E

Groundwater Report

GROSVENOR MINE

G200s PROJECT

EPBC Act Environmental Assessment Report

Australasian
Groundwater
and Environmental
Consultants Pty Ltd
(AGE)

Report on

G200s Project

Groundwater Impact Assessment

Prepared for
Hansen Bailey Pty Ltd

Project No. G1807A September 2016
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Report on

G200s Project
Groundwater Impact Assessment

1 Introduction

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) was commissioned by Hansen Bailey on behalf of Anglo Coal (Grosvenor) Pty Ltd (the proponent) to complete a Groundwater Assessment for the G200s Project (the project). A referral for the project is being made under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and this Groundwater Assessment forms part of the Environmental Assessment Report (EAR) that has been prepared in support of the EPBC Act referral.

1.1 Project description

The project is located wholly within the existing mining lease for the Grosvenor Coal Mine (Mining Lease 70378), near Moranbah, Central Queensland (Figure 1). Figure 1 shows the area that is currently subject to underground longwall mining within the Grosvenor Mining Lease. This area is termed the "approved Grosvenor mining area" in this report. The project involves extending longwall mining into an area to the west of the approved Grosvenor mining area, in an area termed the G200s mining area (Figure 2). The G200s mining area is proposed to be developed and mined using equipment from the Grosvenor Mine, and the underground mining area will be accessed via the existing portals and drifts at the Grosvenor Mine. A single coal seam is proposed to be mined (the Goonyella Middle [GM] Seam), which is the same seam being mined at the Grosvenor Mine. Coal from the G200s mining area is proposed to be mined at a maximum coal production rate of 10.5 million tonnes per annum (Mtpa) run of mine (ROM).

The project will also make use of the Grosvenor Mine's existing surface infrastructure, with no upgrades of the infrastructure required for the project. As per the arrangement at the Grosvenor Mine, coal from the project will be processed at the adjacent Moranbah North Mine (MNM).

Mining in the G200s mining area will extend the mine life of the Grosvenor Mine by approximately six years.

1.2 Background to assessment

The G200s mining area is located within the Grosvenor Mining Lease directly north of Moranbah township in Central Queensland's Bowen Basin (Figure 1). There is a long history of mining and exploration data relating to the geology and coal resources in the vicinity of the G200s mining area. This data has been supplemented by recent groundwater studies for the existing mining operations. The local geology and hydrogeology are therefore well understood.

Longwall mining has the potential to result in depressurisation of the surrounding geology. Depressurisation of the local geology can potentially induce dewatering of groundwater bearing strata in the vicinity of mining, and influence the local and regional hydrogeology. The availability of groundwater resources, the reliability of water supplies, and groundwater expression in surface waters can potentially be affected as a result.

This report presents an assessment of depressurisation effects arising from longwall mining associated with the project. A numerical model has been developed to quantify these depressurisation effects in terms of groundwater level change and groundwater inflow rates during the operations phase and post mine closure. This report provides an assessment of the potential impacts of these changes on groundwater users and the surrounding environment. This report also provides an assessment of the potential impacts of the project on groundwater quality.

1.3 Scope of assessment

The scope of work for this groundwater assessment includes:

- reviewing relevant groundwater, geotechnical and environmental reports to develop an appreciation of the geological and hydrogeological setting of the project;
- reviewing exploration bore data;
- reviewing hydrogeological data held on the Department of Natural Resources and Mines (DNRM) groundwater database (GWDB) for existing groundwater bores;
- undertaking a census of existing groundwater supply bores to confirm locations, usage and groundwater quality;
- analysis of all data and conceptualising the groundwater regime of the G200s mining area and surrounding areas;
- developing a numerical model and undertaking predictive modelling of the scale and extent of mining impacts upon groundwater levels, groundwater quality and groundwater users at various stages of mine operations and post closure;
- assessing groundwater impacts and developing feasible mitigation and management strategies where potential adverse impacts are identified; and
- developing a groundwater monitoring program.

The assessment of groundwater dependent ecosystems (GDEs) and stygofauna within the G200s mining area and its surrounds are beyond the scope of this report.

1.4 Report structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the project and the assessment scope.
- Section 2 – Regulatory Framework: describes the regulatory framework relating to groundwater.
- Section 3 – Environmental Setting: describes the environmental setting of the project including the climate, terrain, land uses and other environmental features relevant to the project.
- Section 4 – Geological Setting: describes the geological setting of the project including the regional geology and local stratigraphy.
- Section 5 – Investigation Methodology: describes the assessment method including the analysis of hydrogeological data.
- Section 6 – Groundwater Data and Results: provides an interpretive summary of the hydrogeological data used in the groundwater assessment.
- Section 7 – Existing Hydrogeology: describes the existing local groundwater regime for the G200s mining area and surrounding area.

- Section 8 – Impact Assessment: provides a detailed description of the proposed mining activities and the potential effects on the local groundwater regime. This section also presents the predicted effects on groundwater and the assessment of resulting impacts on groundwater users and the receiving environment.
- Section 9 – Groundwater Monitoring and Management Plan: describes the proposed measures for monitoring and management of groundwater impacts.
- Section 10 – Conclusions.

Appendix A provides a detailed description of the numerical modelling undertaken for the project, including details on model construction, calibration and sensitivity analysis. Appendix B presents the details of all groundwater monitoring bores near the G200s mining area. Appendix C presents a full summary of the water quality data used in this assessment.

2 Regulatory framework

The following sections summarise Commonwealth and Queensland groundwater legislation and policy relevant to the project.

2.1 Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the Australian Government's principal piece of environmental legislation, and is administered by the Department of the Environment and Energy (DotEE). The EPBC Act is designed to protect national environmental assets, known as Matters of National Environmental Significance (MNES), which include water resources impacted by large scale coal mining development.

This report will be used to support a referral for the project under the EPBC Act.

2.2 Queensland regulatory framework

The Queensland *Water Act 2000* (Water Act), supported by the subordinate *Water Regulation 2002*, is the primary legislation regulating groundwater resources in Queensland. The purpose of the *Water Act* is to advance sustainable management and efficient use of water resources by establishing a system for planning, allocation and use of water.

The water resource planning process provides a framework for the development of catchment specific Water Resource Plans (WRPs). A WRP provides a management framework for water resources in a plan area, and includes outcomes, objectives and strategies for maintaining balanced and sustainable water use in that area. A Resource Operations Plans (ROPs) implements the outcomes and strategies of a WRP.

Groundwater Management Areas (GMAs) and their component Groundwater Management Units (GMUs) are defined under WRPs. Authorisation is required to take water from a regulated GMA or GMU for specified purposes. The specified purposes are defined under a WRP, the *Water Regulation 2002* or a local water management policy.

The *Water Reform and Other Legislation Amendment Act 2014* (WROLA Act) was passed on 26 November 2014. The WORLA Act includes a number of key changes to the Water Act that would potentially affect the regulation of groundwater resources and groundwater take in relation to resource activities. Commencement of these provisions has been deferred until December 2016 under the *Water Reform and Other Legislation Amendment (Postponement) Regulation 2015* (WROLA Postponement Regulation).

The Queensland Government is currently considering the *Water Legislation Amendment Bill 2015* (WLA Bill) which includes changes to provisions passed under the WROLA Act. No changes to the deferred WROLA Act provisions for the management of groundwater impacts associated with the resource activities are currently proposed under the WLA Bill.

2.2.1 *Groundwater resources of the Fitzroy Basin*

The G200s mining area is located in the Isaac Connors GMA as defined under Schedule 3 of the Water Resource (Fitzroy Basin) Plan 2011 (Fitzroy Basin WRP) (Figure 3). The Isaac Connors GMA comprises two GMUs, as follows:

- Isaac Connors Groundwater Unit 1 comprising the Quaternary alluvium aquifer; and
- Isaac Connors Groundwater Unit 2 comprising all subartesian aquifers within the Isaac Connors GMA other than the aquifers included in Isaac Connors Groundwater Unit 1.

Within the mapped areal extents, the Isaac Connors Groundwater Unit 1 is limited to the geological limits of the Quaternary age Isaac River alluvium. The geological distribution of these alluvial deposits in relation to the G200s mining area is discussed in Section 4.2.6.

The potential project impacts on these designated aquifers has been assessed as part of this groundwater study and are discussed in Section 8.5.1.

A key ecological outcome of Fitzroy Basin WRP is to maintain groundwater discharge to watercourses in the Isaac Connors groundwater management area. The potential impacts of the project on groundwater interaction with watercourses are discussed in Section 8.5.3.

The G200s mining area is approximately 160 km from the Great Artesian Basin groundwater management area boundary.

2.2.2 *Groundwater licensing for the project*

The taking of or interfering with groundwater is regulated under the water licensing provisions of the Water Act. The Water Act requires that a water licence is required to take or interfere with groundwater within areas declared as management areas or declared areas under subordinate Queensland legislation. The Fitzroy Basin WRP also states that an entitlement is required for the take of groundwater for purposes other than stock or domestic water supply (e.g. groundwater take for mine dewatering). As discussed in Section 8.5.1, the project will result in the take or interference with groundwater. The administering authority for the Water Act is the DNRM.

The proponent will consult with the DNRM in relation to its obligations under the Water Act and will comply with any relevant requirements.

2.2.3 *Groundwater values*

The *Environmental Protection (Water) Policy 2009* (EPP Water) provides a framework to protect and/or enhance the suitability of Queensland waters for various beneficial uses. Groundwater resources within the vicinity of the G200s mining area are scheduled under the EPP Water.

The relevant local groundwater uses and associated values are described in Sections 3 and 7. Section 8 describes the impacts on groundwater resources and relevant environmental values.

3 Environmental setting

This section describes the regional and local setting of the project and discusses the location, land use, climate and terrain. The geological setting of the G200s mining area is discussed in Section 4.

3.1 Location and land use

The project is located directly north of the Moranbah Township (Figure 1). The project comprises approximately 903 ha of gently undulating land, much of which has been cleared in the past, primarily for cattle grazing.

The predominant surrounding land uses are mining, coal seam gas (CSG) production, and agriculture in the form of cattle grazing. Figure 1 shows the location of nearby mines and projects, including Moranbah North Mine, Moranbah South Project, and Isaac Plains Mine.

Longwall mining commenced in the approved Grosvenor mining area in May 2016. Longwall mining at Moranbah North Mine has been carried out since 1998. The Moranbah South Project is an underground mine project with a mine life in excess of 30 years. Isaac Plains Mine is an existing open cut coal mine, located to the north-east of the G200s mining area.

Arrow Energy operates an extensive CSG production field in PL 191 which overlies a significant portion of the Grosvenor Mining Lease and G200s mining area. Figure 4 shows the location of PL 191 and the CSG production wells near the G200s mining area.

The potential for cumulative groundwater impacts associated with the surrounding land use is discussed in Section 8.6.

3.2 Terrain and drainage

The Grosvenor Mining Lease and the G200s mining area are located in the Isaac River catchment, a sub-basin of the upper Fitzroy Basin.

The Isaac River traverses the north-eastern corner of the G200s mining area in a south-easterly direction. The Isaac River traverses Moranbah North mining area and the approved Grosvenor mining area immediately upstream and downstream of the G200s mining area, respectively (Figure 5). The Isaac River and its tributaries exhibit highly ephemeral, short duration, surface water flows that are typically restricted to the wet season (i.e. November to April).

The local topography is shown on Figure 5. The topography of the G200s mining area is characterised by two broad, gently sloping valleys in the north and south of the G200s mining area that slope from an elevated ridgeline in the west to the low-lying Isaac River floodplain in the east. These valleys are separated by a subtle ridgeline that runs east-west through the centre of the G200s mining area.

These ridgelines form local catchment boundaries as shown on Figure 5. The northern and southern parts of the G200s mining area are located within local catchments that are drained by minor unnamed drainage flowpaths. These drainage flowpaths typically drain in an easterly to south-easterly direction towards the main channel of the Isaac River.

The north-eastern corner of the G200s mining area is located on the flatter terrain of the Isaac River floodplain. This area drains directly to the main channel of the Isaac River.

There are no known springs or seeps in the vicinity of the G200s mining area.

3.3 Climate

The climate of the Moranbah area is sub-tropical characterised by high variability in rainfall, temperature and evaporation, typical of Central Queensland.

Long-term climate data collected by the Bureau of Meteorology (BoM) is available from two weather stations in Moranbah. The Moranbah Water Treatment Plant weather station (Station No. 034038) has a continuous climate record for the period 1972 to 2012 and is located approximately 4 km south-east of the G200s mining area. In 2012, the recording site was relocated approximately 9 km south-east to Moranbah Airport (Station No. 034035) which has a continuous climate record from 2012 to present.

These extensive regional datasets have been compared to an interpolated site-specific dataset obtained from the Scientific Information for Land Owners (SILO) service and provided by the Department of Science, Information Technology, Innovation and the Arts (DSITIA). The data is a 'patched point dataset', meaning that missing or suspect values are 'patched' with interpolated data. Table 1 details the average monthly rainfall from the SILO data, as well as from the BoM stations (Moranbah Water Treatment Plant and Moranbah Airport).

Table 1 Climate data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall (mm)													
Site SILO data*	132.2	111.1	72.6	30.4	27.6	19.9	16.2	19.2	9.9	26.6	64.1	89.4	612.6
BOM weather station data	93.3	98	47.5	34.6	30.1	19.9	17.8	22.9	8.5	31.3	62	92.8	555.9
Evaporation (mm)													
Site SILO data*	197	163.1	168.2	136.4	111.2	90.7	101.7	129.3	166.1	206	211.2	217.4	1,871.3

Note: ** monthly average based on SILO patched point data from 1972 to 2016.*

Recent rainfall years have been put into historical context using the Cumulative Rainfall Departure (CRD) method. This method is a summation of the monthly departure of rainfall from the long-term average monthly rainfall. A rising trend in the CRD plot indicates periods of above average rainfall, whilst a falling slope indicates periods when rainfall is below average.

Figure 6 presents the CRD graph for the Moranbah area. The CRD graph indicates that the area has experienced distinct cycles of above average and below average rainfall. The CRD graph indicates that the Moranbah area experienced generally below average rainfall between 2001 and 2007, and also 2008 to 2010. Conversely the area experienced above average rainfall in 2007, and between 2010 and 2012. Since 2012 rainfall has been in line with the long-term average.

4 Geological setting

The geological setting has been informed by the following data sources:

- geological logs and data compiled from exploration drilling across the G200s mining area, the Grosvenor Mining Lease, Moranbah North Mining Lease, and Moranbah South Project site;
- geological logs and data compiled from geotechnical drilling across the G200s mining area, the Grosvenor Mining Lease, Moranbah North Mining Lease, and Moranbah South Project site;
- geophysical data collected from the Moranbah North Mining Lease;
- high resolution geological model surfaces for the G200s mining area, the Grosvenor Mining Lease, Moranbah North Mining Lease, the Moranbah South Project site;
- geological data from registered bores held on the DNRM GWDB database;
- publicly available geological maps (Wyena and Harrybrandt 1:100,000 map sheets) and reports;
- geological data presented in the Grosvenor Mine, Moranbah South Project, and Red Hill EIS reports; and
- drilling data collected by Arrow Energy across PL 191 (Arrow Energy, 2016).

The proponent has undertaken extensive exploration drilling across the G200s mining area and its surrounds. Exploration drilling has confirmed the geological units present in the G200s mining area and in the surrounding area. The proponent has developed high-resolution geological models from the exploration drilling data which has been used to confirm the stratigraphy and distribution of geological units across the G200s mining area and surrounding area. The geological models provided the structural framework for developing a 3D numerical groundwater model by AGE. Appendix A provides a detailed description of the groundwater modelling approach.

4.1 Regional geology

The project is located on the north-western flank of the Bowen Basin which covers an area of approximately 160,000 km^2. The sediments which comprise the Bowen Basin were deposited on the Collinsville Shelf, a stable tectonic environment characterised by a monoclinal accumulation of sediments gently dipping (between two and eight degrees) and thickening to the east.

The Bowen Basin is a sedimentary basin comprising Permian to Triassic age geology. Regionally, a veneer of more recent Tertiary and Quaternary geology typically overlies the Bowen Basin strata. The stratigraphy of the Bowen Basin is shown in Table 2. Figure 7 shows the sub-crop of the main stratigraphic units within the project site and surrounds. Figure 8 shows the surface geology within the project site and surrounding area. Figure 9 presents a stratigraphic column for the G200s mining area. Figure 10 presents an east to west geological cross-section of the G200s mining area.

Table 2 Summary of regional geology

Basin	Age	Stratigraphic unit		Description
	Cainozoic (Quaternary / Tertiary)	Alluvium (Qa, Qpa, TQa)		Unconsolidated clays, silts, sands and gravels.
	Cainozoic (Quaternary / Tertiary)	Colluvium (Qr, TQr, TQr/f)		Clay, silt, sand, gravel and soil; colluvial and older residual deposits, ferruginous in places
	Tertiary	Suttor Formation (Tu)		Quartz sandstone, clayey sandstone, mudstone and conglomerate; fluvial and lacustrine sediments; minor interbedded basalt.
	Tertiary	Basalt (Tb)		Olivine rich Tuff and ash flows, massive and vesicular weathered to fresh basalt.
Bowen Basin	Triassic	Moolayember Formation (Rm)		Mudstone, lithic sandstone, interbedded siltstone, mudstone, sandstone and thin coal seams.
Bowen Basin	Triassic	Clematis Group (Re)		Cross-bedded quartz sandstone, some quartz conglomerate and minor red-brown mudstone.
Bowen Basin	Triassic	Rewan Group (Rr)		Green lithic sandstone, pebble conglomerate, red and green mudstone.
Bowen Basin	Permian	Blackwater Group	Rangal Coal Measures (Pwj)	Calcareous sandstone, calcareous shale, mudstone, coal, concretionary limestone.
Bowen Basin	Permian	Blackwater Group	Fort Cooper Coal Measures (Pwt)	Interbedded mudstone, sandstone, conglomerate, shale, tuff and coal.
Bowen Basin	Permian	Blackwater Group	Moranbah Coal Measures (Pwb)	Quartzose to sublabile, locally argillaceous sandstone, siltstone, mudstone, carbonaceous mudstone and coal. Contains the target GM seam.
Bowen Basin	Permian	Back Creek Group (Pb)	German Creek Formation	Quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite.

Regionally, the Permian Back Creek Group are the basal sequence within the project site and surrounding area. The Back Creek Group is unconformably overlain by younger Permian coal measures of the Blackwater Group. The Blackwater Group includes the Moranbah Coal Measures and the Fort Cooper Coal Measures which sub-crop within the G200s mining area, and the younger Rangal Coal Measures which sub-crop approximately 10 km east of the G200s mining area (Figure 7).

The Permian strata are overlain by a sequence of Triassic strata which form the upper sedimentary sequence of the Bowen Basin. The Triassic Rewan Formation sub-crops 10 km east of the G200s mining area, while the younger Clematis Sandstone and Moolayember Formation sub-crop approximately 25 km east of the G200s mining area (Figure 7).

Tertiary basalt flows are present regionally and are typically located within palaeochannels incised into the Permo-Triassic sediments. The majority of the Tertiary basalt flows are concealed beneath Tertiary and Quaternary age sediments. Quaternary deposits are associated with the floodplain of the present day Isaac River.

The regional geology exhibits an extensive weathering profile, most notably within the upper Permian coal measures and the upper Tertiary basalt. Surficial weathering is typically present as a thin heterogeneous layer of unconsolidated material (regolith).

4.2 Geology of the G200s mining area

The following main stratigraphic units occur within the G200s mining area and surrounds (from oldest to youngest):

- Back Creek Group (German Creek Formation);
- Moranbah Coal Measures;
- Fort Cooper Coal Measures;
- Tertiary basalt;
- Tertiary Suttor Formation sediments and associated Cainozoic colluvium; and
- Cainozoic (i.e. Quaternary and Tertiary) alluvium.

Each of the main stratigraphic units is discussed in further detail below.

4.2.1 *Back Creek Group (German Creek Formation)*

The German Creek Formation is the uppermost unit of the Back Creek Group at the G200s mining area and comprises quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite. The Back Creek Group is the base unit of the Bowen Basin at the G200s mining area and underlies the Moranbah Coal Measures, which contain the target coal seams for the project. The Back Creek Group sub-crops approximately 2 km west of the G200s mining area.

4.2.2 *Moranbah Coal Measures*

The Moranbah Coal Measures conformably overlies the German Creek Formation and comprises quartzose to sublabile, locally argillaceous sandstone, siltstone, mudstone, carbonaceous mudstone and coal. The Moranbah Coal Measures is approximately 160 m to 460 m thick within the G200s mining area, and gradually thickens down dip to the east.

The Moranbah Coal Measures contains several coal seams. The target coal seam for the project is the Goonyella Middle (GM) seam which is typically 4.5 m to 5.5 m thick within the G200s mining area, splitting and thinning towards the south-east. The depth of the target GM seam is between 80 m and 390 m within the G200s mining area (Figure 11). The GM seam will be extracted at depths from 100 m to 380 m within the proposed longwall panels.

Other coal seams in the Moranbah Coal Measures include the Q seam - P seam sequence, Harrow Creek, and Dysart seams. Arrow Energy targets the Q, seam - P seam sequence along with the GM seam as a part of their CSG production. The Q seam sequence comprises of two seams, QA seam and QB seam which spilt and coalesce within much of the G200s mining area and surrounding area.

A weathered profile occurs across the palaeo surface of the Moranbah Coal Measures. The weathering is present in the upper 30 m of the formation and is characterised by clay bound sediments.

4.2.3 *Fort Cooper Coal Measures*

The Fort Cooper Coal Measures conformably overlies the Moranbah Coal Measures and comprises interbedded mudstone, sandstone, conglomerate, shale, tuff and coal. The base of the Fort Cooper Coal Measures is delineated by the Fair Hill seam which sub-crops within the north-eastern corner of the G200s mining area (Figure 7) and reaches a maximum thickness of approximately 200 m.

A weathered profile occurs across the palaeo surface of the Fort Cooper Coal Measures. The weathering is present in the in the upper 30 m of the formation and is characterised by clay bound sediments consistent with the weathering of the Moranbah Coal Measures.

4.2.4 *Tertiary basalt*

Widespread Tertiary volcanism produced extensive basalt flows which in-filled topographic lows associated with palaeo drainage lines.

The Tertiary basalt underlies Tertiary sediments and overlies weathered Permian strata at the G200s mining area. The Tertiary basalt typically occurs as a single composite unit comprising massive and vesicular lava, tuff and ash flows.

Figure 12 presents the mapped extent and thickness of the basalt at the G200s mining area. Within the project site, the basalt flows are thickest within the palaeo channel of the Isaac River where they are up to 102 m thick. The upper 0 m to 55 m of the basalt profile is highly weathered and comprises a basaltic clay. The weathered Tertiary basalt outcrops in the south-east of the G200s mining area. The maximum thickness of fresh basalt within the G200s mining area is 65 m.

The Tertiary basalt is underlain by localised deposits of Tertiary alluvium that were present within the palaeochannels at the time the basalt flows were extruded. The Tertiary alluvium comprises medium to coarse grained sand and is informally referred to as Tertiary basal sand due to its association with the base of the basalt unit. Where present, the Tertiary basal sand is less than 5 m thick and laterally discontinuous, and instead forms discrete sandy lenses below the basalt.

4.2.5 *Tertiary Suttor Formation*

The Tertiary Suttor Formation comprises a heterogeneous profile of semi-consolidated quartz sandstone, clayey sandstone, mudstone and conglomerate; fluvial and lacustrine sediments; and minor interbedded basalt.

The Suttor Formation has been extensively weathered and reworked during the Tertiary and Quaternary periods, resulting in an upper profile that includes Tertiary and Quaternary colluvial sheetwash deposits and residual soils (regolith) that comprise clay, silt, sand, gravel and soil. The colluvium and regolith exhibit similar properties to each other and are considered comparable due to the predominance of clays. These sediments are also lithologically comparable to the underlying parent rock of the Suttor Formation.

The Suttor Formation and associated sediments generally form a veneer across the underlying basalt and Permian coal measures. Within the G200s mining area the sediments overlie and obscure the Tertiary basalt, and where the basalts are absent, directly overlie the Permian coal measures. Within the G200s mining area these sediments range from 5 m to 72 m thick (Figure 13).

4.2.6 *Alluvium*

Figure 14 shows the extent and thickness of alluvium based on surface geology maps and drilling data.

The alluvium within the G200s mining area comprises several comparable units, including:

- Quaternary alluvium including:
  - o thin beds sands comprising up to 4.9 m of medium to coarse grained sand confined to the present day incised channel of the Isaac River; and
  - o river bank and flood deposits located away from the current Isaac River channel comprising up to 23 m of sand, gravel, clay and silt.
- Tertiary alluvium comprising up to 20 m of red-brown mottled, poorly consolidated sand, silt, clay, minor gravel; high-level alluvial deposits, generally dissected, and related to present stream valleys.

Quaternary and Tertiary aged alluvial sediments are located within and adjacent to the G200s mining area. The sediments are associated with flood deposits and present day stream channels and older alluvial sediments on high terraces. These deposits comprise clay, silt, sand, and gravel and unconformably overlie the semi-consolidated Tertiary sediments, basalt, and Permian coal measures.

Drilling data indicates that the alluvial sediments can be up to 23 m thick near the G200s mining area, however the thickness of the sediments can vary considerably. Geotechnical drilling and ground penetrating radar investigations undertaken at Moranbah North Mine indicated the alluvium was between 2.4 m and 14.2 m thick, whilst the maximum thickness of the bed sands was 4.9 m. Due to the deep incision of the current Isaac River channel, the alluvium was thinnest below the current river channel.

The alluvial sediments are lithologically equivalent and can be considered a single geological unit for the purposes of this groundwater assessment. These sediments are also lithologically distinct from the colluvial and Suttor Formation sediments which exhibit a higher clay component.

4.3 Geological structure

No significant or extensive faults have been detected within the G200s mining area or its surrounds.

Approximately 13 km east of the G200s mining area (Figure 7), the Jellinbah Thrust Fault system is a north-west trending fault zone, which can be traced for over 30 km and has vertical displacement in the order of 600 m to 800 m. The system comprises mostly low angle thrust faults which propagate into the Permian coal measures. The trend of the fault system correlates to the north-west trending synclinal axis of the Bowen Basin. The fault has resulted in the displacement and resultant juxtaposition of distinctly different geological units either side of the fault. Therefore the fault zone represents a regional boundary to groundwater flow.

5 Investigation methodology

This section outlines the methodology adopted for the collection of hydrogeological data to inform the groundwater assessment.

5.1 Overview of methodology

A detailed background study was undertaken to develop an understanding of the hydrogeological setting of the G200s mining area. This included:

- review and interpretation of geological, geotechnical and groundwater studies and other relevant technical reports including reports prepared in relation to Grosvenor Mine, Moranbah North Mine, and Moranbah South Project;
- review and interpretation of geological, geotechnical and groundwater studies and other relevant technical reports prepared by Arrow Energy for PL 191;
- review and interpretation of regional and local geological data, including an extensive exploration and geological database collected by the proponent;
- review of hydrogeological data from the DNRM GWDB for existing registered private groundwater bores; and
- completion of a census of unregistered private bores to confirm groundwater use and quality in the vicinity of the G200s mining area.

All relevant hydrogeological data was compiled and analysed to conceptualise the groundwater regime. A numerical groundwater model was developed to predict the scale and extent of any changes to the groundwater regime throughout the mine operations phase and post closure. These predictions were used to assess the potential project and cumulative impacts on groundwater resources, levels, quality, and users. Appropriate groundwater monitoring and management strategies were developed to address any potential for significant adverse impacts and validate the findings of the assessment.

5.2 Previous Investigations

The G200s mining area is located within the northern Bowen Basin in a hydrogeological setting that has been extensively investigated as part of mining approvals and operations.

Recent groundwater studies undertaken in the vicinity of the G200s mining area have been reviewed to establish the existing groundwater regime and collect data on hydrogeological parameters of the local geology. Data was collected from the following key groundwater studies undertaken in the vicinity of the G200s mining area:

- AGE (2013) provides a groundwater investigation and impact assessment as part of the Moranbah South Project Environmental Impact Statement (EIS). A numerical groundwater model was developed to assess the potential impacts to groundwater from the Moranbah South Project.
- Arrow Energy (2016) Underground Water Impact Report (UWIR) provides information on the potential decline in water levels in aquifers due to the removal of associated water during CSG extraction and production testing. A numerical model is used to predict impacts and forecast water production.
- JBT Consulting (2010) provides a groundwater investigation and impact assessment as part of the Grosvenor Mine EIS. Analytical methods were used to assess the potential impacts to groundwater from Grosvenor Mine.

- Matrix Plus (2009) provides a groundwater investigation and impact assessment as part of the Integrated Isaac Plains Project (IIPP) EIS. A numerical groundwater model was developed to assess the potential impacts to groundwater from the IIPP.
- URS (2013) provides a groundwater investigation and impact assessment as part of the Red Hill EIS. A numerical groundwater model was developed to assess the potential impacts to groundwater from the Red Hill Project, and included mitigation measures and monitoring recommendations.
- URS (2009) provides a groundwater investigation and impact assessment as part of the Caval Ridge EIS. Analytical methods were used to assess the potential impacts to groundwater from Caval Ridge Mine.

The G200s mining area is located within the western portion of the Grosvenor Mining Lease. The Grosvenor Mining Lease is also adjacent to the Moranbah South Project site. The geological setting of the G200s mining area, the Grosvenor Mining Lease and the Moranbah South Project site are therefore comparable, and where key stratigraphic units are present on each site these can be considered equivalent.

The groundwater data reported in these studies has been used to inform the groundwater assessment.

5.3 Groundwater monitoring networks

5.3.1 *Anglo American*

The proponent established a groundwater monitoring network in the mid-1990s as part of exploration drilling investigations and compliance monitoring for established mining activities at Moranbah North Mine. These investigations included the installation of a monitoring bore network, collection of permeability data in all major stratigraphic units, water quality sampling and analysis, and a bore census of surrounding private bores.

The regional groundwater monitoring network currently comprises a total of 68 groundwater monitoring bores, and 33 vibrating wire piezometers (VWPs) in 15 holes across the Moranbah North Mining Lease, Moranbah South Project site, and the Grosvenor Mining Lease (Figure 15 and Figure 16). In addition to the existing monitoring network, the proponent has also collected data from a further 29 historical groundwater monitoring sites which includes groundwater monitoring bores and open exploration holes. Figure 15 and Figure 16 show the location of all current and historical bores, VWPs, and exploration holes used for groundwater monitoring.

A total of 569 samples were collected from 48 sampling rounds between July 2010 and November 2015. The samples were analysed for electrical conductivity (EC), total dissolved solids (TDS), and pH. Of these, 425 samples were analysed for major cations and anions, trace metals, nutrients and total petroleum hydrocarbons (TPH).

Hydraulic conductivity was measured in each of the major stratigraphic units within 34 bores. Methods used to collect the data included falling head and rising head tests on monitoring bores, packer tests on open holes, and an 8 hour constant rate pumping test.

Groundwater data collected from this monitoring network has been compiled and assessed as part of this groundwater assessment.

5.3.2 *Arrow Energy*

As discussed in Section 3.1, Arrow Energy operates an extensive CSG production field in PL 191 which overlies a significant portion of the Grosvenor Mining Lease (Figure 4).

Arrow Energy maintains a network of seven groundwater monitoring bores and eight VWPs in five wells within the vicinity of the G200s mining area (Figure 15 and Figure 16), Appendix B lists the Arrow bores and provides construction details.

A total of 80 samples collected from 12 sampling rounds were collected between February 2012 and November 2015. The samples were analysed for EC, TDS, and pH, major cations and anions, trace metals, nutrients and TPH.

A total of 44 falling head and rising head tests measured in each of the major stratigraphic units within 21 bores.

5.3.3 *DNRM groundwater database of registered bores*

Publicly available data from the DNRM GWDB is incorporated into the study which included lithology logs for the Arrow Energy groundwater monitoring network and one private bore.

5.3.4 *Summary*

Figure 15 and Figure 16 show the location of all regional groundwater monitoring bores for which groundwater monitoring data was available. The monitoring network includes bores held by the proponent and Arrow Energy as a part of their UWIR groundwater monitoring network. Details of all groundwater monitoring bores near the G200s mining area are presented in Appendix B.

6 Groundwater data and results

This section provides a summary of the data analysis for all available data.

6.1 Groundwater distribution and flow

Groundwater level readings provide useful information on the vertical and lateral hydraulic gradients, and can also be used to interpret hydraulic conditions such as groundwater distribution, recharge, flow, and discharge.

Figure 17 presents groundwater level hydrographs for groundwater monitoring bores located within the Quaternary and Tertiary geology, where water is present. Figure 18 presents groundwater level hydrographs for groundwater monitoring bores located within the Permian coal measures. Figure 19 and Figure 20 present horizontal hydraulic gradients, showing interpolated equipotential groundwater elevation contours for the two main groundwater bearing units, the Tertiary basalt and target coal seam (GM seam).

The Tertiary and Quaternary sediments are largely unsaturated in the vicinity of the G200s mining area, hence representative groundwater contours cannot be produced from the available data. However, modelled groundwater elevations and saturated extents within these units have been developed and are presented in Appendix A.

Key trends demonstrated by water level data are as follows:

- The alluvium is saturated at the northern boundary of the G200s mining area, the groundwater level in this area is approximately 209 mAHD. Elsewhere within the G200s mining area the alluvium is unsaturated. Saturated alluvium is present approximately 1 km southeast of the G200s mining area. Regional groundwater levels in the alluvium are between 197 m AHD and 209 mAHD.
- Groundwater levels in Tertiary and shallow Permian strata are similar. The regional groundwater table typically lies within the Tertiary units. Groundwater levels within the Tertiary sediments and basalt are between 170 mAHD and 250 mAHD. The range in recorded levels is influenced by regional topography and mining operations.
- Groundwater levels in the Permian coal measures range from 0 mAHD to 222 mAHD. Groundwater levels are lowest in the vicinity of Arrow Energy CSG operations (as shown on Figure 20) and Moranbah North Mine. Higher groundwater levels are recorded away from these activities. Topography has a secondary influence on groundwater levels in the Permian coal measures in the vicinity of the G200s mining area. This data shows that the Permian coal measures are highly impacted by existing mining and CSG production.

A GPR survey completed at Moranbah North Mine indicates that the bed sands are generally unsaturated. However, the extent and degree of saturation depends upon surface water flow in the Isaac River (JBT Consulting, 2010). Furthermore, available drilling data for the Grosvenor Mining Lease indicates that the alluvium adjacent to the river is generally dry to a depth below the base of the bed sands (JBT Consulting, 2010). This suggests that any groundwater within the alluvium is limited to deeper parts of the alluvium in those areas where the alluvium extend below the regional water table.

6.2 Hydraulic conductivity data

Figure 21 graphs the results of extensive in-situ permeability testing collated from previous groundwater investigations in the G200s mining area and nearby mines, including:

- one pumping test within the Grosvenor Mining Lease;
- 40 packer tests at the Moranbah South Project site; and
- 74 falling head / rising head tests, including:
    - 14 tests in 14 bores at Moranbah North Mine;
    - 13 tests in 13 bores at Moranbah South; and
    - 44 tests in 21 Arrow Energy groundwater monitoring bores.

Hydraulic conductivity data shown in Figure 21 highlights the heterogeneous nature of the alluvium. Higher values are likely to correspond to thicker sequences of saturated, unconsolidated sands and gravels whereas lower values reflect deposits that are partially saturated or more cohesive. Table 3 summarises the range of hydraulic conductivity values available for the alluvium.

Table 3 Hydraulic conductivity of the alluvium at nearby mines

Project	Hydraulic conductivity (m/day)	
	Min.	Max.
Moranbah South	0.007	4.2
Caval Ridge Project	0.09	0.4
Isaac Plains South Project	2.3	3.6

Table 4 presents a summary of the hydraulic testing which target the Fort Cooper Coal Measures and Moranbah Coal Measures. Figure 21 presents the range of hydraulic conductivity values measured in proximity to the G200s mining area. The data show a significant range of hydraulic conductivities across the Permian coal measures.

Table 4 Hydraulic conductivity ranges for the Permian coal measures

	Fort Cooper Coal Measures		Moranbah Coal Measures	
	sediments (interburden)	coal seams	sediments (interburden)	coal seams
No. of tests	2	5	8	21
Range (m/day)	0.2-0.4	0.0004-2.5	0.00002-3	0.005-0.8
Median (m/day)	0.3	0.4	0.006	0.06

Key trends demonstrated from recorded data include:

- The Quaternary alluvium generally exhibits a higher hydraulic conductivity than the underlying Tertiary sediments.
- The Tertiary basalt shows a range of hydraulic conductivity that reflects the compartmentalised nature of these materials, with lower hydraulic conductivity recorded in the massive, low primary porosity basalt and higher hydraulic conductivity recorded in areas where the basalt is vesicular or highly fractured. In addition, the upper weathered basalt typically shows a lower hydraulic conductivity than the fresh basalt.
- On average, the Permian coal seams exhibit a higher hydraulic conductivity than the other interburden and overburden sediments of the Permian coal measures.
- The range in hydraulic conductivity reflects testing of both very tight mudstones and fractured horizons within the Permian strata. Furthermore, the hydraulic conductivity reduces with depth; therefore, the large range can also be attributed to the thickness of the unit and variation in the depth of the test intervals.

6.3 Groundwater quality

Groundwater quality data provides useful information on the geology and groundwater regime. This data can also be assessed against the known uses and values of groundwater. A review of 617 groundwater samples, including 505 for major ion analysis was completed for the project. The samples were collected between February 2012 and November 2015 from monitoring bores at Moranbah North Mine, Grosvenor Mining Lease, and the Moranbah South Project site as well as the Arrow Energy UWIR groundwater monitoring bore network. Appendix C presents a full summary of the water quality data.

Salinity is a key constraint to water management and groundwater use, and can be described by TDS concentrations. TDS concentrations are commonly classified on a scale ranging from fresh to extremely saline. FAO (2013) provide a useful set of categories for assessing salinity based on TDS concentrations as follows:

fresh water	<500 mg/L
brackish (slightly saline)	500 to 1,500 mg/L
moderately saline	1,500 to 7,000 mg/L
saline	7,000 to 15,000 mg/L
highly saline	15,000 to 35,000 mg/L
brine	>35,000 mg/L

Figure 22 shows a histogram of the average TDS for each screened geology unit. Groundwater quality has also been assessed in terms of the environmental values to be protected or enhanced in the vicinity of the G200s mining area (i.e. stock water use). For the purposes of this assessment, groundwater salinity data has been compared to guideline values from the National Water Quality Management Strategy Paper 4: Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) (the ANZECC guidelines). A complete assessment of baseline groundwater quality is provided in Section 7. The proportions of the major anions and cations was analysed to determine the hydrochemical facies of the groundwater. The anion-cation balance is shown on the Piper diagram in Figure 23, which is based on the averaged groundwater quality results for the key stratigraphic units, presented in Appendix C.

Key trends demonstrated by the water quality data include:

- The Tertiary sediments, Tertiary basalt, and the Permian coal measures all yield highly variable water quality ranging from slightly brackish to highly saline.
- The localised Tertiary basal sand yields highly saline water.
- The limited occurrences of groundwater within the Isaac River alluvium are brackish to saline.
- Groundwater near the G200s mining area is predominantly Na-Cl type. There is a trend from no dominant cation towards Na dominant (i.e. towards increasing salinity).
- The piper diagram also shows a natural trend of carbonate dissolution in the unsaturated zone during recharge, followed by precipitation as groundwater moves through the groundwater regime.
- Groundwater samples from the Fort Cooper Coal Measures and the Moranbah Coal Measures show a distinct cation speciation. The Fort Cooper Coal Measures show no dominant cation whereas most samples from the Moranbah Coal Measures are Na dominant. The Fort Cooper Coal Measures overlie the Moranbah Coal Measures and this difference may reflect younger groundwater closer to the recharge source where the Ca and Mg have not had time to precipitate.
- The Isaac River alluvium shows two distinct anion speciations. Firstly, groundwater with no dominant anion which may indicate the water represents recent recharge. Secondly, Na:Cl type groundwater which may indicate connection to the underlying Tertiary groundwater regime.
- Groundwater from the all bores show levels of sodium and chloride above acceptable limits for drinking water guidelines. As a result groundwater is not suitable for drinking water.
- A small proportion of bores show TDS concentration within acceptable limits for livestock watering (cattle). These bores predominantly screen the Tertiary basalt and Permian coal measures.
- A single exceedance for aluminium and two for mercury across all samples for livestock watering guidelines. All other samples were within acceptable limits.
- The data shows that the groundwater at the G200s mining area is not suitable for drinking water supply. Although, it is generally suitable for livestock watering (cattle), the groundwater quality in some bores is outside the allowable limits and therefore as a whole the area would be considered marginal for livestock watering.

6.4 Bore census

The Queensland Government maintains a database with the details of private groundwater bores (QLD Govt. 2016). There are no registered bores within 5 km of the G200s mining area that are used for private water supply.

The proponent undertook a census of surrounding landholders within the immediate vicinity of the G200s mining area in order to confirm the database findings and identify whether any unregistered landholder bores were present in the surrounding area. Based upon feedback from landholders, no private water supply bores were identified within 5 km of the G200s mining area.

6.5 Groundwater inflows to existing mines and coal seam gas operations

6.5.1 *Arrow Energy*

Figure 4 presents the Arrow Energy production well network within PL 191 which overlies much of the Grosvenor Mining Lease, and a portion of the proposed G200s mining area. Arrow Energy is currently extracting CSG from the GML, GM, P, and Q seams and is producing associated groundwater as a result of these operations (Arrow Energy, 2016). Table 1 presents the historical water production and production testing data for PL 191.

Table 5 Historical water production in Megalitres (ML) and production testing data

Target seam	Production		Production testing	
	Year 2003-2011	Year 2012-2015	Year 2003-2011	Year 2012-2015
Q Seam	22.2	0	0	0
P Seam	1038.5	421.2	0	0
GM Seam	1439.4	697.9	0	0
Moranbah Coal Measures[1]	105.4	99.5	4.5	30.2
Fort Cooper Coal Measures and Moranbah Coal measures	0	0	29	0
Total	**2605.5**	**1218.6**	**33.5**	**30.2**

Note: *[1]take from multiple seams including: GML, GM, P, and Q seams*

Most of the water removed due to CSG production to date is from the GM seam. The average rate at which groundwater has been removed is approximately 7 L/s across the entire well field (219 wells in PL 191).

6.5.2 *Grosvenor Mine*

Figure 1 shows the location of Grosvenor Mining Lease. Longwall mining commenced in the approved Grosvenor mining area in May 2016. JBT Consulting (2010) estimated groundwater inflows into the Grosvenor Mine will be in the order of 190 megalitres per year (MLpa); this estimate takes into account depressurisation from Moranbah North Mine and Arrow Energy operations.

6.5.3 *Moranbah North Mine*

Water balance modelling at Moranbah North Mine indicates recent inflow rates are approximately 400 MLpa. Inflows into Moranbah North Mine are primarily from the Moranbah Coal Measures (GM seam) and the overlying Tertiary basalt. The variability of groundwater inflows is attributed to the hydraulic variability of the Tertiary basalt.

7 Existing hydrogeology

This section details the existing hydrogeology of the G200s mining area and its surrounds, by describing the hydrogeological properties of each geological unit based on the data collected (Section 6).

Within the project site, the following stratigraphic units are identified within the existing groundwater regime and surrounds:

- Alluvium;
- Tertiary sediments (comprising the Tertiary Suttor Formation and Cainozoic colluvium);
- Tertiary basalt (including basal sands); and
- Permian coal measures (comprising the Fort Cooper Coal Measures and the Moranbah Coal Measures).

In the G200s mining area, the primary groundwater bearing units are the Tertiary basalt and the Permian coal seams. As discussed in Section 4.2, the Tertiary sediments comprise the Suttor Formation, colluvium and residual soil deposits. These materials are lithologically and hydraulically equivalent and are therefore considered to form a single hydrogeological unit, hereafter referred to as the Tertiary sediments. Furthermore, the Tertiary and Quaternary age alluvial sediments, shown on Figure 8, are also considered hydrogeologically equivalent and are hereafter referred to collectively as alluvium.

The following sections discuss the groundwater distribution, quality, hydraulic characteristics, and groundwater use associated with each of these hydrogeological units.

7.1 Alluvium

7.1.1 *Groundwater distribution*

The alluvium comprises of clay, silt, sand, and gravel associated with present day stream channels and flood deposits and unconformably overlies the semi-consolidated Tertiary sediments, Tertiary basalt and Permian coal measures.

The alluvial thickness is known to vary along the length of the Isaac River. Beds sands within the present day incised channel of the Isaac River are less than 5 m thick within the G200s mining area. Floodplain deposits outside the channel are up to 23 m thick at the G200s mining area. The thickness of the alluvium is shown on Figure 14.

Bedrock highs of the underlying geology will act to separate any localised zones of saturated alluvium. This will result in no direct connection between the zones of saturated alluvium.

The extent and thickness of saturation in the alluvium is shown in Figure 24. The alluvium is locally saturated in a limited area adjacent to the north-eastern corner of the G200s mining area where the alluvium is thickest. There is up to 4 m of saturated alluvium in a small area within the G200s mining area. The alluvium is otherwise unsaturated in the majority of the G200s mining area and the immediate upstream and downstream surrounds.

7.1.2 *Hydrogeological parameters*

The hydraulic conductivity of the alluvium is highly variable and ranges from 8.9 m/day to 45 m/day (geometric mean of 17 m/day) for the bed sands and 0.01 m/day and 5.4 m/day (geometric mean of 0.3 m/day) for the river bank deposits.

The bed sands are not laterally extensive and are confined to the present day channel. The alluvium primarily comprises of the lower permeability flood and river bank deposits, and therefore the average hydraulic conductivity of the alluvium is expected to be at the lower end of the test results.

7.1.3 *Recharge, flow, and discharge*

Recharge to the alluvium occurs in three ways, these include:

- via direct rainfall on to the alluvium;
- via seepage through the stream bed, when the Isaac River is flowing; and
- via the underlying groundwater regime when the alluvium extend below the water table and there is no seepage from the stream bed.

Stream gauging data upstream of the G200s mining area indicates surface water flow along the Isaac River dissipates relatively quickly after flow events. Therefore, recharge from stream flow would occur over short time periods as the water infiltrates relatively rapidly through the alluvium to the groundwater table.

Groundwater levels in the Tertiary basalt can be higher than the base of the alluvium. In these areas the Tertiary basalt and the alluvium are likely to be hydraulically connected. The Tertiary basalt may discharge into the alluvium during periods of no flow in the Isaac River. However, water quality data shows that alluvial groundwater is recent in age (reflective of stream recharge events) and therefore the recharge component of older groundwater from the underlying Tertiary basalt will be relatively small.

The groundwater flow direction in the alluvium is from north-west to south-east and follows the gradient and alignment of the Isaac River.

In the vicinity of the G200s mining area, discharge will occur from the alluvium via seepage to the underlying Permian coal measures, Tertiary basalt and Tertiary sediments. However this will only occur in areas where the alluvium is saturated and a downward vertical hydraulic gradient to the underlying strata occurs.

As the alluvium is largely unsaturated, there is no significant interaction with surface waters within the vicinity of the G200s mining area.

7.1.4 *Groundwater quality*

Alluvial groundwater is brackish to moderately saline and is elevated relative to the low salinity of ephemeral surface water flows in the Isaac River (Figure 22). The range in salinity of the alluvial groundwater highlights two recharge mechanisms.

Firstly, the brackish samples are only slightly more saline than the Isaac River surface water. This relatively small increase in salinity can be attributed to evaporative concentration and dissolution of ions over short residence times within the alluvium. This increased salinity within the alluvium is consistent with the recharge from surface water flows. Secondly, higher concentrations of dissolved solids may be due to recharge of more saline water from the underlying groundwater system.

The groundwater quality results are therefore consistent with the recharge mechanisms described in Section 7.1.3.

7.1.5 *Yields and use*

No groundwater supply bores are located in the alluvium in the vicinity of the G200s mining area due to the general lack of saturation or reliable water supply in these sediments.

7.2 Tertiary sediments

7.2.1 *Distribution*

The Tertiary sediments of the Suttor Formation comprise a heterogeneous profile of semi-consolidated quartz sandstone, clayey sandstone, mudstone and conglomerate; fluvial and lacustrine sediments; minor interbedded basalt. The sediments generally form a widespread shallow cap across the region, although the sediments can be up to 72 m thick.

The Suttor Formation has been extensively weathered and reworked during the Tertiary and Quaternary periods, resulting in an upper profile that includes Tertiary and Quaternary colluvial sheetwash deposits and residual soils (regolith) that comprise clay, silt, sand, gravel and soil. The colluvium and regolith exhibit similar properties to each other and are considered comparable due to the predominance of clays. These sediments are also lithologically comparable to the underlying parent rock of the Suttor Formation.

The Tertiary sediments do not contain significant volumes of groundwater and are often dry.

Groundwater within the Suttor Formation is hydraulically connected to the underlying groundwater regime (Tertiary basalt and Permian coal measures) and is only present where the Tertiary sediments extend below the water table. The extent and thickness of saturated Tertiary sediments is shown on Figure 25.

7.2.2 *Hydrogeological parameters*

Hydraulic testing data indicates the Tertiary sediments have a low hydraulic conductivity ranging from 7×10^{-4} m/day to 0.3 m/day with a median of 0.1 m/day.

Figure 21 shows that the hydraulic conductivity of this unit is lower than the overlying alluvium and comparable to the underlying weathered basalt, and supports the assessment that this layer is not a significant aquifer.

7.2.3 *Recharge, flow, and discharge*

Recharge to the Tertiary sediments occurs via direct infiltration from rainfall in areas where the unit outcrop and via seepage from the overlying Isaac River and alluvium, where present.

Regional groundwater flow direction in the Tertiary sediments is towards the south-east. Flows are locally influenced by mining and CSG production and groundwater within the Tertiary sediments in the northern part of the G200s mining area flows towards Moranbah North Mine.

Discharge predominantly occurs as seepage to the underlying Permian groundwater regime.

Due to the depth of groundwater in the Tertiary sediments, there is no significant interaction with surface waters within the vicinity of the G200s mining area.

7.2.4 *Groundwater quality*

Groundwater is slightly brackish to highly saline. The groundwater is generally unsuitable for stock watering.

7.2.5 *Yields and use*

There are no known groundwater supply bores in the Tertiary sediments within 5 km of the G200s mining area. This is due to the limited yield and lack of reliable water supply in these sediments.

7.3 Tertiary basalt

7.3.1 *Distribution*

The Tertiary basalt underlies Tertiary sediments and overlies weathered Permian strata at the project site and typically occurs as a single composite unit comprising massive and vesicular lava, tuff and ash flows. Within the project site, the basalt flows are thickest within the palaeochannel of the Isaac River where they are up to 102 m thick (Figure 12). The upper 55 m of the basalt profile is highly weathered and comprises a basaltic clay. The weathered Tertiary basalt outcrops in the south-east of the G200s mining area. The maximum thickness of fresh basalt within the G200s mining area is 65 m.

The hydraulic properties of the basalt can vary considerably as groundwater is primarily stored within highly compartmentalised fractures and vesicular zones. Massive zones without either of these properties will have a very low hydraulic conductivity. Furthermore, highly weathered basalt breaks down to clay with a very low hydraulic conductivity. Therefore, shallow highly weathered basalt will generally not contain significant groundwater and can act as a barrier to flow. In contrast, localised vesicular and fractured zones can store and transmit larger volumes of groundwater.

The extent and thickness of saturated Tertiary basalt is shown on Figure 26.

The Tertiary basal sands comprise medium to coarse grained unconsolidated sand. The basal sands are thin (less than 5 m thick) and not laterally extensive. They form discrete lenses below the basalt restricted to former creek beds of the palaeo-Isaac River system. The Tertiary basal sands are hydraulically connected to the overlying basalts and together they form a single aquifer system.

7.3.2 *Hydrogeological parameters*

Figure 21 indicates the weathered basalt (0.002 m/day to 2.6 m/day, average 0.02 m/day) has a lower hydraulic conductivity compared to the fresh basalt (0.03 m/day to 6.5 m/day, average 0.1 m/day). The weathered basalt is generally less permeable than the fresh basalt, the large range in the hydraulic conductivity data highlights the heterogeneous nature of basalt.

The storage coefficient of the Tertiary basalt is between 0.01 and 0.0003.

Although, no hydraulic data is available for the Tertiary basal sand, the unit comprises of medium to coarse grained sand. The hydraulic conductivity is therefore expected to be in the range of 1 m/day to 50 m/day (Driscoll, 1986).

7.3.3 *Recharge, flow, and discharge*

Recharge to the Tertiary basalt and basal sand occurs via direct infiltration from rainfall in areas where the Tertiary basalt outcrops and via seepage from the overlying Tertiary sediments and alluvium, where present.

The regional groundwater flow direction in the Tertiary sediments is towards the south-east. Flows are locally influenced by mining and CSG production such that groundwater in Tertiary basalt in the northern part of the G200s mining area flows towards Moranbah North Mine (Figure 19).

Groundwater discharge from the Tertiary basalt occurs via passive drainage towards Moranbah North Mine and via seepage to the underlying Permian coal measures. Depressurisation of the underlying Permian coal measures has increased the vertical hydraulic gradient and seepage from the Tertiary basalt.

Due to the depth of groundwater in the Tertiary basalt, there is no significant interaction with surface waters or alluvial groundwater in the vicinity of the G200s mining area.

7.3.4 *Groundwater quality*

Groundwater in the Tertiary basalt and basal sand is fresh to highly saline. The suitability of this groundwater for cattle watering is therefore highly variable.

Groundwater in the Tertiary basalt trends between Na:HCO_3 type water to Na:Cl type water which reflects the variation in residence time in the aquifer.

7.3.5 *Yields and use*

Yields from the Tertiary basalt are variable due to its heterogeneous nature. Yields from exploration drilling indicate that air-lift flow rates from the Tertiary basalt aquifer are between 0.45 L/s in basalt and 12.9 L/s in the basal sands, with a mean of 3 L/s and median of 1.5 L/s.

There are no known groundwater supply bores in the Tertiary basalt within 5 km of the G200s mining area.

7.4 Permian coal measures

7.4.1 *Distribution*

The Permian coal measures include the Back Creek Group, Moranbah Coal Measures, and the Fort Cooper Coal Measures. They comprise alternating layers of fine to medium grained sandstone, siltstone, and coal. Hydraulic conductivity within the Permian coal measures is generally associated with secondary porosity through fractures, and cleats within the coal seams. The thick sequences of siltstone and sandstone interburden form confining aquitards within the coal measures.

The Permian coal measures are uniformly saturated within the G200s mining area. Where the coal measures sub-crop to the east and west of the G200s mining area they may become unsaturated. The coal seams have been extensively depressurised within the G200s mining area and its surrounds due to Arrow Energy CSG production and mining at Moranbah North Mine.

7.4.2 *Hydrogeological parameters*

The interburden of the Permian coal measures has a greater range of hydraulic conductivity than the coal seams and ranges from 0.2 x 10^{-5} to 2.95 m/day.

The median hydraulic conductivity of the coal seams and interburden of the Permian coal measures is 0.01 m/day and 0.07 m/day, respectively (Figure 21). The Permian coal seams exhibit a higher median hydraulic conductivity than the Permian interburden. The range within the interburden is a result of testing of both very tight mudstones and fractured horizons. Hydraulic conductivity reduces with increasing depth. As testing was undertaken at a range of depths within the coal measures, the range in hydraulic conductivity also reflects the depth profile of the coal measures.

7.4.3 *Recharge, flow, and discharge*

Groundwater recharge to the Permian coal measures is very low. Recharge occurs via the sub-crop west of the G200s mining area, and via downward seepage from overlying strata. Mining and CSG production have enhanced downward seepage from the overlying groundwater regimes due to the depressurisation of the coal seams.

Figure 20 presents the potentiometric surface for the GM seam. The undisturbed groundwater flow direction in the Permian coal measures is towards the south-east. However, depressurisation of the coal seams for CSG production and passive drainage into underground workings at Moranbah North Mine and Grosvenor Mine, have significantly altered the local groundwater flow direction. The Arrow Energy CSG production wells and existing underground mines represent groundwater sinks where groundwater drains towards these operations.

Groundwater discharge near the G200s mining area is dominated by CSG production in PL 191 and passive drainage towards Moranbah North Mine.

7.4.4 *Groundwater quality*

Groundwater is brackish to highly saline and is generally unsuitable for livestock watering.

7.4.5 *Yields and use*

Groundwater yields from the Permian coal measures are typically low, with a median yield of 0.8 L/s. This shows that there is no widespread potential for significant groundwater yields from the Permian coal measures. Higher yields have been measured in the Permian coal measures in localised areas where there was a contributing influence from the overlying aquifers. There are no known groundwater supply bores in the Permian coal measures within 5 km of the G200s mining area.

7.5 Summary of existing conceptual groundwater regime

This section describes the processes that control and influence the storage and movement of groundwater in the hydrogeological system. Figure 27 represents a cross-section through the G200s mining area (Figure 26), from west to east. The cross-section shows graphically the main processes and mechanisms influencing the groundwater regime including recharge, flow directions and discharge.

The geology comprises a relatively thin cover of Tertiary and Quaternary sediments and volcanics overlying Triassic strata and Permian coal measures which dip to the east. The main groundwater bearing units at the G200s mining area are the Tertiary basalt and the Permian coal seams. The Isaac River alluvium and Tertiary sediments do not form permanent, saturated aquifers, and persistent groundwater is expected only where these sediments extend below the regional water table.

Recharge at the G200s mining area occurs in two ways. Firstly via direct and diffuse rainfall to the Tertiary or alluvial cover, a portion of the rainfall moves downwards to the water table then moves through the system following the hydraulic gradient. Secondly recharge occurs via leakage from the alluvium during flow events in the Isaac River. Recharge to the Tertiary basalt and Permian coal measures will occur where the unit sub-crops below the Tertiary sediments or alluvium.

The groundwater flow direction in the Tertiary and Permian groundwater regime has been significantly altered by CSG production and mining operations near the G200s mining area. A zone of depressurisation above Moranbah North Mine results in groundwater within the Tertiary basalt flowing towards the mine via the Permian coal measures.

The Arrow Energy CSG production has resulted in significant depressurisation in the Permian coal measures. The sandstone and siltstone interburden form a confining aquitard over the floor and roof of the depressurised coal seams such that drawdown in the overlying Tertiary groundwater regime attributable to CSG production is minimal (Arrow Energy, 2016).

Groundwater quality across all groundwater regimes is highly variable ranging from slightly brackish to highly saline. There are no known groundwater users in the G200s mining area or its surrounds.

8 Impact assessment

8.1 Introduction

The proposed activities have the potential to impact on the groundwater regime of the region through:

- extracting coal by longwall mining and in so doing depressurising surrounding strata;
- fracturing of subsurface strata overlying the proposed longwall mine, changing the permeability of the overlying units and influencing groundwater levels; and
- use of hydrocarbons and chemicals which have the potential to give rise to groundwater contamination.

This section provides a detailed assessment of these potential impacts and is structured as follows:

- Section 8.2 provides an overview of the proposed underground mining activities, and includes a general explanation of the way in which groundwater may be impacted by subsurface fracturing associated with underground longwall mining.
- Section 8.3 provides an overview of the groundwater model that has been developed to assess the impact of mining. Appendix A provides a detailed technical description of the model development, construction and calibration.
- Section 8.4 summarises the predictions of the groundwater modelling, including changes in groundwater levels during mining operations, groundwater inflow to the underground mine workings and recovery of groundwater levels post mine closure.
- Section 8.5 describes potential impacts to groundwater users and the environment.
- Section 8.6 outlines potential cumulative impacts with the adjacent mines and CSG production.

8.2 Overview of mining

The project will involve establishing a longwall operation in the G200s mining area. The layout of the mine is shown on Figure 2. Eight longwall panels are proposed.

Longwall mining will result in subsidence of the overlying strata. Subsidence results in the progressive formation of shallow trough-like depressions on the surface relative to natural topography. Subsidence will fracture strata overlying the longwall panel and has the potential to depressurise or fully drain the fractured strata.

Appendix A describes how the groundwater model represented the proposed mining.

8.2.1 *Overview of subsidence effects on hydrogeology*

Subsidence predictions are provided in the EAR Subsidence Report. The EAR Subsidence Report explains that longwall mining results in collapse of the overlying rock strata into the void left by coal extraction. The collapsed or disturbed overburden material is referred to as the goaf. The collapse propagates upwards from the extracted seam until bulking of the goaf limits vertical movement and the tensile strength of the rock strata is sufficient to hold up the overburden without failure. There are a number of zones above the extracted seam that have different degrees of cracking and the height of cracking is important in assessing the impact of mining on the groundwater regime and groundwater inflow to the mine.

The EAR Subsidence Report describes the following subsidence zones in terms of the known geology of the G200s mining area (in order of increasing height above the extracted coal seam):

- Continuous cracking zone – changes in vertical and horizontal hydraulic conductivity are possible;
- Discontinuous cracking zone – no changes in vertical hydraulic conductivity, possible changes in horizontal hydraulic conductivity and storativity; and
- Constrained zone – unaffected by subsurface subsidence cracking.

Figure 28 shows the conceptual model of subsurface subsidence cracking.

8.2.2 Zone of *continuous cracking*

In the continuous cracking zone immediately above the extracted seam, broken rock and rubble is highly fractured and permeable. Above this broken rock and rubble, de-stressing of overlying strata results in fractures extending through individual beds, opening of bedding planes and shearing and dislocation of beds ("continuous cracking"). This cracking exhibits increased vertical and horizontal hydraulic conductivity and storativity which decreases with increasing elevation above the extracted coal seam.

Water can potentially drain from an aquifer or surface water body if:

- the zone of continuous subsurface cracking intersects the aquifer or water body; or
- there is a connection between the continuous subsurface cracking zone and any surface subsidence cracking.

The extent of continuous cracking above the proposed underground mining areas is predicted in the EAR Subsidence Report. This report concludes that there is likely to be an upper bound height of 125 m for continuous cracking above the extracted seam. The height of connective cracking would therefore intersect the overlying Tertiary basalt. Section 8.3 and Appendix A describes how the continuous cracking is represented by the groundwater model.

8.2.3 *Zone of discontinuous cracking*

Above the continuous cracking zone, a zone of "discontinuous cracking" may form. In this zone the strata sags, allowing bed separation. This discontinuous cracking increases horizontal hydraulic conductivity, but does not lead to continuous or connected vertical cracking or any significant change in vertical hydraulic conductivity. Therefore the effects of subsidence on groundwater regimes which occur in this zone do not significantly influence the extent or magnitude of the project impacts.

8.2.4 *Constrained zone*

This zone occurs above the discontinuous cracking zone and is characterised by a stress level at which rock masses are not disrupted sufficiently to increase the hydraulic conductivity. Hence there is no significant change in transmissivity or storativity, and therefore groundwater regimes which occur in this zone, are hydraulically unaffected by subsidence.

8.2.5 *Zone of depressurisation*

The process of underground mining reduces water pressure (depressurises) in surrounding rock units beyond the zone directly mined or cracked by subsidence. The extent and magnitude of depressurisation beyond this area depends on the properties of the coal seams and other hydrogeological units, and the fracture network generated by subsidence above the longwall mining area. This zone is referred to as the zone of depressurisation, and is greatest at the working face, gradually reducing with distance from the mining areas. Section 8.4.1 describes the zone of depressurisation due to the project.

8.3 Overview of groundwater modelling

A 3D numerical groundwater flow model was developed for the project using MODFLOW-USG. A detailed description of the modelling methodology is provided in Appendix A. The model represented the key geological units as 17 layers and extended 28 km north-south and 25 km east-west.

Development of the model was based on the high resolution geological model developed by the proponent. The geological model was further enhanced by inclusion of available data from the DNRM GWDB and published geological maps.

The numerical groundwater model reflects the groundwater regime described in Section 7. The model was calibrated to existing groundwater levels using reliable measurements from all representative bores located over an area of 6,375 km^2. A detailed description of the calibration method is provided in Appendix A. The objective of the calibration was to replicate the groundwater levels measured in the monitoring network installed at the G200s mining area and the adjacent Moranbah North Mine, Moranbah South Project site, and Arrow Energy CSG production in PL 191.

The project model was designed and assessed in accordance with modelling guidelines developed by, Barnett *et al*., (2012). The calibration achieved a 5.6 % scaled RMS error which is well within acceptable limits (i.e. 10%) as recommended by the modelling guidelines. Furthermore, the calibrated water levels replicate measured general groundwater trends which have responded to mining. The model calibration is therefore considered robust.

Once calibrated, the model was used to predict changes in groundwater levels and inflows to the proposed mining areas in response to the project, including simulated mining of longwall panels in accordance with the proposed mine plan. The modelling approach included simulation of subsidence induced fracturing above the longwall panels.

As discussed in the previous section, continuous subsurface subsidence cracking may extend through the Permian coal measures into the Tertiary basalt. Continuous cracking will increase the vertical hydraulic conductivity throughout the affected zone, with the magnitude of the increase likely to decrease with increasing height above the extracted seam. However, as with the prediction of cracking height, the prediction of hydraulic conductivity changes due to continuous cracking is inherently uncertain. Given the combined uncertainty in cracking height and hydraulic conductivity change, this assessment has conservatively adopted the following key modelling assumptions as the basis for the prediction of subsidence induced impacts on groundwater:

- the continuously cracked zone will be highly permeable, and represented with a ramp function calibrated to available data; and
- where the zone of continuous cracking is predicted to intersect only part of a geological unit, the entire thickness of that geological unit is assumed to be continuously cracked.

Based upon these assumptions, the vertical hydraulic conductivity assigned to the cracked strata is so high as to be considered uniformly free draining (Gale, 2007). These assumptions more than adequately account for any uncertainty associated with subsidence cracking prediction, and therefore provide a conservative basis for assessing potential worst case groundwater impacts. Modelling of subsidence cracking effects is discussed further in Appendix A.

The sensitivity of the model predictions to the input parameters was tested and analysed. The analysis included varying model parameters and design features that could most influence the model predictions. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters. Sensitivity analysis included testing the effects of changes in:

- horizontal hydraulic conductivity, vertical hydraulic conductivity, specific yield and specific storage of all geological units; and
- the rainfall recharge rate across the model domain.

These changes capture extremes in the potential parameter ranges.

The analysis found that predicted groundwater inflows were most sensitive to changes in storage. Groundwater depressurisation was relatively insensitive to changes in storage and hydraulic conductivity and recharge during mining.

It was also observed that changing the recharge and hydraulic conductivity, and storage parameters increased the overall model error. This shows that the magnitude of these changes reduced the ability of the model to match measured water levels, and indicates that the changes made during the sensitivity analysis are likely to represent conservative extremes for these parameters.

Overall, the sensitivity analysis confirmed that the measured sensitivity of the model calibration and predictions to changes in model parameters is in all instances acceptable.

Appendix A provides a detailed discussion of the sensitivity analyses undertaken. The following sections describe the predictions of the groundwater model.

8.4 Groundwater modelling predictions

8.4.1 *Drawdown and depressurisation during mining operations*

Figure 29 to Figure 31 show the predicted maximum depressurisation within the key stratigraphic units.

The model predicts no drawdown will occur in the alluvium as a result of mining in the G200s mining area.

The Tertiary sediments are saturated where the sediments extend below the regional groundwater table. The maximum predicted drawdown in the Tertiary sediments is 6 m along the western boundary and east of the G200s mining area (Figure 29).

The extent of drawdown within the Tertiary basalt is aligned with the palaeochannel into which it has been deposited (Figure 30) extending approximately 2 km to the north and north-west. Towards the south, drawdown will be limited to within 1 km of the G200s mining area which coincides with the basalt palaeochannel thinning both laterally and vertically (Figure 12). Drawdown within the Tertiary basalt is greatest where the G200s mining area coincides with the reduced rock cover over the GM seam in the central and north-eastern parts of the project area. Over the central part of LW204 (Figure 2) the model predicts drawdown within the Tertiary basalt will reach a maximum of 43 m.

The GM seam is depressurised most significantly where the seam is the deepest, in the north-eastern part of the G200s mining area (Figure 31). The potentiometric surface for the GM seam is up to 315 m above the base of the seam prior to mining. The model predicts a maximum decline in potentiometric surface of up to 236 m in response to mining. This depressurisation effect extends 1.4 km to the north, 1.8 km to the south, 800 km to the east and 2.1 km to the west of the G200s mining area and reduces in magnitude with distance.

8.4.2 *Groundwater inflow to mining areas*

Figure 32 shows the predicted rate of groundwater inflow into the proposed mining operations. The predicted groundwater inflow rates vary throughout the project life. The variability is due to a range of factors, including mining depth, thickness/hydraulic conductivity of strata and hydraulic gradients induced by depressurisation.

The predicted inflows gradually increase as the mine progresses west and the GM seam becomes shallower, allowing connective cracking over the goaf to extend up to the Tertiary basalt. Inflow to the underground mine peaks at 11 ML/day in the final year of mining.

The groundwater inflow rates presented in Figure 32 represent the total daily amount of groundwater predicted to be removed from the groundwater regime. The actual volume of groundwater pumped from the mining area will be less than that predicted by the numerical model, as a component of this groundwater will be lost to wetting of surfaces, ventilation and retained moisture within the coal. These inflow rates do not include the loss factor used to convert groundwater inflow rates to mine dewatering rates.

8.4.3 *Post closure groundwater recovery*

The numerical model also simulated the recovery of groundwater levels post mining. Appendix B outlines the development of the post mining groundwater model.

The modelling indicates the underground will gradually fill with water over time. This filling process will reduce the hydraulic gradient and magnitude of drawdown immediately surrounding the mined areas until the groundwater level fully recovers to pre-mining conditions.

8.5 **Project impacts**

This section describes the operational and post-closure impacts of the project on:

- groundwater resources (Section 8.5.1);
- existing groundwater users (Section 8.5.2);
- surface drainage features (Section 8.5.3); and
- groundwater quality (Section 8.5.4).

The prediction and assessment of cumulative impacts is discussed in Section 8.6.

8.5.1 *Impact on groundwater resources*

As discussed in Section 2, the G200s mining area and surrounds is managed under Fitzroy WRP and is within the Isaac Connors GMA. The Isaac Connors GMA includes two groundwater units, Isaac Connors Groundwater Unit 1 which includes the Isaac River alluvium, and Isaac Connors Groundwater Unit 2 comprising all subartesian aquifers within the Isaac Connors GMA other than the alluvium associated with the Isaac Connors Groundwater Unit 1.

Whilst no drawdown is predicted within the alluvium, the model predicts a very small groundwater take from the alluvium. The alluvium is generally unsaturated within the G200s mining area; however, a small disconnected zone of saturated alluvium is present at the northern boundary (Figure 24). Where drawdown is present below the saturated alluvium, seepage will occur. Although no drawdown is predicted to extend into the alluvium, the model predicts a small volume of groundwater will be removed from the alluvium due to mining in the G200s mining area (Figure 33). The model predicts up to 1.2 MLpa is removed from the alluvium by the end of mining. In reality, the volume of water is negligible and no groundwater take from the alluvium (Groundwater Unit 1) is likely to occur.

Figure 34 presents the predicted 'water take' from the Permian coal measures which is encompassed within Groundwater Unit 2. The predicted 'water take' gradually increases peaking at 3,000 MLpa in the final year of mining.

Post mining, the underground workings will be allowed to flood and the groundwater level will recover. As there is no final void, there will be no evaporative losses from the system and hence no post mining 'water take'.

The proponent will consult with the DNRM in relation to its obligations under the Water Act and will comply with the relevant requirements for groundwater take.

8.5.2 *Impact on groundwater users*

No groundwater users have been identified near the G200s mining area.

8.5.3 *Impact on surface drainage*

The Isaac River traverses the north-eastern corner of the G200s mining area in a south-easterly direction. The Isaac River and its tributaries (Figure 5) are ephemeral and are characterised by short duration, surface water flows that are typically restricted to the wet season (i.e. November to April).

Figure 35 presents the depth to water across the G200s mining area. The figure shows that at its shallowest, the depth to water is greater than 15 metres below ground level; therefore groundwater is disconnected from surface water.

While the G200s mining area does extend below the Isaac River, the thickness of overburden is greater than 350 m (Figure 11). The extent of continuous cracking above the proposed underground mining area is presented in the EAR Subsidence Report. This report concludes that there is likely to be an upper bound height of 125 m for continuous cracking above the extracted seam. The height of connective cracking would therefore not reach the alluvium associated with the Isaac River.

The numerical model predicts no reduction in baseflow in the Isaac River as a result of mining in the G200s mining area. This is due to the Isaac River being an ephemeral river that does not have any measurable baseflow within the G200s mining area.

The model predicts groundwater drawdown will not extend to the other ephemeral creeks in the vicinity including Teviot Brook, and Grosvenor Creek.

8.5.4 *Impact on groundwater quality*

The project will utilise existing infrastructure at Moranbah North Mine for processing coal and storage of rejects associated with coal processing. Therefore, there is no potential for contamination from new surface infrastructure areas. The underground mining operations are otherwise not a potential source of contamination during operations or post closure.

There is potential for groundwater contamination to occur as a result of hydrocarbon contamination from underground machinery and storage areas. However, adequate bunding and immediate clean-up of spills which is standard practice and a legislated requirement at mine sites will prevent the contamination of the groundwater regime.

8.6 Cumulative mining and coal seam gas impacts

The following activities also extract groundwater and therefore require consideration of the potential for cumulative impacts with the project:

- approved underground mines, including Grosvenor Mine, Moranbah North Mine, and the Moranbah South Project; and
- Arrow Energy's CSG production field.

The G200s mining area is adjacent to the approved Grosvenor mining area and 250 m south of the Moranbah North longwall mining area. As discussed in Section 6.5.1, Arrow Energy operates a CSG production field in PL 191 which overlies a significant portion of the Grosvenor Mining Lease and G200s mining area (Figure 4). Associated groundwater is removed from the coal seams as a by-product of the CSG production, and this has resulted in significant depressurisation of the Permian coal measures near the G200s mining area.

The numerical groundwater model was used to assess the cumulative groundwater impacts associated with the project during mining and post closure. In order to assess the potential for cumulative impacts, the numerical model included the mining and the Arrow Energy CSG production field listed above and included the progression of the other mine areas concurrently with the project, as detailed in Appendix A.

Figure 36 to Figure 38 show the maximum predicted extent of the cumulative groundwater depressurisation during mining. These figures also show the extent and percentage of cumulative depressurisation that is attributable to the project. As discussed in Section 8.4.3, the groundwater levels are predicted to fully recover post mine closure.

The findings of the cumulative modelling assessment (by stratigraphic unit) are as follows:

- Alluvium - the project will not drawdown groundwater in the alluvium and will therefore not contribute to any cumulative impacts on alluvial groundwater.
- Tertiary basalt and Tertiary sediments – the project will contribute to cumulative drawdown on the Tertiary groundwater regime with Moranbah North Mine, Grosvenor Mine, and Arrow Energy CSG production. The project contributes a minor proportion of the total cumulative depressurisation beyond the G200s mining area.
- Permian coal measures – the project will contribute to localised cumulative depressurisation of the Permian coal measures with Arrow Energy CSG production, Moranbah North Mine, Grosvenor Mine. The extent of cumulative depressurisation is typically localised to the G200s mining area. The project will result in a minor contribution to cumulative depressurisation of the coal measures extending up to 2 km from the G200s mining area.

The area of predicted cumulative depressurisation associated with the project does not include any groundwater users or other features potentially impacted by the project.

9 Groundwater monitoring program

The proponent maintains a groundwater monitoring program for Grosvenor Mine in accordance with EA (EMPL00987013).

Table 6 summarises the groundwater monitoring program including bore details and monitoring frequency. The monitoring bore locations are shown on Figure 39.

Table 6 Grosvenor Mine monitoring network

Bore ID	Status	Easting	Northing	Surface elevation (mAHD)	Target unit	Monitoring frequency
RDG065	Grosvenor Mine EA	604608	7571202	224.1	Tertiary basalt	SWL: monthly Quality: quarterly
RDG066MB	Grosvenor Mine EA	601135	7574497	263.2	Tertiary basalt	SWL: monthly Quality: quarterly

Note: *coordinates in GDA94 zone 55*

The layout and objectives of the existing groundwater monitoring program are suitable to monitor the potential impacts of the project. The existing groundwater monitoring program will therefore be continued throughout the life of the project. No modifications to the existing groundwater monitoring program are required.

Groundwater levels will continue to be measured from the existing monitoring network on a monthly basis.

In addition, the proponent has a data sharing arrangement with Arrow Energy that provides groundwater level and flow rate data from the Arrow CSG production wells and UWIR monitoring network. This data will be used to supplement the data collected from the existing groundwater monitoring network.

Groundwater quality sampling of existing monitoring bores will continue in order to provide longer term baseline groundwater quality, and to detect any changes in groundwater quality during and post mining.

The full groundwater quality suite will include:

- physio-chemical parameters – pH, EC, TDS;
- major ions – Ca, Mg, Na, K, Cl, SO_4, alkalinity (CO_3, HCO_3);
- dissolved metals – Al, Ag, As, Fe, Hg, Mo, Sb, and Se; and
- hydrocarbons – Total Petroleum Hydrocarbons (C10-14, C15-28, and C29-36).

10 Conclusions

The results of the modelling and overall findings of the groundwater assessment are summarised as follows:

- The Isaac River alluvial aquifer will not be impacted by the project for several reasons:
    - the Isaac River alluvium is largely unsaturated near the G200s mining area;
    - the depth of cover over the proposed longwall which extends under the Isaac River is greater than 350 m, which is well beyond the predicted maximum extent of connective cracking; and
    - the low permeability interburden of the Permian coal measures will retard any hydraulic connectivity between the underground mining area and the alluvium.
- The G200s mining area and surrounds has already been significantly depressurised by existing mines and CSG production such that the additional impact to the groundwater regime from the project is negligible.
- The water take from the Permian coal measures is estimated to reach a maximum of 3,000 MLpa at the end of mining. The proponent will monitor the inflows to the mine and obtain any necessary licences for mine dewatering.
- The numerical modelling indicates the project will depressurise the siltstones, shales and coal seams of the Moranbah Coal Measures and Fort Cooper Coal Measures as well as the Tertiary basalt and sediments in a zone around the project site. This depressurisation will not affect any groundwater supply bores.
- Post mining the underground workings will be allowed to refill and eventually the water level will recover to pre-mining levels.
- The area of predicted cumulative depressurisation associated with the project does not include any groundwater users or other features potentially impacted by the project.

11 References

AGE (2013) '*Groundwater Impact Assessment Report for the Moranbah South Project*', prepared for Anglo American Metallurgical Coal Pty Ltd, Project No. G1576A, March 2013.

Arrow Energy (2016) '*Underground water impact report - for petroleum leases 191, 196, 223, 224*', January 2016.

Australian and New Zealand Environment Conservation Council (2000) *'Australia and New Zealand Guidelines for Fresh and Marine Water Quality',* National Water Quality Management Strategy, Chapter 4 Primary Industries.

Barnett, B., Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A., Boronkay, A., (2012) '*Australian groundwater modelling guidelines*', Waterlines report, National Water Commission, Canberra.

Driscoll, F.G (1986) '*Groundwater and wells*', 3rd Edition, St Paul, Minnesota 55112: Johnson Filtration Systems Inc.

FAO (2013) Food and Agricultural Organisation of the United Nations: http://www.fao.org/docrep/t0667e/t0667e05.htm.

JBT Consulting (2010) '*Grosvenor Coal Project Environmental Impact Study - Groundwater Impact Assessment*', prepared for Anglo American Metallurgical Coal Pty Ltd, Report No. JBT01-007-003, September 2010.

Matrix Plus (2009) '*Integrated Isaac Plains Project Amalgamated Environmental Impact Statement*', Chapter 7.

URS (2009) '*Caval Ridge Groundwater Impact Assessment*', prepared for BM Alliance Coal Operations Pty Ltd, Report No. 42626158, March 2009.

URS (2013) '*Red Hill Mining Lease EIS - Groundwater Impact Assessment*', prepared for BM Alliance Coal Operations Pty Ltd, Report No. 42627136, September 2013.

12 Abbreviations

Ag	silver
AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
Al	aluminium
As	arsenic
ANZECC	Australian and New Zealand Environment and Conservation Council
BoM	Bureau of Meteorology
Ca	calcium
Cl	chloride
CO_3	carbonate
CRD	Cumulative Rainfall Departure
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNRM	Department of Natural Resources and Mines
DotEE	Department of the Environment and Energy
DSITIA	Department of Science, Information Technology, Innovation and the Arts
EA	Environmental Authority
EC	electrical conductivity
EIS	Environmental Impact Assessment
EPP	Environmental Protection Policy
EV	environmental value
Fe	iron
GMA	Groundwater Management Area
GPR	ground penetrating radar
GWDB	Groundwater Database
HCO_3	bicarbonate
Hg	mercury
IIPP	Integrated Isaac Plains Project
k	hydraulic conductivity
km	kilometres
L/s	litres per second
m	metres
mAHD	metres above Australian height datum
mbgl	metres below ground level
m/day	metres per day
Mg	magnesium

MGA	Make Good Agreement
ML	Megalitres (million litres)
MLpa	megalitres per year
MNES	Matters of National Environmental Significance
MNM	Moranbah North Mine
Mo	molybdenum
Mtpa	million tonnes per annum
MU	Management Unit
Na	sodium
No.	number
PL	Petroleum Lease
RMS	root mean square
ROP	Resource Operations Plans
Se	selenium
SILO	Scientific Information for Land Owners
SO_4	sulfate
SRMS	scaled root mean square
TDS	total dissolved solids
UWIR	Underground Water Impacts Report
VWP	vibrating wire piezometer
WLA	Water Legislation Amendment Bill
WROLA	Water Reform and Other Legislation Amendment Act
WRP	Water Resources Plan
%	percentage

13 Glossary

Alluvium - Sediment (gravel, sand, silt, clay) transported by water (i.e. deposits in a stream channel or floodplain).

Aquifer - Rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

Aquifer, confined - An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer.

Aquifer, perched - A region in the unsaturated zone where the soil may be locally saturated because it overlies a low-permeability unit.

Aquifer, unconfined - An aquifer in which there are no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Water-table aquifer is a synonym.

Colluvium - Sediment (gravel, sand, silt, clay) transported by gravity (i.e. deposits at the base of a slope).

Drawdown - A lowering of the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping of ground water from wells or excavations.

Falling Head Test - A test made by the instantaneous addition of a known volume of water or solid 'slug' to a well. The subsequent well recovery is measured.

Hydraulic Conductivity - A measure of the rate at which water moves through a soil/rock mass. It is the volume of water that moves within a unit of time under a unit hydraulic gradient through a unit cross-sectional area that is perpendicular to the direction of flow.

Hydraulic gradient - The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

Model calibration - The process by which the independent variables of a digital computer model are varied in order to calibrate a dependent variable such as a head against a known value such as a water-table map.

Piezometer - A non-pumping well, generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen through which water can enter.

Porosity - The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

Potentiometric surface - A surface that represents the level to which water will rise in tightly cased wells. If the head varies significantly with depth in the aquifer, then there may be more than one potentiometric surface. The water table is a particular potentiometric surface for an unconfined aquifer.

Pumping Test - A test made by pumping a well for a period of time and observing the response/change in hydraulic head in the aquifer.

Rising Head Test - A test made by the instantaneous removal, of a known volume of water or solid 'slug' from a well. The subsequent well recovery is measured.

Specific storage - Volume of water released from storage from a unit volume of aquifer per unit decline in hydraulic head.

Specific yield - The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur.

Storage coefficient (storativity) - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer, per unit change in head.

Unsaturated zone - The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched ground water, may exist in the unsaturated zone. Also called zone of aeration and vadose zone.

Water table - The water table is the surface where the water pressure head is equal to the atmospheric pressure. It represents the top of the zone where subsurface strata are saturated with groundwater.