacts presented in the EIS comprised two parts, firstly, a quantitative assessment of cumulative groundwater drawdown as represented in the EIS groundwater model, and, secondly a qualitative assessment based on literature from existing and operating mines in the Project vicinity.

7.8.1.1 *Quantitative Assessment*

The groundwater impact assessment completed for the EIS considered the results of two modelling scenarios, one limited to forecast groundwater extraction from the Project (identified as the Project only scenario in the EIS groundwater model) and the second incorporating the Project and other identified large scale impacts on Bowen Basin groundwater systems (identified as the cumulative scenario in the EIS groundwater model). The cumulative scenario combined forecast associated water production from the Project with third-party groundwater extraction entitlements, as determined from the NRM water entitlements database and CSG associated water production from the Moranbah Gas Project. The EIS assumed that these third-party and Moranbah Gas Project impacts, in conjunction with the potential impacts from the Project, will have a cumulative impact on groundwater systems.

The cumulative impact scenario assumed that entitlements identified in the NRM water entitlements database would be in full continuous use from 2003 to the end of the model simulation in 2122. The actual usage, in fact, may be as little as 20% of annual entitlement (SKM, 2009a) and may change due to policy changes and expiration of entitlements. The resulting volume of groundwater production due to water extraction entitlements in the model is significant. It totals 108,700 ML between 2000 and the end of 2011. Based on the water extraction entitlements, the predictive model includes an annual volume of 13,000 ML between 2017 and 2072 (totalling 715,000 ML). This is 2.6 times more groundwater extraction than projected for the Project for the same period based on the conceptual development plan presented in the EIS. The total simulated groundwater production for the Project presented in the EIS (55 years) was approximately 274,000 ML.

The Moranbah Gas Project adds a relatively small volume to the projected production volume for the Project within the same target coal measures. The historical production from 2003 to 2011 is 3,300 ML of water. The future predictions into 2049 indicate an additional 11,400 ML of groundwater production for a total groundwater production of 14,700 ML over the life of the Moranbah Gas Project.

The EIS groundwater model assumed that groundwater drawdown impacts related to other mines would occur on a local scale (i.e. within 10 km of the mine site). This assumption, coupled with a lack of detailed publically available information meant that groundwater extractions from operating coal mines in the model domain were not incorporated into the cumulative impacts scenario.

The cumulative impacts modelling conducted for the EIS indicated that drawdown could be significant throughout the model domain including several areas outside of the Project area primarily within the aquifers of the shallow groundwater system, which are associated with to the third-party extraction identified in the NRM water entitlements database, not CSG water production related to the Project.

Figures presented in Appendix F of the Supplementary Groundwater Assessment (Appendix E) of the SREIS show the modelled drawdowns in selected target aquifers for the cumulative scenario at the end of CSG production and 50 years thereafter. Based on the modelling (Ausenco-Norwest, 2012) it is considered that post-production recovery would be relatively slow, and the baseline pressure in the target coal seams are unlikely to be re-established within less than approximately one thousand years. Further to this, the rate of groundwater recovery may be slowed even more by the existing and future mining operations in proximity to the Project.

7.8.1.2 *Qualitative Assessment*

The second portion of the cumulative impact assessment conducted for the EIS included a qualitative assessment of cumulative impacts on groundwater resources from the Project in conjunction with the following proposed projects:

- Caval Ridge Mine;
- Codrilla Coal Project;
- Daunia Mine;
- Eagle Downs Coal Project;
- Grosvenor Longwall Expansion Project;
- Middlemount Coal Project (Stage 2);
- North Goonyella Longwall Expansion Project; and
- Washpool Coal Project.

The EIS acknowledged that all the future coal mines identified as part of the assessment are likely to have groundwater impacts. Of these, Eagle Downs is the only underground mine development. During operations, and either as a result of the post mining open cut voids or the underground goafed (mined void) areas, all of the coal mining projects are likely to result in localised depressurisation of the groundwater systems around the sites. Review of the available EIS documentation found the zones of depressurisation to be generally limited to a 5 km to 10 km radius with varying durations. Those projects where EIS documents were not available were also considered to contribute to the cumulative groundwater impacts however, this was difficult to assess in the absence of technical data available in the public domain.

7.8.2 Supplementary Cumulative Impact Assessment

A review of the projects included in the cumulative impact assessment with consideration for any new information that has become available since preparation of the EIS was conducted for the SREIS.

There is no standard methodology in Queensland for the assessment of cumulative impacts as part of an EIS process and there are no specific requirements in the legislation as to how cumulative impacts should be addressed. For the purposes of the EIS and SREIS, cumulative impacts were defined as changes to the environment that are caused by an action in combination with other past, present and future human actions (Hegmann et al., 1999). The Queensland Coordinator Generals' generic ToR provides guidance on the cumulative impact assessment for an EIS.

For this cumulative impact assessment, the combined effects of different developments within a similar spatial and temporal scope are considered. Cumulative impacts occur when impacts from individual developments combine to result in an impact which is greater than the individual residual impact of each development, when considered in isolation. This impact may be positive or negative. The severity and duration of the cumulative impact will depend on the timing and duration of operational activities. It should be noted that many new mines will not require dewatering as existing mines may have already lowered the water table to sufficient depths to allow for mining.

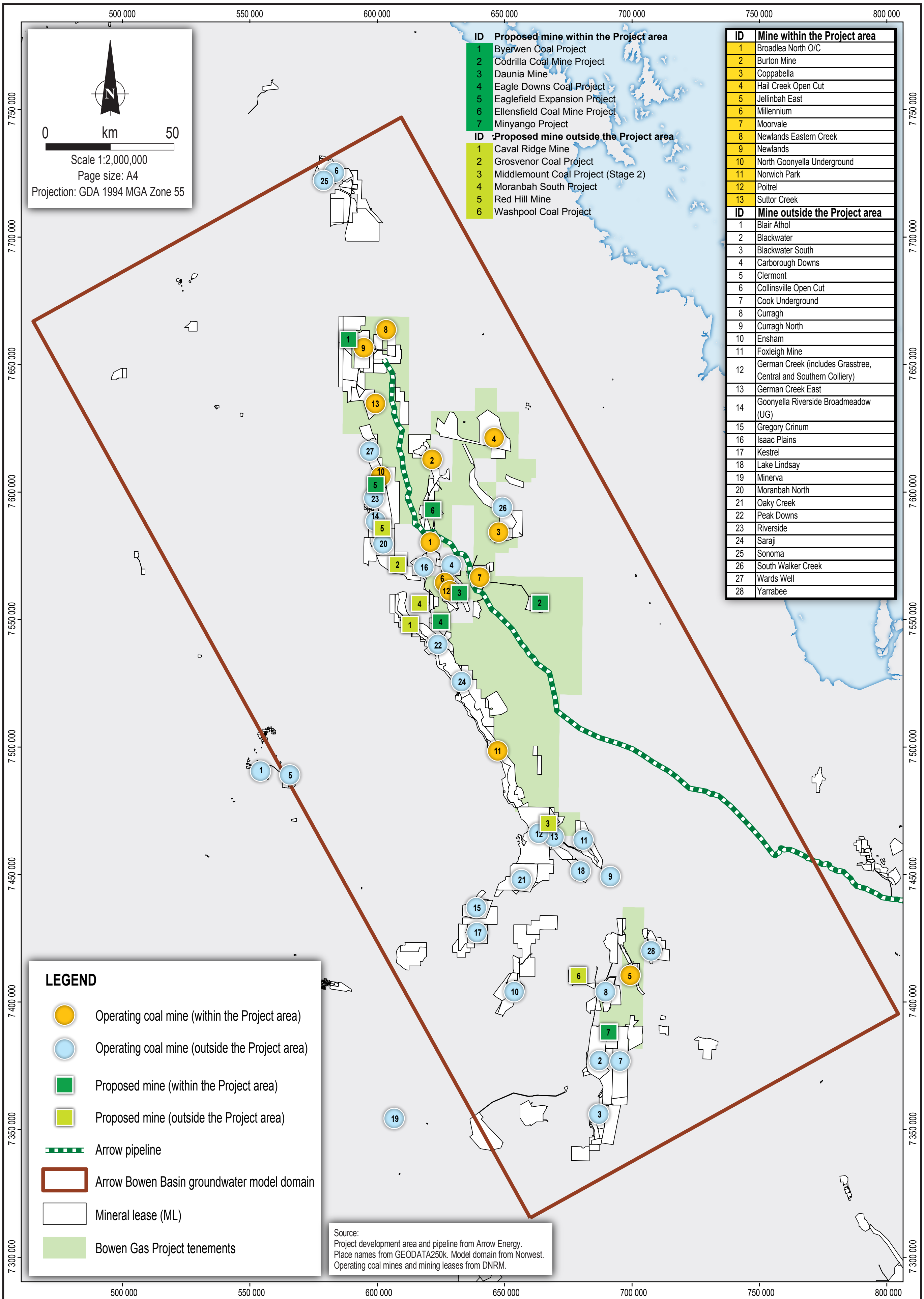
Mining operations are relatively dispersed across the Bowen Basin due to its size and the distribution of coal resources across the area. Most existing coal mine projects in the Bowen Basin are located on the western limb of the basin, targeting the Permian coal seams. There are 13 operational coal mines within the Project area with a further 28 coal mines operating beyond the Project area, but within the Arrow Bowen EIS groundwater model domain (Figure 7-12). There are approximately a further 13 projects under development in the Bowen Basin, as at December 2013 (Figure 7-12).

The potential for the impacts identified in the supplementary groundwater assessment to contribute to a cumulative impact was evaluated for each of the potential impact categories, as follows:

- Direct impacts caused by coal seam depressurisation.
- Indirect impacts caused by coal seam depressurisation (i.e. subsidence).
- Impacts caused by field and infrastructure development, operation and decommissioning.
- Induced seismicity.

7.8.2.1 *Direct Impacts Caused by Coal Seam Depressurisation*

Predictive groundwater modelling from coal mines in the Moranbah area indicate that groundwater drawdown within the confined target coal seams, as a result of mine dewatering and associated depressurisation, could potentially extend 5 km to 30 km. The drawdown extent varies across mine sites as the depth to the target coal formations vary across the Bowen Basin. For the existing Newlands coal mine, groundwater modelling shows that drawdown in the coal seams is generally limited to within 1 km of the mining footprint. This is supported by groundwater modelling conducted for the proposed Byerwen coal project (not undertaken as part of the Project assessment) where induced drawdown is expected to be within 2 km in the target coal seams.



coffey	Date: 17.04.2014 MXT: 7043_03_GIS034_v1_1 File Name: 7043_03_F07.12_GIS_GL	Arrow Energy Limited Bowen Gas Project	arrow energy go further	Proposed and operational mines within and surrounding the Project area	Figure No: 7.12

Groundwater drawdown has also occurred in the coal seams within the Grosvenor mining lease area which is also located within Arrow's Moranbah Gas Project area. Existing groundwater extraction undertaken at the Moranbah Gas Project and drainage to the Moranbah North Mine underground workings contribute to cumulative groundwater drawdown in this area. This also has implications for coal handling for the affected coal mining operations due to greater dust production and more friable coal. The predictive groundwater modelling undertaken for the Moranbah South Project (Hansen Bailey, 2013) further supports that cumulative impacts from coal mining and CSG activities occurring in this area.

Groundwater modelling was also undertaken as part of the proposed Eaglefield Expansion Project. The estimated cumulative dewatering drawdown impact associated with this project and surrounding existing mines (North Goonyella, Eaglefield and Goonyella-Riverside) is approximately 4 km in the Fort Cooper Coal Measures and Moranbah Coal Measures. The Rangal Coal Measures overlie and are separated from the Moranbah Coal Measures by the Fort Cooper Coal Measures. The low vertical permeability of the Moranbah Coal Measures and Rangal Coal Measures and the separation of the Fort Cooper Coal Measures is expected to limit vertical flow between these formations such that the cumulative impact of drawdown is considered to be limited in these areas. In addition, fault permeability in the region is predominantly low and unlikely to provide a mechanism for significant vertical flow.

The cumulative case considered by the EIS groundwater model was based on a proposed production of 274 GL over the project life, as well as the cumulative effects of the non-CSG users from the NRM water entitlements database. Given that the revised production case is significantly reduced (153 GL) and the actual non-CSG usage is estimated at less than 20% of the NRM water entitlements database, modelling has overstated drawdown arising from the cumulative impact case. It is concluded that the cumulative modelling scenario prepared for the EIS does not predict potential cumulative groundwater drawdown impacts.

In considering the observations made at, and the cumulative modelling scenarios undertaken for other coal mining projects in the area, it is likely that Arrow's activities may impact on other coal mines if they are located within the predicted area of drawdown. However given that coal mines already dewater to access the coal, any potential impacts associated with CSG depressurisation are likely to be low.

7.8.2.2 *Indirect Impacts Caused by Coal Seam Depressurisation*

Identified indirect impacts caused by CSG depressurisation include:

- Groundwater quality impacts caused by inter-aquifer groundwater flow;
- Reduced groundwater supply to existing or future groundwater users;
- Reduced groundwater availability for groundwater-dependent ecosystems and cultural and spiritual values; and
- Subsidence.

The low vertical permeability of the target coal seams limit vertical flow between formations such that the cumulative impact of drawdown is considered to be limited in those areas, and further that fault permeability in the region is low and unlikely to provide a mechanism for significant vertical groundwater flow. Therefore groundwater quality impacts caused by inter-aquifer groundwater flow are not indicated, nor are impacts to groundwater supply.

The subsidence interpreted from satellite monitoring of the Moranbah Gas Project area indicates minor ground movements comparable in scale to those occurring from natural processes. This will also apply to the Project because the Moranbah Gas Project area and the activities undertaken are considered to be a reasonable analogue of the Project area and the proposed Project activities. Consequently, the magnitude of potential cumulative subsidence resulting from CSG development in the Bowen Basin is expected to be substantially less than that arising from longwall coal mining, where subsidence is typically greater than 1 m.

7.8.2.3 *Impacts Caused by Field and Infrastructure Development, Operation and Decommissioning*

Contamination of groundwater systems is a potential cumulative impact that could result from a variety of CSG construction and operation surface activities (e.g., storage and handling of hazardous materials) and subsurface activities (e.g., drilling and installation of production and monitoring wells) combined with mining activities.

Other projects (existing and future) with the potential to contribute to cumulative impacts from field and infrastructure development, operation and decommissioning will be limited spatially to those located within the Project area (identified in Figure 7-12).

Potentially contaminating surface activities are more likely to impact on outcropping aquifers than deeper confined systems, however as depth to groundwater is typically 5 m to 20 m below ground surface the source of contamination would be required to be of sufficient volume or a release over a sufficient period to allow migration to the water table. The likelihood of this occurring would also be dependent on the site-specific lithology.

Aquifers of deeper systems are isolated by depth, and are less likely to be adversely impacted by leaks and spills of hazardous materials or CSG water from surface storage infrastructure. Also, in the event of a leak or spill, the contaminants would more likely migrate laterally away from the source, and in the direction of local groundwater flow and at a rate comparable with the groundwater flow velocity. The shallow groundwater systems are often localised systems that are less likely to be accessed by multiple proponents. The mitigation measures developed to address this potential impact require that dams and surface storage infrastructure be installed to relevant standards, together with impact detection systems (e.g., shallow groundwater monitoring bores) in the vicinity of the infrastructure. Therefore, the potential for cumulative contamination of shallow groundwater systems from surface activities is considered to be the same as the residual impact of the Project in isolation.

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 fields. Adherence to all industry standards as they relate to the appropriate storage, handling, and disposal of hazardous materials and the drilling and installation of wells will mitigate potential cumulative impacts. Regular maintenance and well testing will further limit potential impacts.

Monitoring programs conducted by all proponents operating in the Bowen Basin will ensure that groundwater quality indicators are used to implement appropriate response actions in the event of leaks, spills, or inadequate well installations.

Given the cumulative impact is considered to be the same as the residual impact of the Project in isolation, no additional mitigation and management measures are proposed to manage Arrow's potential contribution to cumulative impact. Monitoring programs conducted by existing and future proponents will ensure that groundwater quality indicators are used to implement appropriate response actions in the unlikely event of leaks, spills, or inadequate well installations.

7.8.2.4 *Induced seismicity*

Induced seismicity associated with hydraulic stimulation of rocks results in seismic events of very low magnitude (microseismic events), with no demonstrated potential to result in damage to buildings or infrastructure. Based on data from Pinnacle (2013) the magnitude of these microseismic events is demonstrated to be very low, and measured as negative magnitudes.

Preliminary research on hydraulic stimulation induced seismicity in Australia indicates that induced earthquakes release less energy than naturally occurring earthquakes of similar size (Geoscience Australia, 2013) and are generally less than magnitude 1. It is feasible for hydraulic stimulation to induce movement on existing fault planes, however this requires that the extent of stimulation is sufficient to intersect nearby potentially active faults, and also that such faults would be active.

In the Bowen Basin, existing faults are comparatively well mapped and subsequently avoided when locating CSG wells. Hence, risks are reduced, and confined to the intersection of unknown small faults. Together with the low seismic activity in the basin, risks of induced earthquakes are small, and any such events would be of low magnitude.

Induced seismicity comprises events associated with hydraulic stimulation operations that are constrained in time and place. Therefore the magnitude of these events is not cumulative. However it is reasonable to assume that other extractive industries, such as CSG developers or miners, could also trigger induced seismic events. This would increase the overall number of potential events in the Project area, but not the magnitude of events.

In summary, the demonstrated evidence is that induced seismic events are of very low magnitude that can only be measured with sensitive seismology equipment. They are inherently not cumulative in magnitude terms, and it is concluded that the risk associated with induced seismicity in the Bowen Basin due to hydraulic stimulation is very low.

7.8.3 Mitigation, Management and Monitoring Measures

The mitigation measures identified in the EIS have been revised and new commitments have been made by Arrow for the management of potential impacts on groundwater values from the Project as a result of the supplementary groundwater assessment are detailed in Table 7-7. New commitments relate to the:

- Design of hydraulic stimulation events (if conducted) in accordance with the requirements set out in the EP Act, P&G Act and relevant industry guidelines.

- Development of a framework to manage any impacts on potentially impacted groundwater-dependent ecosystems (excluding springs) reliant on the surface expression or sub-surface presence of groundwater.
- Continued provision of information to the OGIA in relation to the northern portion of the Surat CMA intersected by the Project area and compliance with inspection and monitoring requirements of the Surat CMA UWIR.

Arrow will continue to implement existing monitoring programs. Existing programs are consistent with the requirements set out in Water Act for the fulfilment of underground water obligations and requirements set out under the EP Act for the application of an EA.

Arrow will develop new monitoring programs if required.

7.8.4 Residual Impacts

The magnitude of potential impacts after the implementation of mitigation and management measures has been determined for all potential impacts. The review determines the significance of the residual impacts and makes a comparison with the findings presented in the EIS. The results of the review indicate that all residual significance rankings remain very low to low.

7.9 Conclusion

The supplementary groundwater assessment was prepared to address comments and submissions received on the EIS and to incorporate any information that became available since publication of the EIS, including updates to the project description.

The supplementary groundwater assessment built on the information provided in the EIS through the detailed review and analysis of key information sources. The focus of the review was to improve the knowledge base from which the impact assessment was conducted and specifically involved further investigation on:

- The role faulting and folding has on the movement of groundwater and how the drawdown associated with depressurisation of the CSG targets may be influenced by these features;
- Areas where the alluvial and sedimentary aquifers may be directly underlain by coal formations and there is the potential for increased hydraulic connectivity between the groundwater systems;
- The potential for CSG production induced subsidence;
- Mechanisms associated with induced seismicity in response to CSG extraction and hydraulic stimulation; and
- The types of groundwater-dependent ecosystems present within the Project area and immediate surrounds, their potential connectivity to various aquifer units, groundwater chemistry characteristics and ecological values.

Further numerical groundwater modelling was undertaken to address specific aspects such as faults, at a local scale. The additional groundwater model scenarios simulated the potential for faults to provide preferential pathways between aquifers, and considered how the effect of such changes to aquifer interconnectivity would influence the potential drawdown impacts caused by the Project.

The outcome of further groundwater modelling and looking specifically at the behaviour of faults and other aspects, at a local scale was the validation of the modelling predictions presented in the EIS.

The EIS findings are demonstrated to be a conservative representation of the potential drawdown resulting from CSG depressurisation.

The impact assessment framework adopted for the EIS was re-applied for the potential Project impacts. It is demonstrated that the residual significance assessment in the EIS did not understate the mitigated impacts, and that where additional potential impacts were identified, these could be mitigated such that residual impact significance is low or very low.

A review of mitigation and management measures identified in the EIS showed that the measures are predominantly still relevant for the management of groundwater-related impacts and that six new measures have been added to further protect the groundwater environmental values.

7.10 Commitments Update

Six new and four updated management measures (commitments) relevant to groundwater were identified as a result of revisions to the project description (where further clarity was provided for the assessment of impacts on deep aquifers), to incorporate the findings of information made available since publication of the EIS and to make reference to the latest codes, standards and legislative requirements. These are presented in Table 7-8.

The full list of commitments, including those that remain unchanged from the EIS and details on those that have changed, are included in Commitments Update (Appendix O) of the SREIS.

Table 7-8 Commitments Update: Groundwater

No.	Commitment	Revised / New
B644	If the need to hydraulically stimulate any wells arises, prior to the commencement of hydraulic stimulation activities Arrow will develop and implement a procedure that satisfies the relevant regulatory requirements relating to hydraulic stimulation, for each hydraulic stimulation campaign.	New
B249	Construct, decommission or repair all CSG production wells in accordance with the *Code of Practice for Constructing and Abandoning CSG Wells in Queensland* (DEEDI, 2011b), or relevant code at the time of construction, which details mandatory requirements for well installations, monitoring, management and eventual decommissioning. Should production wells be converted into monitoring bores, do so in accordance with relevant regulations.	Revised to capture latest legislative requirements and to align with Surat Commitment C150

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No.	Commitment	Revised / New
B250	Construct, decommission or repair all water bores (including monitoring bores) in accordance with the pertinent legislation; either the relevant minimum requirements; the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC, 2012) or the *Minimum Standards for the Construction and Reconditioning of Water Bores that Intersect the Sediments of Artesian Basins in Queensland* (DERM, 2004); or the *Code of Practice for Constructing and Abandoning CSG Wells in Queensland* (DEEDI, 2011b).	Revised to reflect recent legislative changes and to align with Surat Commitment C138
B281	Connect wastewater and sewerage systems to sewers where locally present. Alternatively, install wastewater treatment or reuse systems in accordance with AS / NZS 1547: 2000 On-site Domestic Wastewater Management (Standards Australia, 2012); DERM guideline for managing sewerage infrastructure to reduce overflows and environmental impacts (DERM, 2010); and Queensland water recycling guidelines (DERM, 2005).	Revised to align with Surat Commitment C148 and to reflect current legislation
B398	Liquid waste generated (other than CSG water and sewage) will be stored and periodically removed for disposal or recycling. All waste drilling fluids resulting from drilling activities will be contained in dams or storage tanks, lined as appropriate, prior to re-use, recycling, treatment or disposal. Putrescible solid waste will be stored in covered containers to prevent odours, public health hazards and access by fauna.	Revised to more accurately reflect legislative requirements
B655	Arrow will continue to provide information to the Office of Groundwater Impact Assessment (OGIA), as required by the Underground Water Impact Report, to enable continual development and updates to the regional cumulative model administered by OGIA.	New
B656	Design all hydraulic stimulation wells and events in accordance with relevant requirements of the Petroleum and Gas (Production and Safety) Regulation 2004 and the Environmental Protection Act 1994 (EP Act 1994).	New
B657	Manage non-spring groundwater-dependent ecosystems (GDE) according to the following framework: • Identify potential GDE landscapes; • Use modelling to predict impacts; • Identify GDEs at risk of impact through a risk assessment. Where identified as being at risk of impact, conduct further assessment including field studies and monitoring to ascertain connectivity of GDE to underlying aquifers; and • Monitor and manage impacts as required.	New
B658	Investigate potentially impacted sites of Indigenous cultural and spiritual importance that may have dependence on groundwater to determine the status of the feature, confirm groundwater-dependence and develop mitigation measures where required.	New
B659	Where sites of cultural and spiritual significance within the Project area that may have dependence on groundwater will be potentially impacted by Project activities: • Liaise with traditional owners of the land in accordance with any endorsed Cultural Heritage Management Plan to located potentially impacted features and further understand their significance;	New

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No.	Commitment	Revised / New
	• Undertake field surveys to confirm the status of potentially impacted features (i.e. whether feature still exists and/or is actively used) associated with groundwater; and • Develop monitoring, management and mitigation measures to assess, manage, avoid or minimise impact to the feature(s).	