Report

Red Hill Mining Lease EIS

Groundwater Impact Assessment

24 SEPTEMBER 2013

Prepared for
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Abbreviations

Abbreviation	Description
AHD	Australian Height Datum
BBCGP	Bowen Basin Coal Growth Project
BMA	BHP Billiton Mitsubishi Alliance
BoM	Bureau of Meteorology
BRM	Broadmeadow underground mine
CHPP	coal handling and preparation plant
CSG	coal seam gas
DERM	Department of Environment and Resource Management
DSDIP	Department of State Development, Infrastructure and Planning
EIS	environmental impact statement
EPP (Water)	*Environmental Protection (Water) Policy 2009*
GDE	groundwater dependant ecosystems
GLS	Goonyella Lower Seam
GMA	groundwater management area
GMS	Goonyella Middle Seam
GPR	Ground Penetrating Radar
GRB	Goonyella Riverside and Broadmeadow
GRM	Goonyella Riverside Mine
GUS	Goonyella Upper Seam
IDAS	Integrated Development Assessment System
IMG	incidental mine gas
K	hydraulic conductivity
Kh	hydraulic conductivity – horizontal
Kv	hydraulic conductivity – vertical
LOM	life of mine
m	metre
MIA	mine industrial area
ML	mining lease
MLA	mining lease application
MR Act	*Mineral Resources Act 1989*
NRM	Department of Natural Resources and Mines
RHM	Red Hill Mine
RMSE	root-mean-square error
SP Act	*Sustainable Planning Act 2009*
STRM data	digital elevation data
TDS	total dissolved solids
ToR	Terms of Reference
URS	URS Australia Pty Ltd
VWP	Vibrating Wire Piezometers
Water Act	*Water Act 2000*
WQG	Water Quality Guidelines
WQO	Water Quality Objectives

Abbreviations

Unit	Description
^{o}C	degrees Celsius
%	per cent
GL	gigalitres
L/s	litres per second
m^3/t	cubic metres per tonne
m/day	metres per day
mbgl	metres below ground level
mg/L	milligrams per litre
µS/cm	microSiemens per centimetre

Introduction

The Red Hill Mining Lease is located adjacent to the existing Goonyella, Riverside and Broadmeadow (GRB) mine complex in the Bowen Basin, approximately 30 kilometres north of Moranbah and 220 kilometres south-west by road from Mackay, Queensland (refer **Figure 1–1**).

BHP Billiton Mitsubishi Alliance (BMA), through its joint venture manager, BM Alliance Coal Operations Pty Ltd, proposes to convert the existing Red Hill Mining Lease Application (MLA) 70421 to enable the continuation of existing mining operations associated with the GRB mine complex. Specifically, the mining lease conversion will allow for:

- An extension of three longwall panels (14, 15 and 16) of the existing Broadmeadow underground mine (BRM).
- A future incremental expansion option of the existing Goonyella Riverside Mine (GRM).
- A future Red Hill Mine (RHM) underground expansion option located to the east of the GRM.

The three project elements described above are collectively referred to as 'the project'. Further detail on each project component is as follows:

- The extension of BRM longwall panels 14, 15, and 16 into MLA70421. Key aspects include:
  - No new mining infrastructure is proposed other than infrastructure required for drainage of incidental mine gas (IMG) to enable safe and efficient mining.
  - Management of waste and water produced from drainage of IMG will be integrated with the existing BRM waste and water management systems.
  - The mining of the BRM panel extensions is to sustain existing production rates of the BRM mine and will extend the life of mine by approximately one year.
  - The existing BRM workforce will complete all work associated with the extensions.
- The incremental expansion of the GRM. Key aspects include:
  - underground mining associated with the RHM underground expansion option to target the GMS on mine lease (ML) 1763;
  - a new mine industrial area (MIA);
  - a CHPP adjacent to the Riverside MIA on MLA1764 and ML1900 − the Red Hill CHPP will consist of up to three 1,200 tonne per hour modules;
  - construction of a drift for mine access;
  - a conveyor system linking RHM to the Red Hill CHPP;
  - associated coal handling infrastructure and stockpiles;
  - a new conveyor linking product coal stockpiles to a new rail load-out facility located on ML1900; and
  - means for providing flood protection to the mine access and MIA, potentially requiring a levee along the west bank of the Isaac River.
- A potential new Red Hill underground mine expansion option to the east of the GRB mine complex, to target the GMS on MLA 70421. Key aspects include:
  - the proposed mine layout consists of a main drive extending approximately west to east with longwall panels ranging to the north and south;
  - a network of bores and associated surface infrastructure over the underground mine footprint for mine gas pre-drainage (IMG) and management of goaf methane drainage to enable the safe extraction of coal;
  - a ventilation system for the underground workings;

1 Introduction

— a bridge across the Isaac River for all-weather access. This will be located above the main headings, and will also provide a crossing point for other mine related infrastructure including water pipelines and power supply;
— a new accommodation village (Red Hill accommodation village) for the up to 100 per cent remote construction and operational workforces with capacity for up to 3,000 workers; and
— potential production capacity of 14 million tonnes per annum of high quality hard coking coal over a life of 20 to 25 years.

URS Australia Pty Ltd (URS) was commissioned by BMA to conduct a groundwater investigation and impact assessment as part of the project Environmental Impact Statement (EIS). For the purposes of this report, the area within the EIS study boundary is called the 'EIS study area'. The groundwater study, however, covered a larger area and this is defined as the 'survey area'. Refer to **Figure 1-1** which shows both boundaries.

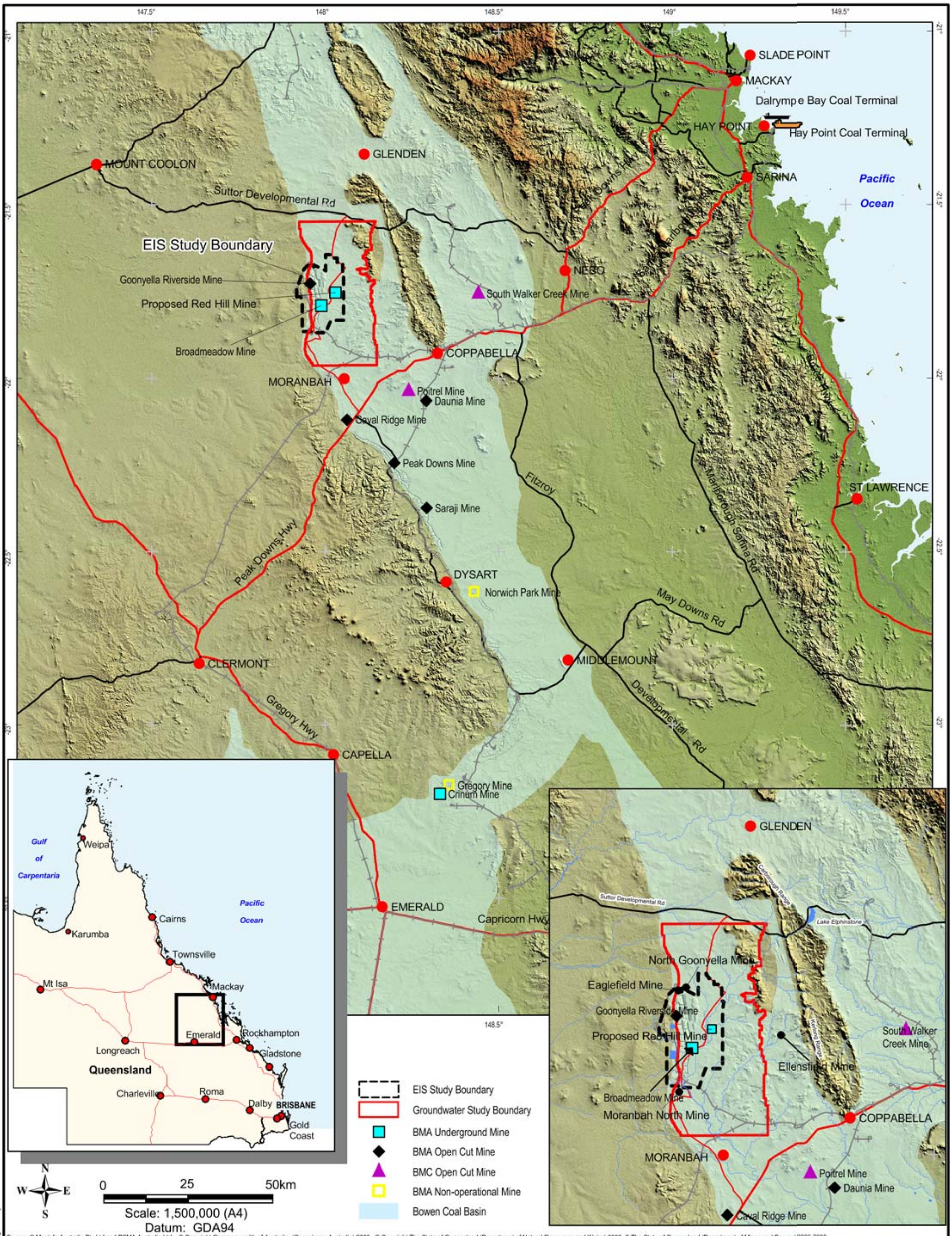
This standalone technical report provides details of an assessment of potential groundwater impacts associated with the proposed project, and includes recommended mitigation measures and monitoring protocols.

1.1 Scope of Work

The scope of work for the groundwater investigation was based on the terms of reference (ToR) for the project (Coordinator-General 2013).

The objective of this study was to assess the potential impacts of the proposed underground coal mining activities on the hydrogeological regime and, where necessary, identify measures for mitigation and/or monitoring of impacts as specified in the ToR. To achieve this objective, the scope of work included:

- A review of hydrogeological and geological data existing in the public domain, including reports and records held by the Department of Natural Resources and Mines (NRM) and maps published by the Geological Survey of Queensland.
- A review of exploration and monitoring bore data and groundwater reports provided by BMA.
- A review of hydrogeological data held on the NRM Groundwater Database for existing water bores in the area.
- Field investigations comprising groundwater sampling and aquifer parameter (variable head) tests.
- Survey of existing groundwater facilities (bores, wells) within the BMA properties and in neighbouring properties.
- An assessment and analysis of all available hydrogeological data though the development of a conceptual hydrogeological model and predictive hydrogeological modelling.
- Preparation of a report detailing the potential impacts of the proposed development on the groundwater regime.



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BMA
BHP Billiton Mitsubishi Alliance

RED HILL MINING LEASE
GROUNDWATER IMPACT ASSESSMENT

SURVEY AREA LOCALITY

URS

GROUNDWATER

Figure: **1-1**

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Legislative Framework and Requirements

A summary of the relevant policies, guidelines and legislation relevant to the project are outlined in **Table 2-1**.

Table 2-1 Summary of Relevant Policies, Guidelines and Legislation to the Project Area

Policy, Guidelines, or Legislation	Description	Relevance to the Project – Groundwater Impact Assessment
Environmental Protection Act 1994 (EP Act)	The objective of the EP Act is to protect the Queensland environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (Queensland Government 2012). Subordinate to this act is the Environmental Protection Regulation 2008, which provides for the effective administration and enforcement of the objectives and provisions of the EP Act.	All persons must not carry out any activity that causes, or is likely to cause, environmental harm unless the person takes all reasonable and practical measures to prevent or minimise the harm (Section 319 of the Act). This general duty to the environment requires the implementation of proactive measures to prevent environmental degradation and act in accordance with the precautionary principle. This requirement is underpinned by the impact assessment and mitigation process in this study.
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	The purpose of the Act is to provide for the protection of matters of national environmental significance (MNES), including groundwater dependant ecosystems (GDEs) and MNES species that rely on springs. Since June 2013, Queensland is a signatory to the Council of Australian Governments National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development (NPA). The NPA requires CSG or large coal mining development proposals undergoing environmental impact assessment that are likely to have a significant impact on water resources to be referred to an Independent Expert Scientific Committee (IESC).	The project is considered under the EPBC Act, as the EPBC Act is triggered for assessment of MNES. For groundwater this would be for assessment of impacts to mound springs or significant species habitat from drawdown. Regarding the EPBC Act, the depth of groundwater limits any potential use by listed or threatened species and migratory birds. Any potential changes in groundwater levels as a result of mine dewatering are therefore not considered to impact on listed or threatened species and migratory birds. After consultation between The Department of Environment and BMA this project is to include a summary report for the IESC as per the water resource trigger detailed in the NPA.
Water Act 2000 (Water Act)	The purpose of the Act is to provide for the sustainable management and efficient use of water and other resources, a regulatory framework for providing water services and the establishment and operation of water authorities. Water resource plans have been developed to define the availability and allocation of water and to ensure the sustainable management of water in Queensland. The objectives of the water resource plans are to balance the needs of humans and the environment in a sustainable manner.	Water use and the obligations, processes, and framework for coal mining in relation to groundwater monitoring, reporting, impact assessment and management of impacts on other water users including 'make good' agreements is regulated under the Act.

2 Legislative Framework and Requirements

Policy, Guidelines, or Legislation	Description	Relevance to the Project – Groundwater Impact Assessment
The Water Supply (Safety and Reliability) Act 2008	The purpose of the Act is to provide for the safety and reliability of water supply in Queensland. The Act sets out requirements for Environmental Management Plans and obligations in relation to the potential to impact on drinking water supplies.	The Project is automatically captured by this process for injection, direct supply or discharge of water, however; an exemption can be applied for.
Environmental Protection (Water) Policy 2009 (EPP (Water))	The purpose of the Policy is to achieve the objectives of the EP Act in relation to Queensland waters while allowing for ecologically sustainable development.	The environmental values are to be enhanced or protected (Section 6 of the Act). The relevant environmental values vary depending on the ecological value of the water, level of disturbance and intended use of the water. The management controls/ mitigation measures in this study were prepared to meet the requirements of this policy.
Sustainable Planning Act 2009	The purpose of the Act is to regulate the development of infrastructure outside petroleum tenures.	The Project is located within the Isaac Connors Groundwater Management Area (GMA) where any works for taking or interfering with water for purposes other than stock or domestic use (other than small diameter groundwater monitoring bores) are assessable activities and require a development permit.
Water Resource (Fitzroy Basin) Plan 2011	The Water Resource (Fitzroy Basin) Plan 2011 provides for the allocation and management of water in the Fitzroy Basin and the subordinate legislation under the Water Act.	Tenements in the northern portion of the Project area are located within the declared Isaac Connors GMA, as defined under Chapter 2, Section 7, Schedule 3, Schedule 4, and Schedule 7 of the Fitzroy Basin WRP 2011. Any long-term water take or interference from groundwater sources requires authorisation by way of a licence.

2.1 Water Act 2000

2.1.1 General

The *Water Act 2000* (Water Act) vests all rights to the use, flow and control of groundwater, overland flow water and water in watercourses, lakes, springs and dams in the State and provides a comprehensive planning and management regime for all vested water resources in Queensland.

Chapter 2 of the Water Act (allocation and sustainable management) seeks to advance sustainable management and efficient use of water and other resources by establishing a system for the planning, allocation and use of water in accordance with the principles of ecologically sustainable development.

Part 6 of Chapter 2 deals with the process of the allocation of licences or permits for the taking of or interfering with water. This includes groundwater. Land owners and other approved entities, including an applicant for, or the holder of, a mineral development licence or mining lease under the *Mineral*

Resources Act 1989 (MR Act), may apply for a licence or permit to take or interfere with groundwater. This application process includes a public notification requirement, and requires that the chief executive consider information about the effects of interfering with the water on natural ecosystems and the physical integrity of the aquifers, among other considerations.

The Water Act also deals with the 'make good' obligations of an entity such as the holder of a mineral development licence or mining lease under the MR Act to the owner of a pre-existing Water Act bore.

2.1.2 Water Resource (Fitzroy Basin) Plan 2011

Water Resource Plans provide for the allocation and management of water in Queensland and are subordinate legislation under the Water Act. The Water Resource (Fitzroy Basin) Plan 2011 includes groundwater, in part due to the significant increase in the demand for groundwater resources in recent years, driven mainly by mining in the Isaac-Connors system. There is a risk that groundwater resources in this catchment may be over committed (DERM 2009).

The survey area is located within the declared Isaac Connors Groundwater Management Area (GMA), as defined under Section 6, Schedule 3 and Schedule 4 of the Water Resource (Fitzroy Basin) Plan 2011. Within the declared management area, water licenses and/or development permits are not required for stock or domestic bores, and NRM also generally exclude groundwater monitoring bores from the requirement for development permits.

Other groundwater-related activities, such as drilling of test pumping bores, and undertaking pumping tests, requires authorisation (by way of permits) from NRM, as well as a development permit (operational works) to allow drilling and construction of water bores. Any long-term water take or interference (whether actively via bores or passively via drainage to and dewatering of mine workings) from groundwater sources requires authorisation by way of a licence. The project will require a water licence for groundwater interfered with as a result of IMG drainage and mine dewatering activities.

2.2 Sustainable Planning Act 2009

The *Sustainable Planning Act 2009* (SP Act) provides the mechanism (via the Integrated Development Assessment System (IDAS)) through which assessment of a proposed development is undertaken, and under which a development permit is granted.

Within the declared Isaac Connors GMA any works for taking or interfering with water for purposes other than stock or domestic use are assessable activities and will require a development permit. Works that are for stock and domestic purpose are self-assessable development and do not require a development permit but must conform to the relevant self-assessable development code. NRM currently allows small diameter groundwater monitoring bores to be constructed without a development permit.

2.3 Environmental Protection (Water) Policy 2009

The Environmental Protection (Water) Policy 2009 (EPP (Water)) serves to protect Queensland's waters while allowing for ecologically sustainable development. This purpose is achieved within a framework that includes:

- Identifying environmental values for aquatic ecosystems and for human uses (e.g. water for drinking, farm supply, agriculture, industry and recreational use).

2 Legislative Framework and Requirements

- Determining water quality guidelines (WQGs) and water quality objectives (WQOs) to enhance or protect the environmental values.

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

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

As discussed further in **Section 6.4**, the beneficial use of groundwater for some of these human uses within the EIS study area is limited to cases where salinity is suitably low and metal/metalloid concentrations are below guideline levels. Groundwater suitability for these anthropogenic uses therefore need to be assessed on a case-by-case basis, and in some cases it is interpreted that groundwater would have no practical use.

Review of Available Information

This groundwater assessment is based on a desktop review of available information and additional data collected on-site between March and June 2011. Previous groundwater studies undertaken within the survey area (as defined in **Section 4**) and the additional data collected during the compilation of this EIS have been used to describe the existing groundwater resources and thus allow for the assessment of the project on the current groundwater status.

The description of existing hydrogeological conditions within the survey area is based on the following available information:

- historical reports and groundwater monitoring data held by BMA for the GRB mine complex;
- data collected by BMA from the exploration drilling conducted for the GRB mine complex and the RHM;
- regional and local aeromagnetic geophysical surveys;
- environmental impact studies conducted for other coal mines in the area (**Figure 1-1**), including:
  - Anglo Coal (Grosvenor) Pty Ltd – Grosvenor Project, located 3 kilometres north of Moranbah and south of Moranbah North Mine (JBT Consulting 2010);
  - Peabody (Bowen) Pty Ltd – Eaglefield Expansion Project, located 36 kilometres north of Moranbah and immediately north of Goonyella Riverside Mine (GRM) (METServe 2010); and
  - Ellensfield Coal Management Pty Ltd – Ellensfield Coal Mine Project, located 35 kilometres north-east of Moranbah (AGE 2008);
- Geological Survey of Queensland Mount Coolon 1:250,000 Geological Map (Sheet SF55-7) and Bowen Basin Digital Geology;
- a search of the NRM groundwater and licensing database for registered bores located within a 10 kilometre radius of the site (conducted on 13 September 2011);
- a survey of existing groundwater facilities (bores, wells) within the EIS study boundary and neighbouring properties;
- Underground Water Impact Report (Arrow Energy 2011); and
- additional groundwater data collected on-site by URS for baseline studies between March and June 2011.

Previous hydrogeological investigations undertaken at GRB mine complex have focussed on assessing potential inflows to pits and underground workings and the establishment of boxcut or pit dewatering bores for mine design and production purposes. In each case, monitoring and dewatering bores have been constructed in the coal seams targeted for mining rather than overlying or underlying lithological units. Thus the hydrogeological work conducted previously on the site has covered:

- an assessment of Tertiary (units) permeability for a proposed boxcut at GRM (Thatcher 1976);
- an assessment and design of dewatering requirements for the Cleanskin Pit boxcut extension in the Goonyella Lower Seam (GLS) and double bench mining (Coffey & Partners 1987a, 1987b);
- a geotechnical assessment of slope stability for mining of the GLS beneath the existing Goonyella Middle Seam (GMS) pit at Ramp 13 (BHP Engineering 1993);
- hydraulic testing of the Goonyella Upper Seam (GUS) and GMS accompanied by numerical modelling of the GMS for the then proposed Goonyella No2 Mine (Rust PPK 1996; IESA 1996);
- installation of monitoring bores, numerical modelling of inflows for feasibility and tender purposes for the BRM (AGE 1998a, 1998b, 2000, 2002; BMA 2003);

3 Review of Available Information

- construction of monitoring bores, numerical modelling and installation/operation of depressurisation bores for the initial Airstrip pit boxcut and subsequent southerly extension of the pit (IESA 2001a, 2001b; AGE 2004a); and
- installation of monitoring bores and numerical modelling for the proposed double bench mining at Ramp 8 (AGE 2004b).

Physical Setting

The EIS study area is located within the upper sub-catchment of the Isaac River, which lies within the northern part of the Fitzroy River Basin (**Figure 1-1**).

4.1 Topography and Drainage

The upper Isaac River sub-catchment containing the EIS study area is bordered by the Peak Range to the southwest, Denham Range to the northwest, and the Broadsound and Connors Ranges to the east and northeast, respectively (**Figure 1-1**). Drainage gradients in the Isaac River sub-catchment are generally low across the central part of the sub-catchment and high around the margins, with elevations varying from a maximum of over 700 metres in the Connors Range down to approximately 90 metres at the junction with the Mackenzie River (Pearce & Hansen 2006). The central part of the sub-catchment is essentially flat lying where change in relief is typically less than 60 metres (SKM 2009).

The EIS study area is located within a broad valley through which the Isaac River flows, generally in a southerly direction. The northern portion of the EIS study area is formed by a low broad ridge that defines the northern extent of the Isaac River catchment. The low hills located to the east of the Isaac River near the GRB mine complex are undulating with a well-developed system of drainage lines.

The topography of the Isaac River valley near the EIS study area varies from approximately 250 metres AHD elevation along the Isaac River in the east of the EIS study area to approximately 325 metres AHD elevation along portions of the Denham Range that define the western edge of the valley. The relatively steep slopes associated with the Denham Range contrast with the extensive flat areas across the base of the river corridor, where gradients are generally less than 1v:100h.

There are five main ephemeral creeks within the EIS study area: Goonyella Creek, Eureka Creek, Fisher Creek, Platypus Creek, and 12 Mile Gully. These are tributaries of the Isaac River.

4.2 Climate

The climate of the Isaac River sub-catchment is predominantly dry tropical with hot summers and mild winters. Average maximum daily temperatures range from approximately 24°C in June-July to 34°C in December-January, whilst average minimum daily temperatures vary from approximately 10°C in July to 22°C in January-February for the Moranbah area (Bureau of Meteorology (BoM) monitoring station 034038). Rainfall is highly variable, both spatially and temporally across the sub-catchment. In the Moranbah area, the mean annual rainfall is approximately 600 millimetres (**Chart 4-1**). Rainfall is summer dominant with approximately 70 per cent of annual rainfall falling during months of the wet season from November to March (**Chart 4-2**). Average monthly evaporation consistently exceeds average rainfall over all months. However episodic, high intensity rainfall events do occur related to monsoonal troughs and cyclones, resulting in excess rainfall above evaporation at a frequency of eight per cent, with a duration between events ranging from approximately one to six years (SKM 2009). It is considered that infiltration of rainfall and subsequent groundwater recharge may be most likely to occur during high intensity rainfall events.

4 Physical Setting

Chart 4-1 Total Yearly Rainfall at the Moranbah Monitoring Station (BoM station no: 034038)

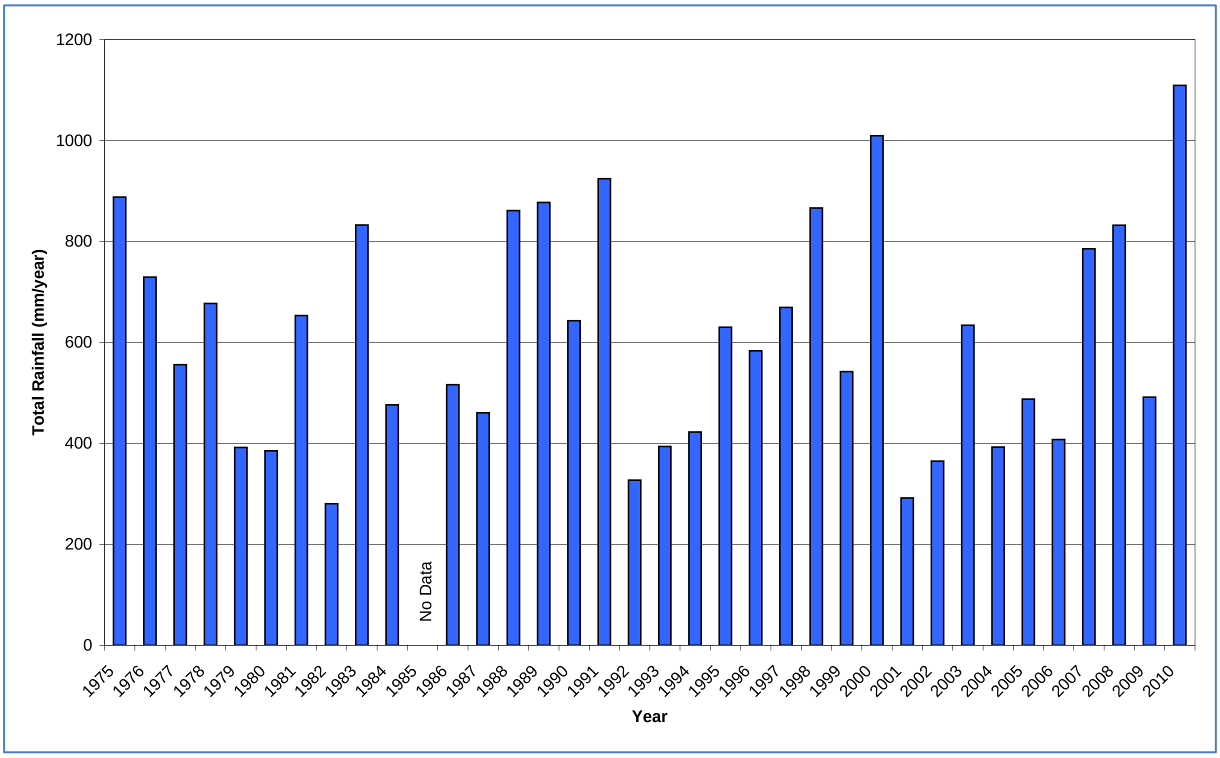
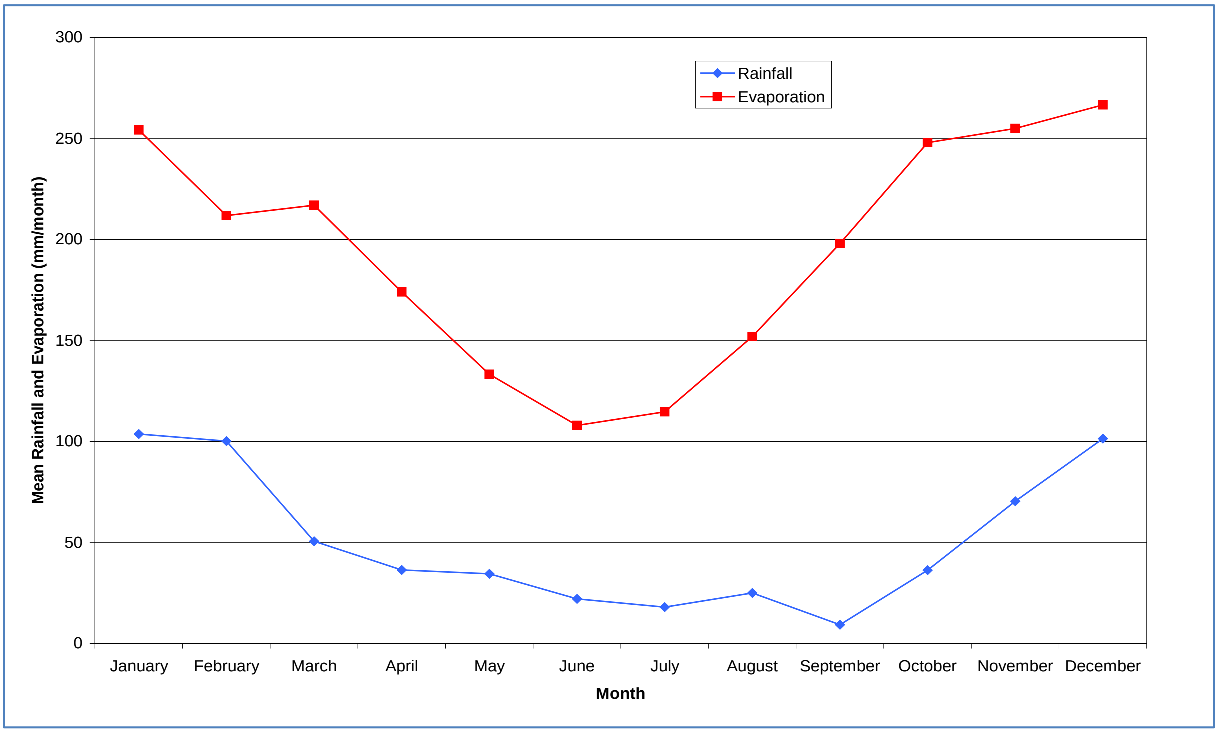


Chart 4-2 Mean Monthly Rainfall and Evaporation at the Moranbah Monitoring Station (BoM station no: 034038, 1986 to 2010)



4.3 Land Use

Since European settlement, the Isaac River sub-catchment has been extensively used for agriculture. SKM (2009) reported that approximately 90 per cent of land within the sub-catchment was dedicated to grazing (predominantly beef cattle) of relatively natural (limited clearing) environments. Dryland cropping and coal mining are the other significant land uses in the sub-catchment, the latter primarily focussed in the western part of the sub-catchment.

Coal mining is undertaken to the north and south of the EIS study area, with North Goonyella underground and open cut mine (Eaglefield Pit) operated by Peabody Energy to the north and the Moranbah North underground coal mine operated by Anglo American Coal to the south.

The existing GRM is an open cut operation producing hard coking coal while the BRM is an underground, punch longwall mine and has been developed in an existing highwall of the open cut operation.

The RHM footprint has previously been cleared for cattle grazing. However, small patches of remnant bushland and scrub remain, particularly along riparian corridors. The local agricultural industry is partially dependent on groundwater for stock watering; the remaining water requirements are met by surface water supplies. Groundwater is primarily extracted from the coal seam aquifers and sandstone units of the Bowen Basin or alluvium associated with the main rivers. Increasing demand on groundwater from both agriculture and mining has led to these groundwater systems being regulated in the Water Resource (Fitzroy Basin) Plan 2011.

Geological Setting

5.1 Regional Geology

The geological Bowen Basin is an elongated, north-south trending basin which extends from east-central Queensland to northern New South Wales. The basin covers an area of approximately 200,000 square kilometres, and is exposed over 600 kilometres from Collinsville in the north to Rolleston in the south. It contains a sedimentary sequence of Permo-Triassic clastics, which attain a maximum thickness of 9,000 metres in the depo-centre of the Taroom Trough.

The Bowen Basin is divided into a number of tectonic units comprising north/north-west – south/south-east trending platforms or shelves, separated by sedimentary troughs. The major structural unit surrounding the EIS study area is the Collinsville Shelf, underlain at shallow depths (one to two kilometres) by the Clermont Stable Block which bounds the northern Bowen Basin to the west. The Collinsville Shelf was a stable tectonic environment and is characterised by a monoclinal accumulation of sediments, which dip gently (two to eight degrees) and thicken to the east. Folding is gentle and mostly related to drag on thrust faults at the eastern margin of the basin limb. The boundary between the Collinsville Shelf and the adjoining major axis of deposition, the Nebo Synclinorium of the Taroom Trough, is marked by a major thrust fault termed the Burton Range Thrust Fault, which is located approximately 10 kilometres east of the EIS study area. This scarcity of regional significant structures or fault zones distinguishes the Collinsville Shelf sediments from the tightly folded and intruded sediments of the Nebo Synclinorium.

Regionally, the stratigraphic sequence is summarised as follows: the Permo-Triassic sediments of the Bowen Basin are overlain by a veneer of unconsolidated Quaternary alluvium and colluvium, poorly consolidated Tertiary sediments of the Tertiary Suttor Formation and, in places, remnants of Tertiary basalt flows.

5.2 Local Geology and Stratigraphy

A summary of the stratigraphy from the survey area is presented in **Table 5-1** and the local geology is shown in **Figure 5-1**.

The marine influenced Early to Middle Permian Back Creek Group is the oldest Bowen Basin succession observed in the survey area. This is conformably overlain by the Late Permian Blackwater Group, which contains the coal seams of economic interest to BMA. Following deposition of the Blackwater Group, fluviolacustrine deposition led to the deposition of the Triassic Mimosa Group. Tertiary volcanic deposits composed mostly of basaltic lava flows overlie the Bowen Basin successions. These Tertiary volcanics occur as isolated exposures in the north of the survey area. Extensive Quaternary alluvial deposits are associated with the Isaac River system.

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Table 5-1 Stratigraphy of the Survey Area

Period		Stratigraphic Unit				Description	Max. Thickness (m)	Presence in Survey Area
Quaternary		Alluvium				Clay, silts, sand, gravel, floodplain alluvium	37 m in survey area	Confined to present day stream alignments and palaeochannels
Tertiary		Basalt				Olivine basalt flows	35 m in survey area	Isolated patches in north of survey area
		Suttor Formation				Clay, silts, sand, gravel, colluvial and residual deposits, fluvial and lacustrine deposits	80 m in survey area	Most extensive in the mine areas and to the east
Triassic	Early	Bowen Basin	Mimosa Group	Rewan Formation		Green lithic sandstone, pebble conglomerate, red and green mudstone	Unknown in survey area	Small area within the north east
Permian	Late		Blackwater Group	Rangal Coal Measures		Sandstone, siltstone, mudstone, coal, tuff, sandstone	100 m	Outcrops or subcrops in the majority of the survey area
				Fort Cooper Coal Measures	Burngrove Formation	Mudstone, siltstone, sandstone, coal, tuff	400 m	
					Fair Hill Formation	Labile sandstone, quartzose sublabile sandstone, siltstone, mudstone, calcareous and tuffaceous sandstone, volcanic conglomerate, carbonaceous mudstone, coal		
				Moranbah Coal Measures		Quartzose to sublabile, locally argillacoues sandstone, siltstone, mudstone, carbonaceous mudstone and coal	250 m	
	Early to Middle		Back Creek Group			Quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite	Unknown in survey area	Outcrops west of mines and extends under mined areas to the east
Carboniferous	Early	Basement	Drummond Basin Succession	Mount Rankin Formation		White and grey siltstone and fine sandstone, minor medium to very coarse grained sandstone, chert, granule to pebble conglomerate, rare tuff, ignimbrite and dacite/andesite	Unknown in survey area	Outcrops west of the survey area and is inferred to form basement under the Bowen Basin in the mine areas
Devonian	Late		Silver Hills Volcanics			Rhyolite, dacite, rhyolitic ignimbrite, volcaniclastic sediments, sinter, minor sandstone and siltstone		
Proterozoic			Anakie Metamorphic Group			Siltstone, fine sandstone, phyllite, schist, commonly cleaved and multiply deformed		

5 Geological Setting

5.2.1 Basement Geology (Proterozoic-Carboniferous)

The nature and age of the crust beneath the Bowen Basin in the survey area is inferred from exposed rocks outside the basin and a deep seismic survey conducted by Geoscience Australia. Exploration drilling to date has not penetrated the basin succession away from its immediate margins.

Units that are exposed to the west of the Bowen Basin and that appear to continue underneath the survey area are the Proterozoic Anakie Metamorphic Group, Devonian Silver Hills Volcanics, and units of the Carboniferous Drummond Basin succession.

5.2.2 Back Creek Group

The Back Creek Group consists of Permian marine sediments, unconformable on the underlying basement. In the survey area, this unconformity is of low relief on a regional scale. The Back Creek Group is comprised of quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite. It is poorly exposed in and to the west of the EIS study area, and dips to the east below the Blackwater Group.

5.2.3 Blackwater Group

The Permian Blackwater Group contains, from oldest to youngest, the Moranbah Coal Measures, Fort Cooper Coal Measures, and Rangal Coal Measures.

The boundary between the Back Creek and Blackwater Groups is conformable and locally transitional. Due to the time involved in the gradual regression resulting in the deposition of the non-marine Blackwater Group, the boundary is diachronous, and the stratigraphy is complicated by facies changes and by changes in provenance of units.

Moranbah Coal Measures

The Moranbah Coal Measures outcrop or subcrop in the west and centre of the EIS study area, where they are mined in the GRM open cut pits.

The Moranbah Coal Measures were deposited in a predominantly fluvial flood plain environment. The lithology of the Moranbah Coal Measures is generally characterised by interbedded fine-grained lithic sandstone, siltstone, mudstone, claystone, and coal. The Moranbah Coal Measures show regular grading of lithological sequences from sandstone to siltstone and mudstone to coal, then tending back to sandstone, typical of depositional flood plain / river systems. The Moranbah Coal Measures are characterised by several laterally persistent thick coal seams interspersed with several thin minor seams, which split and coalesce. The three main seams are the GUS, GMS, and GLS. The GMS is the target seam for the proposed RHM.

Fort Cooper Coal Measures

The Late Permian Fort Cooper Coal Measures conformably overlie the Moranbah Coal Measures, and outcrop or subcrop in the centre to the east of the EIS study area. The Fort Cooper Coal Measures consist of lithic sandstone, siltstone, mudstone, coal, and tuffaceous sediments. A number of coal seams are contained within the Fort Cooper Coal Measures. These coal seams are typically highly banded with claystone, mudstone and siltstone and hence are non-commercial. The lower boundary of the Fort Cooper Coal Measures is taken as the base of a thick and widespread sequence of interbedded dull and stony coal, carbonaceous mudstone and tuff. This unit, referred to as the Fair

Hill Seam, ranges in thickness up to approximately 25 metres and lies approximately 60 to 70 metres above the GUS.

Rangal Coal Measures

The Rangal Coal Measures comprise light grey, cross-bedded, fine to medium grained sandstone, grey siltstone, mudstone, and coal seams. Cemented sections are common in the sandstone. The transition between the Fort Cooper Coal Measures and the Rangal Coal Measures is generally clearly marked by the Yarrabee Tuff, a basin-wide marker bed comprising weak, brown tuffaceous claystone.

5.2.4 Mimosa Group

The Permian sediments are unconformably overlain by the Triassic Rewan Formation. The Permian-Triassic boundary marks the change from the carbonaceous sediments of the coal measures to the non-carbonaceous mainly green, fine to medium grained, micaceous, lithic, labile, sandstone and red, brown, green and locally mottled mudstone.

5.2.5 Cainozoic Cover

The Permian and Triassic formations are mantled by an irregular cover of poorly consolidated Cainozoic sedimentary strata and both fresh and weathered basalt. The Cainozoic cover is up to 110 metres thick in parts towards the north of the survey area, where infilled deeply incised Tertiary palaeochannels.

Tertiary Formations

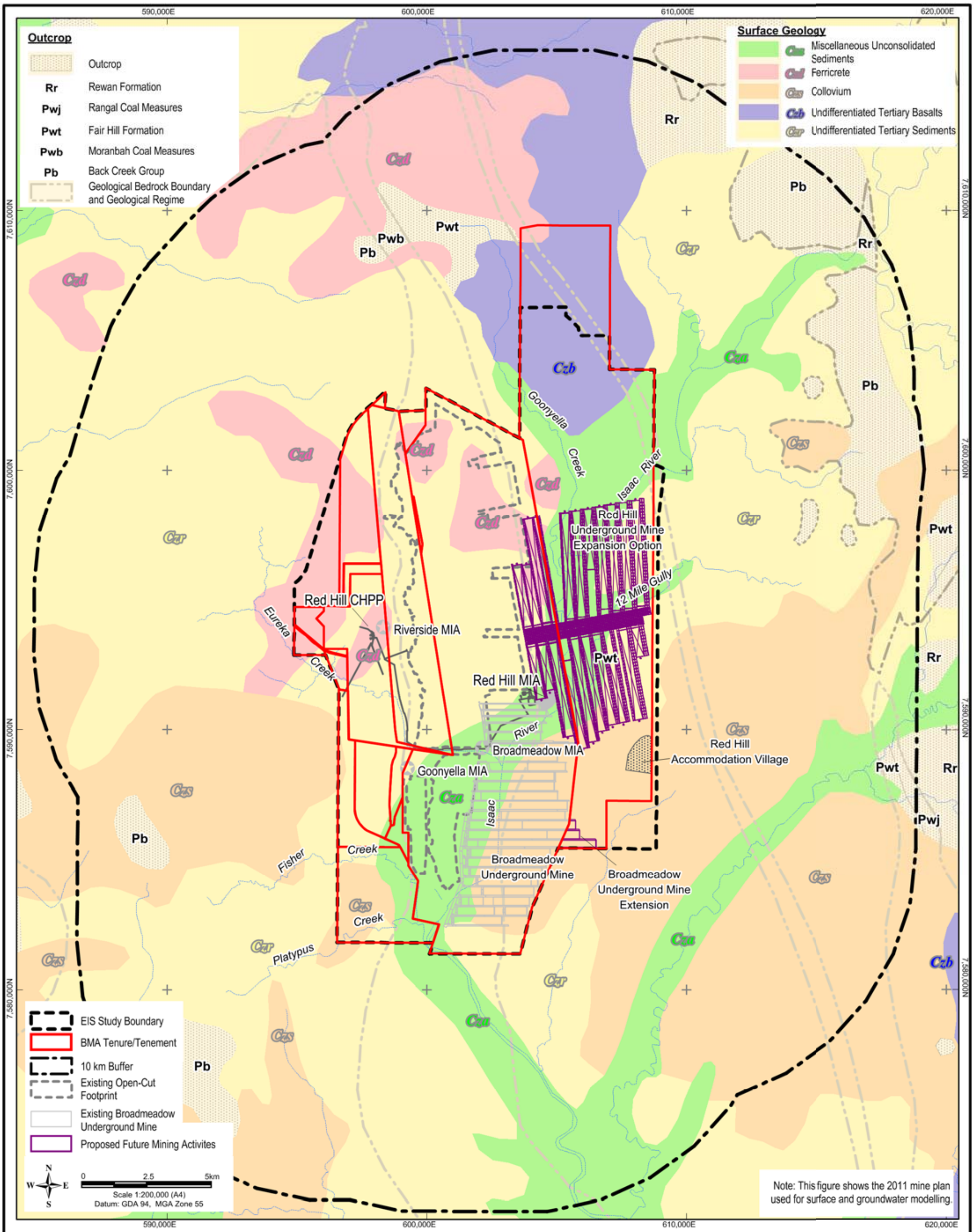
The mid-Tertiary Suttor Formation and its equivalents occur throughout the region, though outcrop is not continuous, and much of the Tertiary sequence is concealed by younger alluvium and colluvium. These strata consist of basalt, clay, silt, sand, weakly cemented sandstones, lignite and laterites. The Tertiary silts and clays are densely compacted and hard. Lag deposits of sand and gravel are found directly on the Tertiary/Permian unconformity.

The basalt appears to fill channels cut into the Tertiary sediments or into the Permian rocks. The basalts are deeply weathered and ferruginised in most places, but the thicker flows are fresher in their lower parts. Previous studies have reported basalt units range in thickness up to a maximum of 35 metres in palaeochannels in the GRM (Davies 1983).

A single major period of deep weathering has been identified for the region (Hutton *et al.* 1998). The weathering period was responsible for the strongly mottled and leached profiles on the Suttor Formation and its equivalents, and the basalts and older rocks. The associated duricrusts are generally cemented by clay minerals and silica.

Quaternary Formations

The Quaternary to Recent alluvial sediments consist of sand, gravel, clay and silt of varying content that have been unconformably deposited in an eroded, valley-fill environment associated with the creeks and drainage channels in the EIS study area. The alluvial deposits are thin, linear, irregular and lensoid in nature.



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GROUNDWATER IMPACT ASSESSMENT

SURFACE GEOLOGY OF THE SURVEY AREA

URS

GROUNDWATER

Figure: **5-1**

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Hydrogeological Regime

6.1 Groundwater Occurrence

An aquifer is defined as a groundwater bearing formation sufficiently permeable to transmit and yield water in useable quantities. The groundwater regime in the survey area is considered to include:

- Quaternary alluvial aquifers associated with the creeks and Isaac River;
- Tertiary sediment aquifers;
- Tertiary basalt aquifers; and
- Permian-Triassic sedimentary fractured rock aquifers.

The EIS study area is located within the declared Isaac Connors GMA, as defined under Section 6, Schedule 3 and Schedule 4 of the Water Resource (Fitzroy Basin) Plan 2011. Within the Isaac Connors GMA, aquifers in the Quaternary alluvium are known as the Isaac Connors Groundwater Unit 1, with all other aquifers grouped together as the Isaac Connors Groundwater Unit 2. The alluvium associated with the Isaac River in the survey area is defined as the Isaac Connors Alluvium groundwater sub-area of the Isaac Connors GMA. Groundwater supply is not considered to be a major water source in the groundwater survey area. Based on a review of available data, the beneficial use of groundwater in the survey area is considered to be low due to low sustainable yields and poor groundwater quality.

The occurrence and continuity of the above mentioned aquifers will be highly dependent on the spatial distribution of the corresponding geological units in the area. The conceptual model of the groundwater regime in the survey area is presented in **Figure 6–1**.

6.1.1 Quaternary Alluvial Aquifers

Distribution

Quaternary alluvial deposits in the survey area occur predominantly within the Isaac River floodplains as shown in **Figure 6-2**. Along the Isaac River these deposits consist of clay, sandy clay, and sands and gravels with varying proportions of clay, to a depth of up to 37 metres, as observed for monitoring wells GW01 and 43840. Investigations in the Isaac River at the Moranbah North mine (located immediately south of the EIS study area) indicated that the thickness of bed sands in the Isaac River was two to three metres (JBT Consulting 2010). The alluvium associated with Eureka Creek consists of approximately nine metres of silty sand and poorly sorted sand and gravel at monitoring well GW08, with no alluvium present at GW07.

The sand and gravel deposits are recognised within the creek beds with the overbank deposits being silty and clayey with minor sand. In the upper catchments of the smaller creeks rock bars are evident. Sand and gravel deposits tend to build up behind the rock bars.

Groundwater Occurrence, Recharge and Flow

Potential for usable groundwater resources exists within the more permeable sand and gravel dominant sections of the alluvium, and represents an unconfined to semi-confined aquifer. However, drilling in the survey area alluvium indicates variable saturated thickness and does not form a consistent interconnected aquifer. The alluvial aquifer is classed as a porous media aquifer where groundwater occurs within the voids between individual grain particles. The volume of groundwater associated with the alluvium depends on the interconnection of permeable units, saturated thickness,

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and the ability to store groundwater, i.e. effective storage allowing for baseflow to creeks and rivers during the dry season.

The alluvial aquifers are considered to be strongly linked (recharged during flow events) to surface water (SKM 2009). The Isaac River and creeks within the EIS study area are ephemeral and recharge of the alluvium is by:

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

Available hydrologic data suggests that water infiltrates / drains to the base of the alluvium relatively quickly after rainfall events where more permeable units are at surface. This saturation is sporadic, producing semi-permanent, localised, thin, aquifers.

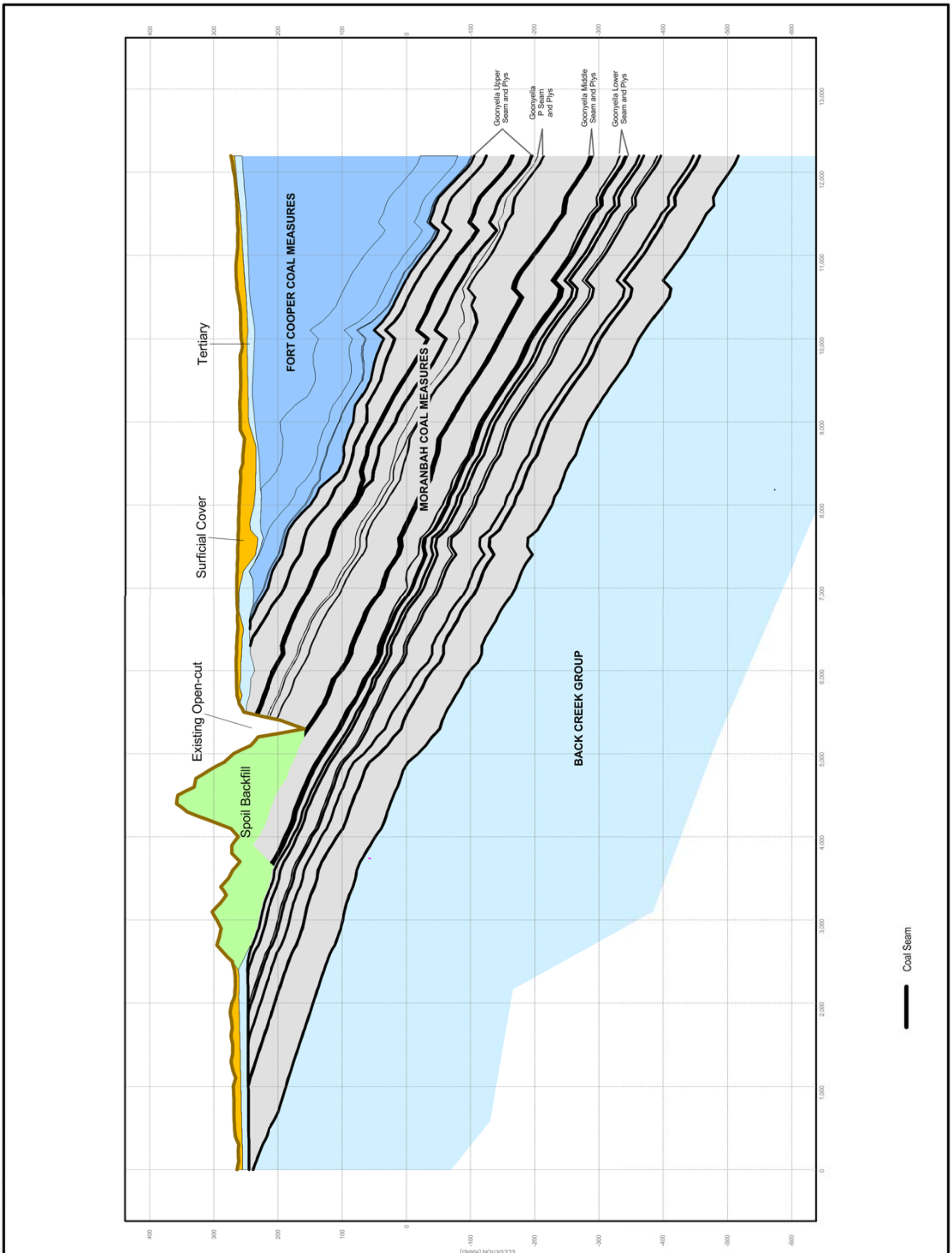
Groundwater discharge from the alluvium occurs through:

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

During a ground penetrating radar (GPR) survey of the Isaac River at Moranbah North mine, accessible during the dry season, it was noted that all test pits dug for the GPR survey within the bed sands were dry, or only damp in the base layer. This indicates that the Isaac River alluvium has limited effective storage, provides only limited volumes of baseflow, and does not contain groundwater all year round. Limited groundwater resources may, however, occur in the deeper and relatively narrow parts of the channel.

Due to the generally shallow saturated thickness and the lack of continuity of the more permeable gravel and sand sections, the Quaternary alluvium is not considered a significant aquifer as it has limited sustainable yield. However, during periods of creek or river flow, the alluvium may become fully saturated and discharge to sub-cropping coal seams or other underlying aquifers. Drilling on site indicates that, where groundwater does occur, depth to groundwater in the Quaternary alluvium was approximately 11 to 13 metres below ground level (mbgl). The groundwater level in the alluvium, measured in a study by Thatcher (1976), was about 20 metres above the piezometeric (confined) water level in the coal at the same location. These groundwater levels indicate a marked separation between the perched alluvium groundwater level and the piezometeric levels associated with the deeper coal seam aquifer groundwater. It is, thus, unlikely that changes in groundwater levels in the coal would significantly impact on the perched water table associated with the alluvium.

Owing to the paucity of data for the Quaternary alluvium, limited information exists regarding groundwater flow, however regionally, groundwater flow within the aquifer is expected to follow topography and drainage patterns.



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GROUNDWATER IMPACT STATEMENT

TYPICAL GEOLOGICAL CROSS SECTION

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Figure: **6-1**
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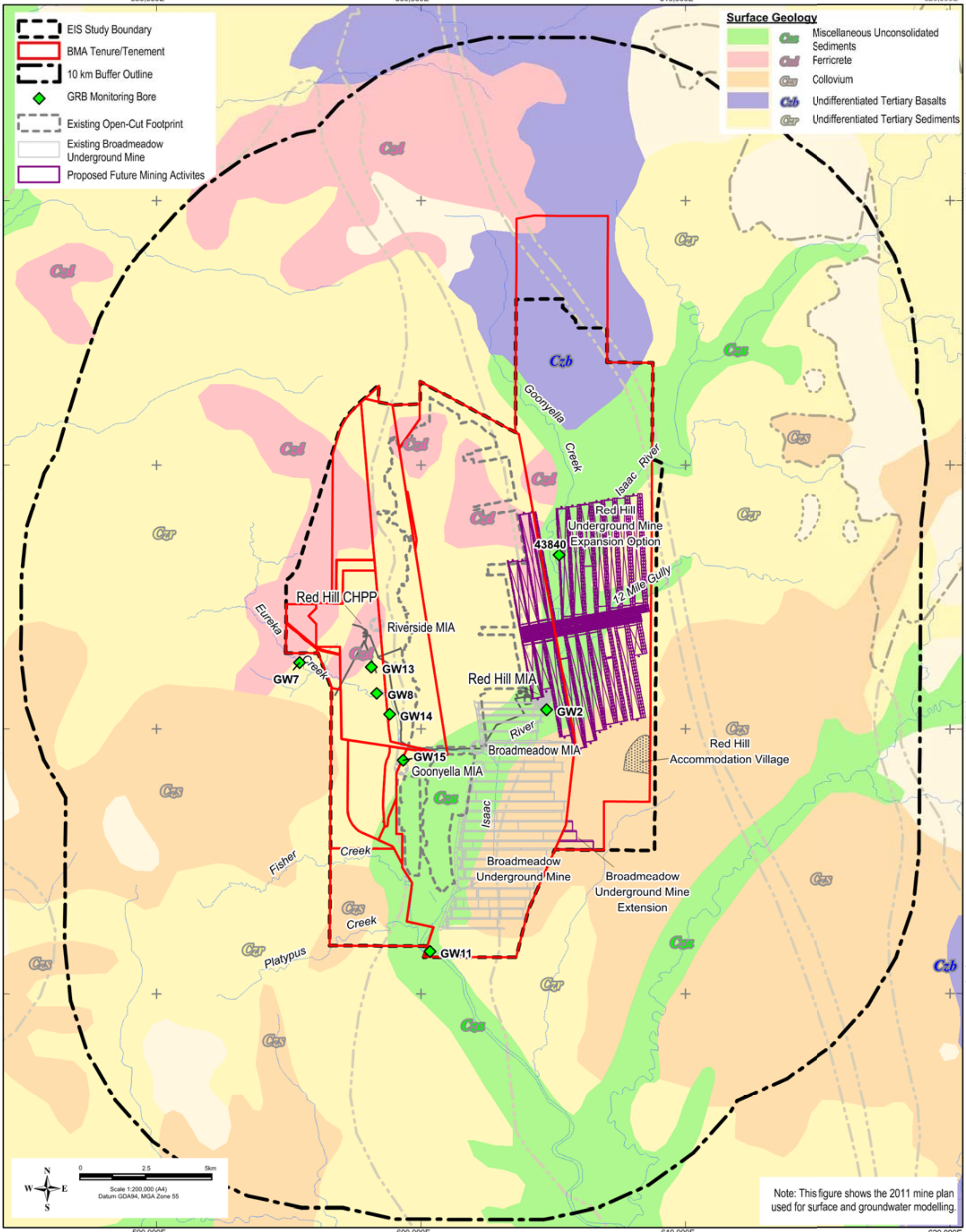

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GROUNDWATER IMPACT ASSESSMENT

QUATERNARY AND TERTIARY FORMATIONS WITHIN AND SURROUNDING THE EIS STUDY AREA

URS

GROUNDWATER

Figure: **6-2**

File No: **42627136-g-2097.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4

Hydraulic Parameters and Yield

Aquifer hydraulic properties of Quaternary alluvium material (Isaac River bed sands) and flood plain deposits were obtained from investigations undertaken at Moranbah North mine (JBT Consulting 2010). These hydrogeological investigations determined that permeability of the alluvium ranged from 8.9 to 45.4 metres per day (for some investigation sites water dissipated so rapidly that measurements could not be taken, indicating permeability higher than this range). These investigations also found that the Quaternary flood deposits (river bank sediments) were generally finer grained than the bed sands, and returned permeability values between 0.01 and 10 metres per day. This testing indicated that the river bank sediments were less permeable than the bed sands, and would be regarded as being of low to moderate permeability, compared to the higher permeability of the bed sands. Onsite, hydraulic testing of the Quaternary alluvium associated with the Eureka Creek at GW08 provided a hydraulic conductivity of 0.001 metres per day, typical for silty clay.

Even though the permeability of some areas of the Quaternary alluvial aquifers are high, the alluvium is not regionally extensive (continuous) and does not maintain a significant saturated thickness and hence is considered ephemeral in nature. Accordingly, groundwater extraction at high rates would not be sustainable in the long term (i.e. limited sustainable yields due to limited volumes held in storage).

6.1.2 Tertiary Sediment Aquifers

Distribution

The distribution of the Tertiary sediments is shown in **Figure 6–2**. The undifferentiated Tertiary sediments and Suttor Formation occurs extensively throughout the survey area, though outcrop is not always continuous, and much of the Tertiary sequence is concealed by younger alluvium and colluvium.

The Tertiary sediments generally consist of lenses of palaeochannel gravels and sands separated by sandy silts, sandy clays and clays. A review of the borehole logs within the RHM footprint showed the Tertiary sediments vary in thickness up to approximately 80 metres with a typical thickness of up to 15 metres. The thickness and extent of these Tertiary sediments are variable and for the most part, groundwater resources are limited and typically have poor quality. These Tertiary sediments have limited groundwater environmental values.

Groundwater Occurrence, Recharge and Flow

Potential for groundwater exists within the more permeable sand and gravel sections of the Tertiary sediments, and represents an unconfined to confined aquifer depending on location, degree of weathering, the nature of the overlying alluvium, and clay content.

Variable permeability within the Tertiary sediment, resulting in different pore pressures, has resulted in occurrences of pit wall instability. However, due to the limited storage the Tertiary sediment aquifers dewater with time. Dry open cut mining (at the GRB mine complex) indicates that this is not an ongoing problem and that these units readily dewater.

Recharge processes in the Tertiary sediment aquifers are via:

- direct infiltration of rainfall and overland flow where Tertiary sediments outcrop and no substantial clay barriers exist in the subsurface; and
- overlying Quaternary alluvial aquifers.

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

- through flow into adjacent or underlying aquifers (outcropping or sub-cropping coal seams); evapotranspiration; and
- groundwater extraction.

The depth to groundwater in monitoring wells on-site in the Tertiary sediment aquifer is typically less than 15 mbgl (IESA 2001a).

Hydraulic Parameters and Yield

Most of the clean sand and gravel lenses in the Tertiary sediments are permeable but are of limited lateral and vertical extent. Thus the volume of groundwater stored and the ability to transmit groundwater depends on the particle size of the material and the saturated thickness of the sediments. A review of bore logs within the RHM footprint showed that the Tertiary sediments are dominated by low permeability clays and sandy clays with isolated areas of loose more permeable sand. The interpreted hydraulic conductivity value of 6.6×10^{-4} metres per day obtained from the variable (falling) head test for monitoring well GYTD7 during investigations for the Airstrip Pit Boxcut (IESA 2001a) is very low, indicating predominantly clay intersected within this bore. No other site specific testing of hydraulic properties has been undertaken on the shallow Tertiary sediments. Installation of monitoring bores (GW1 to GW15) showed that the Tertiary sediments, where intersected, comprise predominantly of clays, containing only very minor sand lenses, and intersected little or no groundwater. Data from exploration drilling also indicates that these sediments are often dry, and occurrence of groundwater in these sediments is sparse. However, where the sediment is coarse in composition, the unit may have localised zones of enhanced hydraulic conductivity.

6.1.3 Tertiary Basalt Aquifers

Distribution

An aeromagnetic geophysical survey has been undertaken over the Bowen Basin (GSQ 2004). The resultant magnetic data indicates that Tertiary basalt exists as small discontinuous remnants to the south and in the west of the EIS study area, with a larger continuous unit to the north (**Figure 6-2**). No basalt is mapped within the footprint of the RHM.

Groundwater Occurrence, Recharge and Flow

For the majority of exploration boreholes that intersected basalt, the basalt is logged as highly to extremely weathered, clayey and dry. The distribution of less-weathered, fractured and vesicular water-bearing basalt is variable. The Tertiary basalt aquifers are classed as a secondary porosity aquifer and are expected to represent unconfined to confined aquifers depending on location. Groundwater is principally stored and transmitted in the fractures, joints and other discontinuities within the rock mass.

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

- infiltration of rainfall in rock outcrop areas where no substantial clay barriers exist in the shallow subsurface; and

- vertical seepage or though flow from overlying or adjacent alluvial or tertiary sediment aquifers.

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

- down gradient Tertiary basalt outcrop areas;
- through flow into adjacent or underlying aquifers (outcropping or sub-cropping coal seams); evapotranspiration; and
- groundwater extraction.

Depth to groundwater in the Tertiary basalt aquifers have historically been measured at between 23 and 34 mbgl (AGE 2004b).

Hydraulic Parameters and Yield

The nature of the Tertiary basalt, and hence its permeability and porosity, is highly variable, depending on the degree of weathering and the intensity and interconnectedness of jointing and/or fracturing. Where the basalt is less weathered and more fractured or vesicular, the unit may have local zones of moderate to high hydraulic conductivity. Hydraulic testing at Moranbah North mine (JBT Consulting 2010) indicated the Tertiary basalt to be moderately permeable with hydraulic conductivity values ranging from one to four metres per day and storage coefficient between 1×10^{-2} and 1×10^{-4}. Onsite, interpreted hydraulic conductivity values of 1.21 and 0.48 metres per day were obtained from the variable head test for monitoring wells 45314 and 45319, respectively during investigations for the groundwater depressurisation assessment of the southern extension of the Airstrip Pit (AGE 2004a) located in the southwest of the EIS study area. The drilling program undertaken as part of this Airstrip Pit groundwater study showed that the Tertiary basalt appears to be highly heterogeneous and discontinuous locally. In the area of the Airstrip Pit, the basalt intersected during drilling was generally not water-bearing; however for the few holes that did intersect measurable groundwater flows, airlift yields were at most 1.25 litres per second (L/s).

6.1.4 Permian-Triassic Strata Aquifers

Distribution

The Permian-Triassic formations constitute the two dominant Permian formations, which are the Blackwater Group and the Back Creek Group as well as the Triassic Rewan Formation as shown in **Figure 6–3** and described in **Table 5-1**.

As with the rest of the Bowen Basin, the coal seams are the main aquifers within the Permian sequences, with the overburden and interburden rocks in most mines being described as essentially impervious to groundwater movement (AGE 2008). Within the EIS study area, the GLS, GMS and GUS coal seams constitute the most extensive aquifers. These seams have been removed in the majority of the western extent of the EIS study area through open cut mining. The Triassic Rewan Formation strata occur only in the very north-east of the EIS study area.

Groundwater Occurrence, Recharge and Flow

The coal seam aquifers are confined above and below by very low permeability geological formations and movement of water through the aquifer (transmissivity) is likely to be through the more permeable (cleats) coal rather than the confining units. The confining units also have very low vertical hydraulic conductivity (leakance), such that very slow, as is the rate at which water flows into the aquifer

6 Hydrogeological Regime

(recharge) is limited. Groundwater occurs within the coal seam cleats and fissures and within open fractures that intersect the seams. Other sediments in the coal overburden and interburden sequence are relatively impermeable (either due to high clay content or significant cementing) and form aquitards. The Permian and Triassic strata may, therefore, be categorised into the following hydrogeological units:

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

Groundwater recharge in this aquifer occurs from:

- infiltration of rainfall and overland flow in outcrop and sub-crop areas;
- downward seepage or though flow from overlying or adjacent alluvial or tertiary aquifers where no significant clay barriers exist; and
- leakage between aquifers by faulting and other structural discontinuities in overburden and interburden sediments.

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

- downgradient Permian-Triassic strata outcrop areas;
- through flow into adjacent (outcropping or sub-cropping coal seams) or seepage into underlying aquifers (via structural discontinuities); and
- groundwater extraction (IMG and other mine dewatering activities).

Groundwater levels in the Permian formations have been measured for hydrogeological investigations assessing potential inflows to pits and underground workings and the establishment of boxcut or pit dewatering bores for mine design and production purposes, as discussed in **Section 3**. There are 41 groundwater level measurements from 32 bores installed in the Permian formations over the period from 1995 to 2009, however many of these bores have been destroyed during mining. Consequently, there are no long term hydrographs of groundwater levels available, and the groundwater level information is not evenly spatially distributed.

Evidence from piezometeric observations for the coal seam aquifers during these previous investigations suggests the groundwater levels were slightly different for each seam, with the GUS seam being one to two metres higher than the GMS seam, and the GLS seam being up to 14 metres lower than the GMS seam at the same location. This variation in hydraulic heads between coal seams indicates the aquitard nature of the interburden and the limited potential for induced flow. The phreatic surface varied from 15 to 50 mbgl. Prior to development of the GRB mine complex operations, groundwater flow direction in the coal seam aquifers appears to have been from the north and west to the south and east across the site. This flow direction is consistent with recharge to the coal seams occurring at the subcrops in the west of the site and discharge occurring downgradient in the Isaac River subcatchment in the Bowen Basin. The current groundwater flow pattern has been altered locally with groundwater flow towards the existing mine pits and underground workings due to mine dewatering and depressurisation. Groundwater modelling (AGE 2002) and groundwater level measurements indicate that groundwater levels are affected by mining induced drawdown up to 2.7 kilometres from the mine workings.

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The occurrence of groundwater in the interburden is limited. Aquifers in the interburden are discontinuous with heterogeneous hydraulic properties creating isolated, lens-like aquifers. Due to the heterogeneity and discontinuity of the interburden aquifers within the Permian strata, the groundwater flow direction cannot be determined on a regional scale for these aquifers.

No data exist on the seasonal fluctuations of groundwater level within the Permian-Triassic aquifers. However, due to the depth and confined nature of these aquifers, they are expected to show a subdued response to recharge or discharge.

Hydraulic Parameters and Yield

Interpreted hydraulic conductivity values determined for the Moranbah Coal Measures in the EIS study area are presented in **Table 6-1**. The aquifer testing results indicate that the cleats and joints in the coal are less open with depth, with a corresponding decrease in permeability. WDS (2011) conducted an engineering study for coal seam degassing required prior to mining of the RHM, using data derived from packer testing in 31 seam/site combinations in the Moranbah and Fort Cooper Coal Measures. This study found that:

- with increasing depth, effective stress increases and permeability decreases;
- with increasing ash (mineral matter), rock stress and effective stress increases and permeability decreases; and
- with increasing gas content to the east, primary permeability decreases.

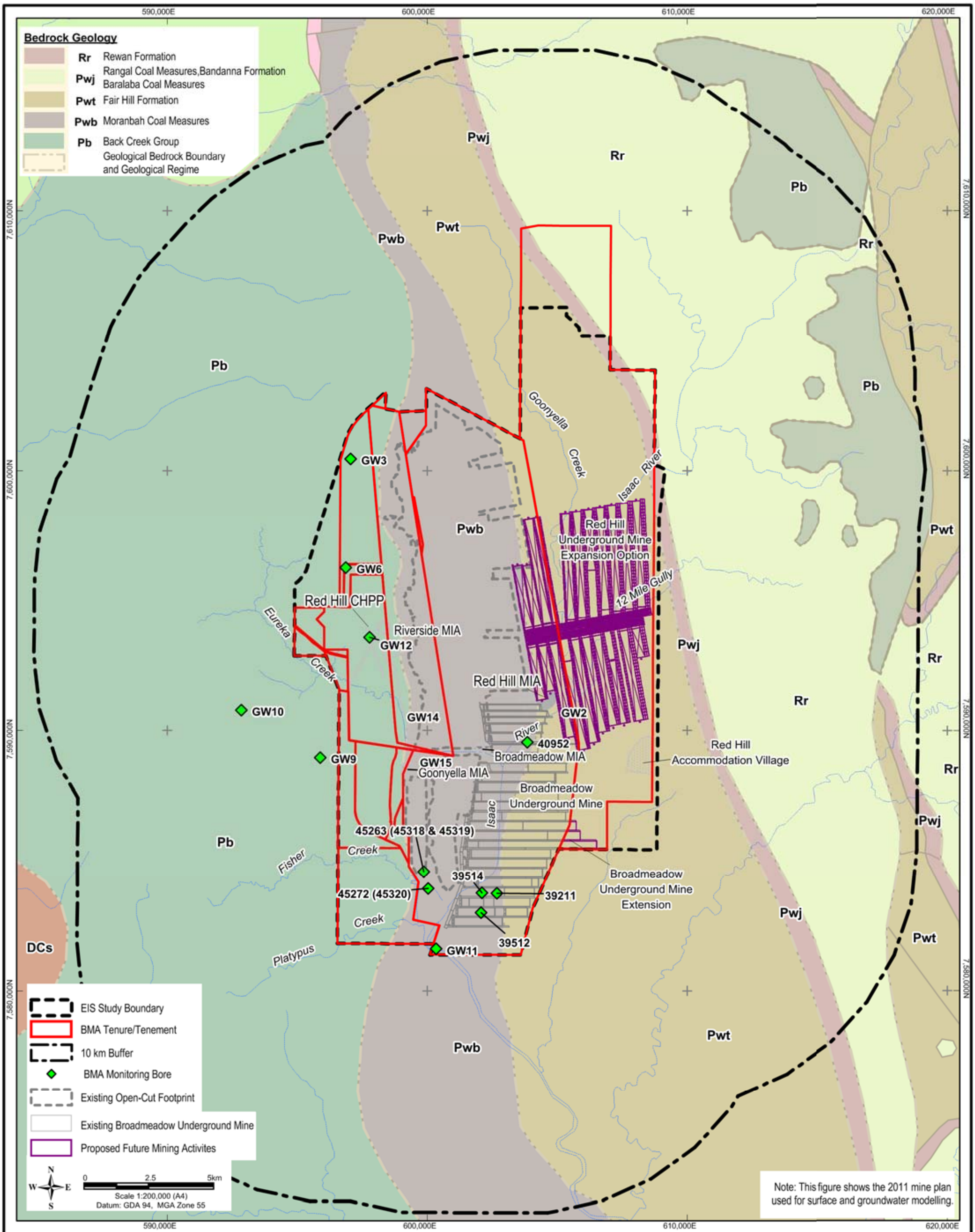
A relationship was determined for permeability variation with depth, ash, and gas content as part of this study. This relationship is:

- Permeability (mD[1]) = -0.00548 x Depth (metres) - 0.2549 x Gas Content at 15 per cent ash + 4.045688.
- It applies to the GUS, GMS and GLS seams for depths of 132 to 593 metres, Gas Content at 15 per cent ash of 0.2 to 13.7 cubic metres per tonne (m^3/t).

Interpreted hydraulic conductivity values determined for the Back Creek Group during investigations as part of the EIS were between 0.002 and 0.1 metres per day.

Hydraulic testing of the interburden units (AGE 2004b) and of drill core undertaken for this EIS revealed highly variable hydraulic conductivity from moderately pervious to highly impervious. This is evidence that the Permian formations are heterogeneous, having discrete zones of higher permeability over short distances and the very low hydraulic conductivity in the majority of the interburden and overburden isolate more conductive parts associated with the fracture/fault systems.

[1] milliDarcys an empirical unit of permeability



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GROUNDWATER IMPACT ASSESSMENT

PERMIAN AND TRIASSIC FORMATIONS WITHIN AND SURROUNDING THE EIS STUDY AREA

URS

GROUNDWATER

Figure: **6-3**

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Table 6-1 Interpreted Hydraulic Conductivity of Permian Strata Aquifers

Area of Investigation	Permian Strata Investigated	Method of Determination	Hydraulic Conductivity (m/day)
Goonyella No2 (Rust PPK 1996)	GMS	Pumping test	0.003 to 0.034
	GMS	Packer test	0.009 to 0.085
Airstrip Boxcut (IESA 2001a)	GLS	Falling head slug test	0.06 to 0.47
Goonyella Longwall Development (AGE 2002)	GMS	Calibration of groundwater numerical model	0.0009 to 0.1
Airstrip South Boxcut (AGE 2004a)	GLS	Falling head slug test	0.06 to 0.80
		Calibration of groundwater numerical model	0.82
Ramp 8 (AGE 2004b)	GLS	Shut in pressure test	0.10
		Falling head slug test	0.01 to 0.03
	Interburden	Falling head slug test	2E-05 to 0.33
EIS study area	Interburden	Constant head core test	Horizontal 2E-06 to 3E-05 Vertical 9E-07 to 9E-05

A review of the BMA exploration bore database was undertaken to assess airlift yields recorded during drilling. An airlift yield is the rate at which groundwater is removed from a bore during drilling with an air flushed drilling method, and is an estimate of the potential yield of a bore. Of the 659 exploration bores in the RHM area identified with recorded yield data, 440 bores (67 per cent) were identified as no recordable yield (i.e. dry), and 174 (26 per cent) had airlift yields of less than 0.5 L/s. Airlift yields recorded during drilling of the exploration bores are summarised in **Chart 6-1**. Many of the exploration bores that did not have recorded airlift yields in the exploration database may have been dry, thus the above histogram may overestimate the yield from the Permian strata. The length of time for which the airlifting was conducted was not available, therefore the sustainability of these yields is not known. The airlift yields generally decrease with airlift depth as shown in **Chart 6-2** confirming permeability decreases with depth as a response to fractures being less open at depth.

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Chart 6-1 Histogram of Airlift Yields of Exploration Bores

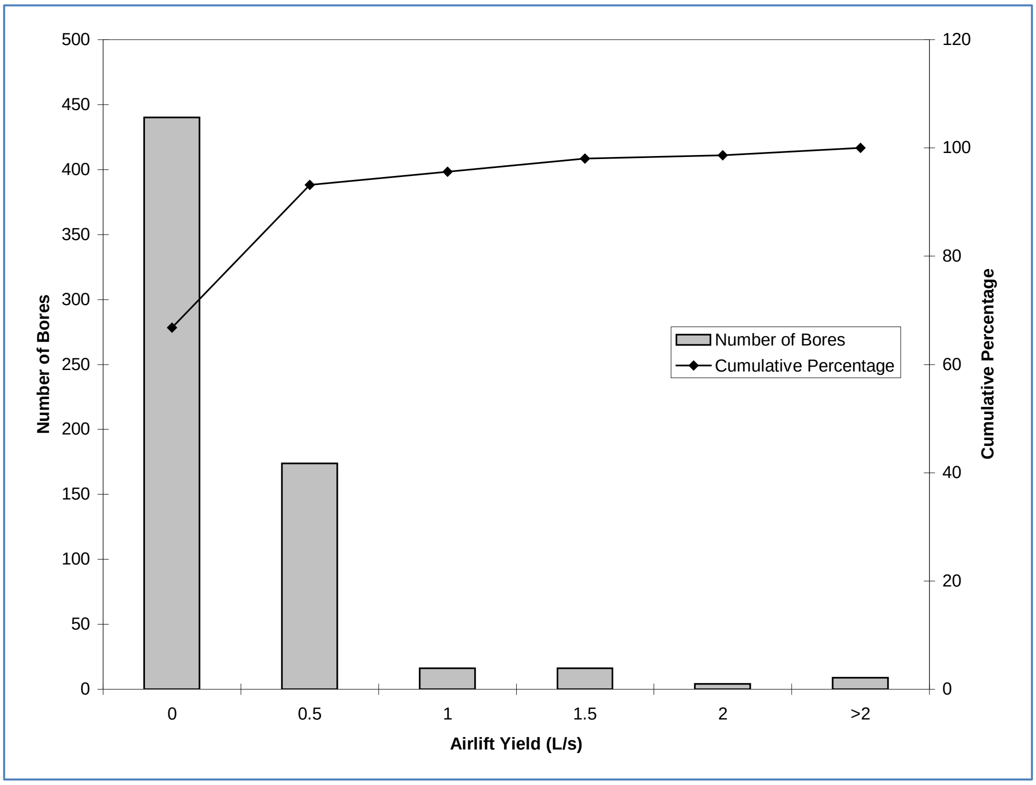
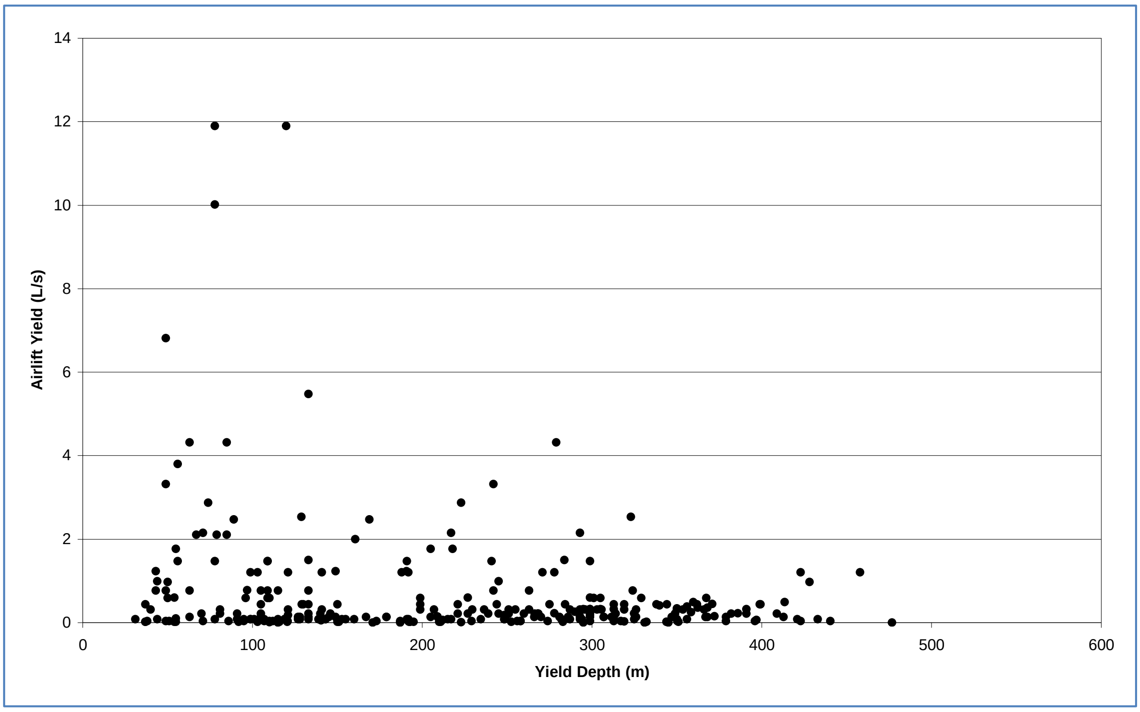


Chart 6-2 Airlift Yield and Airlift Depth for Exploration Bores



6.2 Groundwater Quality

Groundwater samples were collected for chemical analysis from piezometers installed around the site during previous site investigations and for this EIS study.

The physico-chemical results obtained during groundwater sampling within the EIS study area for the period 2001 to 2010, which have been summarised and presented in **Table 6–2**, indicate the groundwater chemistry is typically neutral to weakly alkaline (pH) for all formations. The Tertiary and Permian formations have variable salinity (measured as electrical conductivity), ranging from brackish to saline, while the groundwater quality within the alluvium is fresh.

It should be noted that the depth of the aquifer and its distance from the area of recharge are likely to influence the result at a given sample point, as salinity is highly variable, and appears to increase with depth and the distance from the area of recharge. Based on ANZECC/ARMCANZ (2000) guideline values, the groundwater may be suitable for livestock drinking water and irrigation of salt tolerant crops. However, the low yield typical of the aquifers would preclude use for large-scale irrigation.

Median groundwater salinity values were greater than the 50th percentile WQO nominated in the (Water) for groundwaters in the Isaac River Sub-basin (zone 34, which covers part of the survey area). The limited dataset does, however, indicate that groundwater results cover a wide range for each unit (due to depth, distance from recharge, and age of water). The lower end of the range results are within the WQO.

Results of the analyses of groundwater samples between 1998 and 2011 from monitoring bores installed on site are shown in **Table 6-3**. The Permian Moranbah Coal Measures and Back Creek Group has moderate to high salinity principally due to elevated levels of sodium and chloride ions. The Back Creek Group groundwater contains a relatively higher proportion of sulphate due to marine influence during deposition compared to the Moranbah Coal Measures. The groundwater from the Quaternary alluvium is dominated by sodium and bicarbonate ions, and has a lower salinity than the groundwater of the Permian formations.

Major ion concentrations for alluvial groundwater are less than the EPP (Water) 50th percentile water quality objectives for shallow (<30 metre depth) groundwater, while the maximum concentration of zinc recorded is above the ANZECC/ARMCANZ (2000) water quality guideline for aquatic ecosystems.

The median concentration of sodium for groundwater from the Moranbah Coal Measures is just less than the EPP (Water) 50th percentile water quality objective for deep (>30 metre depth) groundwater, while the median concentrations of chloride and bicarbonate are above the respective water quality objectives. The median concentration of manganese is also above the relevant water quality objective, while the median concentrations of nutrients (nitrate and nitrite, total phosphorous) and some dissolved metals (chromium, copper and zinc) are also above the ANZECC/ARMCANZ (2000) water quality guideline for aquatic ecosystems.

The median concentration of all major ions for groundwater from the Back Creek Group are greater than the EPP (Water) 50th percentile water quality objective for deep (>30 metre depth) groundwater. The median concentration of manganese and iron are also above the relevant water quality objective, while the median concentrations of nutrients (nitrate and nitrite, total phosphorous) and some dissolved metals (boron, cadmium, chromium, copper, nickel, selenium and zinc) are above the ANZECC/ARMCANZ (2000) water quality guideline for aquatic ecosystems.

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Table 6-2 Physico-Chemical Results for Aquifers in the EIS Study Area (2110-2010)

Aquifer	Number of Samples	Electrical Conductivity (µS/cm)		pH	
		Range	Median	Range	Median
Quaternary Alluvium	2	521-561		6.88-7.55	
Tertiary Basalt	3	2,670-15,384	13,100	8.19-8.67	8.38
Tertiary Sediment	1	5,060		9.30	
Permian Interburden	6	7,030-18,800	12,805	7.38-8.38	8.06
GMS	5	2,450-16,127	9,110	6.65-7.90	7.12
GLS	30	387-31,300	24,050	2.71-8.76	7.99
Back Creek Group	3	4,530-24,030	22,660	5.98-6.79	6.74
Undifferentiated from airlift sampling during exploration drilling	75	100-30,000	12,593	6.89-9.18	7.68
ANZECC/ARMCANZ (2000) upperlLimits[1] - irrigation - livestock – cattle		2,900-5,200 8,300-16,700[2]			
EPP (Water)[3] – 50th percentile - shallow groundwater (<30 m) - deep groundwater (>30 m)		2,150 6,100		7.75 7.80	

1 – ANZECC/ARMCANZ (2000) Water Quality Guidelines for livestock drinking water (cattle) and irrigation of salt tolerant crops

2 – Electrical Conductivity value based on TDS value for livestock (EC [µS/cm] = 1.67 × TDS [mg/L])

3 – EPP (Water) Isaac River Sub-basin Environmental Values and Water Quality Objectives for Zone 34.

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Table 6-3 Summary of Water Chemistry for Representative Bores On-Site between 1998 and 2011

Parameter	Guidelines					Moranbah Coal Measures				Back Creek Group				Quaternary Alluvium			
	EPP(Water) – 50th Percentile, Shallow (<30 m depth)[1]	EPP(Water) – 50th Percentile, Deep (>30 m depth)[1]	ANZECC/ ARMCANZ (2000) and QWQG (2006) - Freshwater Ecosystems[2]	ANZECC/ ARMCANZ (2000) - Livestock Drinking Water[3]	NHMRC (2011) - Human Drinking Water[4]	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)
Major Ions																	
Sodium	747	1,100	ne	ne	30[6]	13	40	1096	3560	3	824	3470	4400	2	40	-	94
Calcium	84	145	ne	1,000	ne	13	<0.01	49	469	3	34	214	422	2	13	-	39
Magnesium	108	115	ne	ne	ne	13	<0.01	25	570	3	86	542	805	2	7	-	20
Potassium	ne	ne	ne	ne	ne	13	1.4	6	28	3	29	35	38	2	3	-	3
Chloride	1,309	1,900	ne	ne	ne	13	64	2024	7510	3	1390	7000	9750	2	10	-	71
Bicarbonate	536	330	ne	ne	ne	13	85	497	5656	3	10	417	774	2	180	-	293
Sulphate	140	138	ne	1,000	200[6]	13	0.2	4	626	3	223	692	763	2	6	-	26
Fluoride	0.28	0.155	ne	2	1.5	11	<0.1	0.2	1.2					2	0.2	-	0.4
Nutrients																	
Nitrite + Nitrate as N	0.95	2.15	0.015	ne	ne	13	0.02	0.2	0.9	3	0.05	0.09	0.33	2	0.125	-	0.315
Total Phosphorus as P	ne	ne	0.03	ne	ne	13	0.03	0.5	5.08	3	0.78	1.49	1.56	2	0.47	-	0.75
Metals (Dissolved)																	
Aluminium	ne	ne	0.055	5	ne	13	<0.01	<0.01	0.1	3	0.04	0.05	0.05	2	0.05	-	<0.1
Antimony	ne	ne	ne	ne	0.003	2	0.004	-	0.007	3	<0.001	0.004	0.004	-	-	-	-

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Parameter	Guidelines					Moranbah Coal Measures				Back Creek Group				Quaternary Alluvium			
	EPP(Water) – 50th Percentile, Shallow (<30 m depth)[1]	EPP(Water) – 50th Percentile, Deep (>30 m depth)[1]	ANZECC/ ARMCANZ (2000) and QWQG (2006) - Freshwater Ecosystems[2]	ANZECC/ ARMCANZ (2000) - Livestock Drinking Water[3]	NHMRC (2011) - Human Drinking Water[4]	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)
Arsenic	ne	ne	0.013	0.5	0.01	7	<0.001	0.002	0.024	3	0.001	0.008	0.013	2	<0.001	-	<0.01
Barium	ne	ne	ne	ne	2	2	0.168	-	0.313	3	0.046	0.095	0.107	-	-	-	-
Beryllium	ne	ne	ne	ne	0.06	2	<0.001	-	<0.001	3	<0.001	<0.001	0.001	-	-	-	-
Boron	ne	ne	0.37	5	4	7	<0.1	0.26	0.6	3	1.51	1.82	3.32	2	<0.1	-	0.1
Cadmium	ne	ne	0.0002	0.01	0.002	7	<0.0001	0.0002	0.005	3	0.0002	0.0005	0.0006	2	0.0002	-	<0.005
Chromium	ne	ne	0.001	1	0.05	7	<0.001	0.002	0.01	3	0.002	0.003	0.004	2	0.002	-	<0.01
Cobalt	ne	ne	ne	1	ne	7	<0.001	0.003	0.01	3	0.018	0.02	0.08	2	<0.001	-	<0.01
Copper	0.01	0.03	0.0014	1	2	7	<0.001	0.002	0.01	3	0.001	0.002	0.004	2	<0.001	-	<0.01
Gallium	ne	ne	ne	ne	ne	2	<0.001	-	<0.001	3	<0.001	<0.001	<0.001	-	-	-	-
Iron	0.03	0.05	ne	ne	ne	13	<0.01	<0.05	1.2	3	<0.05	0.12	1.94	2	<0.05	-	<0.05
Lead	ne	ne	0.0034	0.1	0.01	7	<0.001	0.001	0.01	3	<0.001	<0.001	<0.001	2	<0.001	-	<0.01
Lithium	ne	ne	ne	ne	ne	2	0.041	-	0.136	3	0.206	0.276	0.41	-	-	-	-
Manganese	0.01	0.05	1.9	ne	0.5	13	0.002	0.18	1.23	3	0.958	0.991	1.07	2	0.037	-	0.16
Mercury	ne	ne	0.00006	0.002	0.001	2	<0.0001	-	<0.0001	3	<0.0001	<0.0001	<0.0001	-	-	-	-
Molybdenum	ne	ne	ne	0.15	0.05	7	<0.001	0.01	0.021	3	<0.001	0.002	0.003	2	<0.00	-	<0.01

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Parameter	Guidelines					Moranbah Coal Measures				Back Creek Group				Quaternary Alluvium			
	EPP(Water) – 50th Percentile, Shallow (<30 m depth)[1]	EPP(Water) – 50th Percentile, Deep (>30 m depth)[1]	ANZECC/ ARMCANZ (2000) and QWQG (2006) - Freshwater Ecosystems[2]	ANZECC/ ARMCANZ (2000) - Livestock Drinking Water[3]	NHMRC (2011) - Human Drinking Water[4]	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count[5]	Min (mg/L)	Med (mg/L)	Max (mg/L)
															1		
Nickel	ne	ne	0.011	1	0.02	2	0.002	-	0.033	3	0.009	0.028	0.131	-	-	-	-
Selenium	ne	ne	0.005	0.02	0.01	7	<0.01	<0.01	0.05	3	<0.01	0.01	0.03	2	<0.01	-	<0.01
Strontium	ne	ne	ne	ne	ne	2	1.75	-	3.86	3	0.675	8.52	10.7	-	-	-	-
Thorium	ne	ne	ne	ne	ne	2	<0.001	-	<0.001	3	<0.001	<0.001	<0.001	-	-	-	-
Titanium	ne	ne	ne	ne	ne	2	<0.01	-	<0.01	3	<0.01	<0.01	<0.01	-	-	-	-
Uranium	ne	ne	ne	0.2	0.017	2	0.002	-	0.005	3	<0.001	0.002	0.003	-	-	-	-
Vanadium	ne	ne	ne	ne	ne	2	<0.01	-	<0.01	3	<0.01	<0.01	<0.01	-	-	-	-
Zinc	0.015	0.025	0.008	20	ne	7	<0.01	0.013	0.13	3	0.05	0.054	0.174	2	0.008	-	0.02

1 – EPP (Water) Isaac River Sub-basin Environmental Values and Water Quality Objectives for Zone 34 groundwater

2 – ANZECC/ARMCANZ (2000) and QWQG (2006) trigger values for moderately disturbed upland stream freshwater ecosystems

3 – ANZECC/ARMCANZ (2000) guidelines for livestock watering of beef cattle

4 – NHMRC (2011) health based guidelines for drinking water

5 – Number of samples

6 – EPP (Water) Isaac River Sub-basin Environmental Values and Water Quality Objectives for drinking water

ne – No guideline value established

6.3 Groundwater Use

The survey area is located within the declared Isaac Connors Groundwater Management Area, as defined under Section 6, Schedule 3 and Schedule 4 of the Water Resources (Fitzroy Basin) Plan 2011. Within the declared management area, water licenses and/or development permits are not required for stock or domestic bores, and NRM also generally excludes groundwater monitoring bores from the requirement for development permits. In Queensland, all wells deeper than six metres, including monitoring wells, must be constructed by, or under the supervision of, a licensed water bore driller who has the correct endorsements on their licence for the type of activity being performed. It is a requirement of the Water Act that a licensed water bore driller submit the records of the drilling and installation of a water well to NRM within 30 days of completion of the well. These records are entered in the NRM database.

From a search of the NRM groundwater database, 31 bores are registered within 10 kilometres of the EIS study area boundary, as shown on **Figure 6-4**. Of the 31 bores, 27 have been installed for private use, and four have been installed by NRM for groundwater monitoring and assessment (three of which have been abandoned and destroyed). Of the 27 bores installed for private use, 16 were installed for coal seam gas (CSG) exploration in the Moranbah or Fort Cooper Coal Measures, with four of the seven other private bores in these formations being abandoned and destroyed. No stratigraphic or casing description information has been included in the NRM database for the three remaining non-CSG bores and accordingly it is not certain from which aquifer these bores extract groundwater. No information exists in the database on the normal pumping rates of these bores, or the drawdown that occurs during pumping. The current use of the bores is not specified in the NRM database, however typical groundwater use in the area is expected to be for stock watering owing to the variable salinity levels and generally low yields. No dewatering for CSG extraction is currently undertaken within the EIS study area, however CSG exploration has been undertaken in the area and producing CSG wells are located to the south east of the project.

A groundwater bore census was conducted within and on properties surrounding the EIS study area boundary to collect information on groundwater bores installed before registration was a requirement, and additional information on bores registered in the NRM database. Four bores were recorded during the census, two on 'Denham Park' and two on 'Broadmeadow'. The location of these bores is shown on **Figure 6–4** and summary of bore details are provided in **Table 6-4**. The bores on 'Denham Park' intersect the basalt aquifers to the northwest of the EIS study area, however, the basalt does not extend into the project's infrastructure or mine areas and so these bores are unlikely to be impacted by it. The bores on 'Broadmeadow' are considered to be constructed into the base of Tertiary (basal sand/sandstone) or the top of the Permian formations. These bores are generally used for stock watering, with one (Tex's bore on Denham Park) also used for house hold supply during drought.

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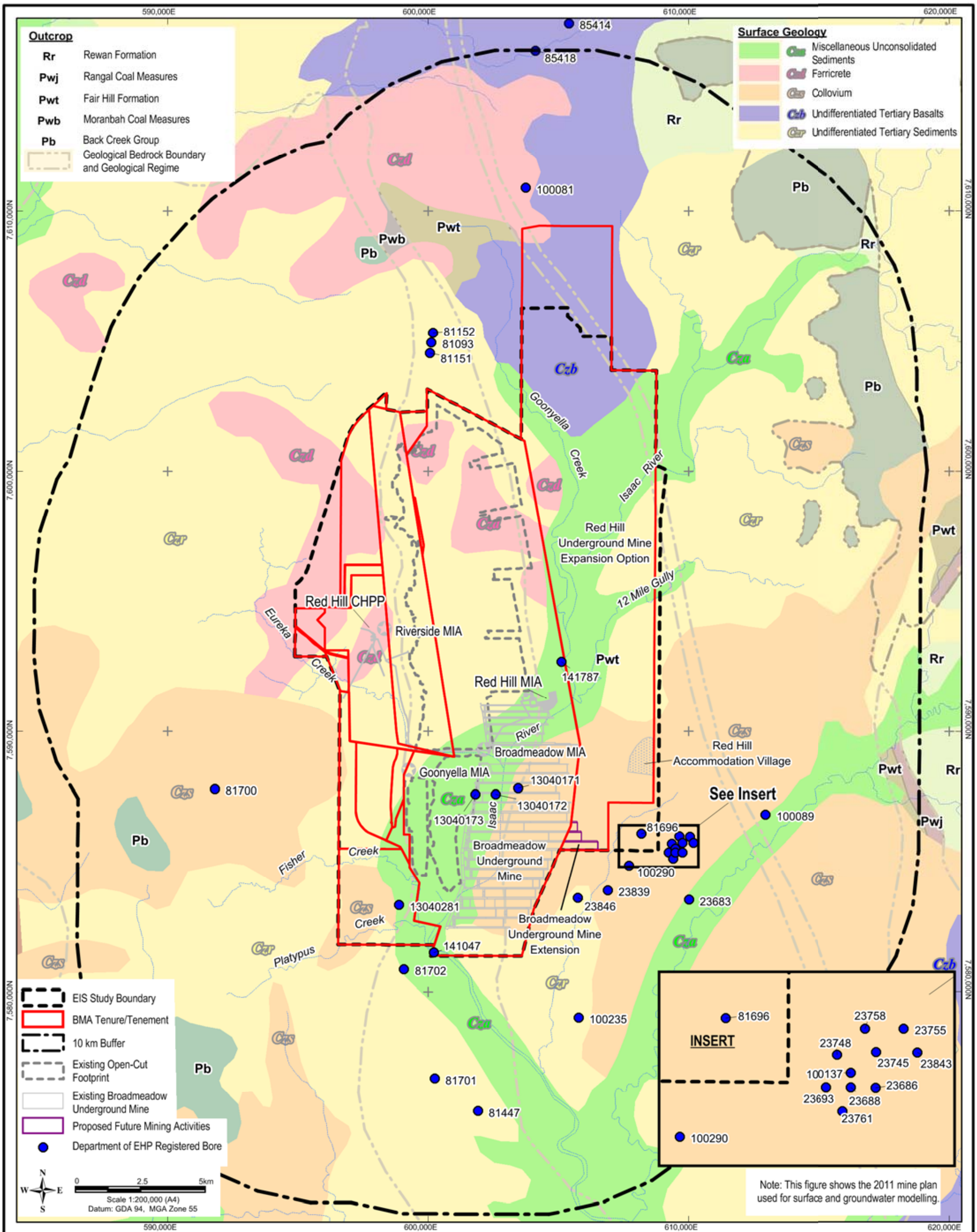
Table 6-4 Summary of Information Collected During Bore Census

Property	Bore Name	Drilled Depth (mbgl)	Depth to Water (mbgl)	Water Use	Pumping Rate (L/s)	Landholder Description of Water Quality
Denham Park	Tex's Bore	118.9	34.13	Domestic and stock watering in drought	4.5	
Denham Park	Old Mill Bore	117.1	90.66	Stock watering	1.9	
Broadmeadow	Skeleton Bore (NRM Registration 81696)	63.7	28.41	Stock watering when required	1.3	'Good'
Broadmeadow	Cleanskin Gully	25.34	14.02	Stock watering when required	2.6	'Good'

There have been groundwater dewatering bores on site at GRB in the past for the establishment of GRM boxcuts, however these were not replaced when they were mined out because groundwater inflow to the open cut pits is limited once mining is established. Due to the large surface area of the open cut pits and the significant excess of evaporation over rainfall in the area, groundwater which seeps from the coal seams in the open pits mostly evaporates, with limited amounts collected in sumps and pumped to the mine water system for reuse. Groundwater is not actively dewatered in advance of mining in the BRM, with seepage collected in sumps and pumped to the surface into the existing mine water system for reuse. Total groundwater contribution rates to the mine water system are not monitored as these are at low levels.



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GROUNDWATER IMPACT ASSESSMENT

LOCATION OF NRM REGISTERED BORES AND BORE CENSUS

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Figure: **6-4**

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6.4 Assessment of Groundwater Environmental Values

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

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

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

Biological Integrity of a Pristine or Modified Aquatic Ecosystem

The local area within and around the RHM footprint has been cleared for agriculture, predominantly beef cattle grazing, as well as for coal mining purposes. These farming and mining practices modify the landscape, affecting the volume and rate of rainfall runoff, the flow characteristics of the creeks, and the recharge to groundwater. As such, the aquatic ecosystems of the area have been modified.

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

The water level measurements undertaken as part of the EIS indicate that the water table within all aquifers on site is generally greater than 10 mbgl, although the depth to water within the bed sands (ephemeral aquifer) in watercourses is less than this when saturated. These depths to groundwater, and the lack of permanent springs in the area, indicate that GDEs are not likely to exist in the vicinity of the site. This was confirmed in the Red Hill Mining Lease EIS Section 9. The vegetation species and regional soil/geology types suggest that the level of groundwater dependence is likely to be relatively low (riparian vegetation communities are considered as opportunistically groundwater dependent) and vegetation is likely to be able to satisfy plant water requirements using retained soil moisture. Water available to ecosystems may include a mix of groundwater with soil water (unsaturated zone) and surface water. Sampling for stygofauna was undertaken as part of the ecology study for the project (refer to Appendix K3 of the Red Hill Mining Lease EIS). No stygofauna were found in any of the accessible groundwater bores on site.

In addition the depth of groundwater limits any potential use by listed or threatened species and migratory birds. Any potential changes in groundwater levels as a result of mine dewatering are therefore not considered to impact on listed or threatened species and migratory birds.

Although groundwater investigations indicate very low potential for groundwater resources to be physically available to support GDEs, the groundwater analytical results, as presented in **Table 6-3**, have been assessed against the EPP (Water) (for Zone 34, which includes the Moranbah area), ANZECC/ARMCANZ (2000), and Queensland (DERM 2009) water quality guidelines (for the protection of moderately disturbed freshwater ecosystems, central region, upland streams). This allows consideration of whether the groundwater resources in the area are of a sufficient quality to provide environmental value to possible GDEs via flow into surface water bodies.

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

Suitability for recreational use (primary recreation)

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

Suitability for Minimal Treatment before Supply as Drinking Water (raw water)

The groundwater analytical results, as presented in **Table 6-3**, have been assessed against the Australian drinking water guidelines (NHMRC 2011) to consider the potential health effects of drinking minimally treated groundwater. The EPP (Water) also give a drinking water guideline of 30 milligrams per litre (mg/L) for sodium and 200 mg/L for sulphate. The groundwater quality from the monitoring wells indicates that, in general, the groundwater is unsuitable for human consumption. This is due to elevated concentrations of sodium, sulphate and several dissolved metals (antimony, arsenic, manganese, nickel and selenium) in some of the groundwater samples collected from the Permian formations. Generally the groundwater samples contain elevated levels of salinity (>1,000 mg/L), which are above the guideline for aesthetics based on the groundwater having an unsatisfactory taste.

Groundwater resources within the survey area would require significant treatment before it could be utilised for drinking. The only local groundwater that may be suitable for human consumption is that which comes from the alluvium associated with the Isaac River. However, concentrations of sodium have been recorded at levels above the EPP (Water) limit of 30 mg/L. It is noted that the concentrations of sodium are less than the Australian drinking water guidelines (NHMRC 2011) limit of 180 mg/L.

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

Suitability for Primary Industry Use

Groundwater quality results presented in **Table 6–2** and **Table 6-3** suggest that groundwater within the study area is generally suitable for stock watering for beef cattle. The higher salinities of the Back Creek Group and Blackwater Group aquifers would potentially result in loss of production and decline in animal condition and health as salinity concentrations are > 5,000 mg/L. The groundwater in some of the Permian formations has levels of selenium that are slightly elevated above the guideline values.

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

Maintenance of Cultural and Spiritual Values

There are no registered groundwater springs or seeps that supply surface water bodies in the survey area. No springs are known to have significant Aboriginal and/or non-indigenous cultural heritage associations.

Shallow groundwater (in the alluvium), however, may sustain baseflow in the Isaac River for short periods after heavy rains or flooding, although shallow aquifers are ephemeral, only existing for short periods after recharge. The Aboriginal cultural heritage values of that section of the Isaac River within the EIS study area are discussed in the Red Hill Mining Lease EIS Section 16.

Numerical Modelling

To assess the potential impacts of the proposed project and associated infrastructure on the regional groundwater regime, predictive groundwater modelling was undertaken. The objectives of the predictive modelling were to:

- estimate groundwater extraction (passive seepage and active dewatering for IMG control) over the mine life;
- predict the zone of influence of dewatering and the level and rate of drawdown at specific locations;
- identify areas of potential risk where groundwater impact mitigation/control measures may be necessary; and
- predict the impact of mine dewatering on groundwater discharges and other groundwater users.

7.1 Available data

To assist in constructing and calibrating the necessary numerical integrated model, the following information was considered:

- the EIS study area, comprises the proposed RHM, Broadmeadow extension, and includes GRB mine complex (approved mining operations);
- the Permian strata dips at between two and eight degrees to the east;
- the final underground mine depth will be approximately 500 metres;
- the geology within the area comprises Quaternary alluvial, Tertiary sediments, and Permian-Triassic formations with coal measures;
- mining of the GRB mine complex continues at currently approved rates with completion of BRM in 2030 and GRM in 2068;
- mining sequences for existing mines and RHM provided by BMA (mine plan dated October 2011);
- no major faults or intrusions are located within the RHM footprint;
- bore logs and hydrogeological data from monitoring bores and the BMA exploration database across the site;
- shape files for the topography, alluvium, tertiary, and coal seams; and
- climate data.

7.2 Model Approach

URS utilised the MODHMS (Hydrogeologic Inc., USA) groundwater modelling package to construct the required groundwater model. MODHMS is based on the standard MODFLOW groundwater modelling code. The MODFLOW code was developed by the United States Geological Survey (McDonald and Harbaugh 1984) for three-dimensional, finite-difference, modular, groundwater flow modelling. The MODFLOW code is the most widely used code for groundwater modelling and is currently considered an industry standard. MODHMS incorporates additional computational modules to enhance the simulation capabilities and robustness. MODHMS was selected as it allowed for:

- the modelling of variable saturation conditions, allowing for unsaturated and saturated conditions thus avoiding dry-cell problems;
- coupled flow and mass transport simulations (if required);
- the inclusion of discrete features, such as the backfill area of open cuts; and
- integrated groundwater and surface water modelling (if required).

A pseudo-steady state model was constructed based on the available data and represented current groundwater flow conditions due to the existing GRB mine complex dewatering. The outcome of this modelling of the existing approved GRB mine complex impacts (drawdown extent) was used as initial conditions for the transient model, which undertook predictive scenarios for RHM. The modelling approach comprised the following:

- Simulations of dewatering cones and extent at the end of mining (both for the currently approved GRB mine complex, and the proposed RHM).
- Groundwater extraction volumes with time to simulate IMG depressurisation and mine dewatering.

7.3 Model Conceptualisation

Every numerical groundwater model has as its foundation a conceptual model. The conceptual model is an understanding of how the groundwater system operates and is an idealised and simplified representation of the natural system.

The conceptual groundwater model of the groundwater survey area was developed based on geological and topographical maps, geological information from coal exploration bores drilled across the GRB mine complex and RHM footprint areas, geological modelling developed by BMA, results from previous hydrogeological investigations in the Bowen Basin, and relevant data from hydrogeological and gas drainage studies conducted by BMA.

The conceptual model area encompasses the upper units of the Back Creek Group, the Blackwater Group, and the overlying units of the Bowen Basin on the Collinsville Shelf and is bounded by:

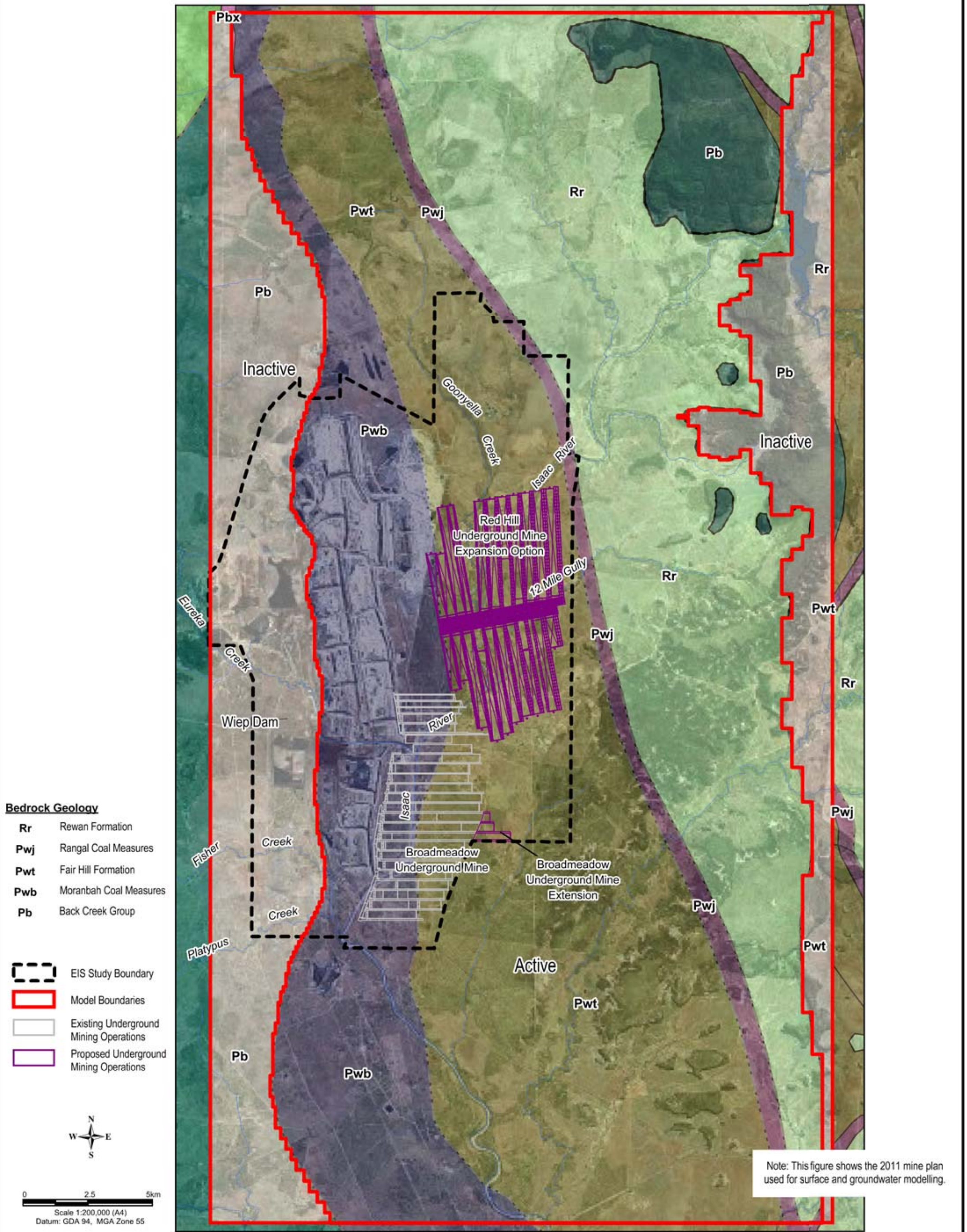
- the outcrop/subcrop of the Back Creek Group to the west of the mine;
- a system of thrust faults approximately 10 kilometres to the east of the proposed RHM that offset the Moranbah Coal Measures; and
- an arbitrary distance of approximately 25 kilometres to the north and south of the RHM that was judged to be beyond the influence of potential mine dewatering (**Figure 7-1**).

7.3.1 Model Extent and Grid

The regional groundwater model was constructed across an area of 24 by 46 kilometres as shown in **Figure 7-1**, with the EIS study area situated towards the western extent of the model based on boundary conditions.

The model was constructed with a refined grid of 100 by 100 metres for the mining area and with grid spacing of 400 by 400 metres outside the EIS study area, as shown in **Figure 7-2**. The finite difference model comprised:

- a model area of 1,104 square kilometres;
- 316 rows and 156 columns; and
- 667,522 active cells for a seventeen-layer model.



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NUMERICAL MODEL EXTENT

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GROUNDWATER

Figure: **7-1**

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NUMERICAL MODEL GRID

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GROUNDWATER

Figure: **7-2**

File No: **42627136-g-2101.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4

7.3.2 Boundary Conditions

Model boundaries were based on available information and data limitations. The boundaries include:

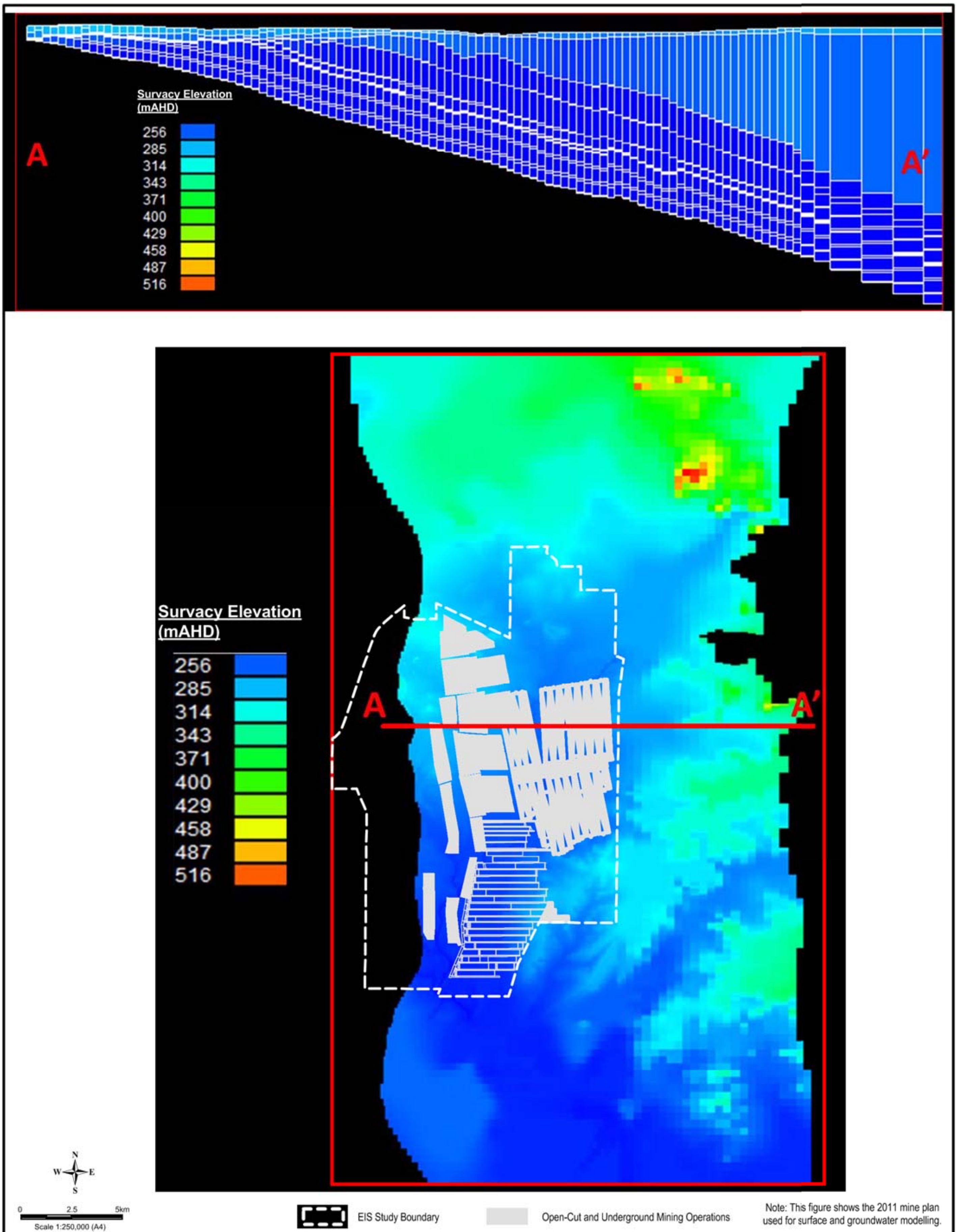
- **Top inflow boundary** comprising recharge and evaporation. Available precipitation and evaporation data was reviewed / verified;
- **Horizontal inflow boundary** based on groundwater level data, which is used to determine the model's east, west, north, and south boundary conditions. Geological log data and groundwater level information was used to set up representative prescribed head boundaries, sufficiently far from the RHM footprint for the southern and northern boundaries. Since few head observations were available near the boundaries, topographic elevations were used as reference elevations relative to groundwater levels. It was assumed that groundwater levels were 35 mbgl for the northern boundary and were 20 mbgl for the southern boundary based on average depth to groundwater from available observations across the survey area. No flow boundaries were ascribed to the western boundary at the outcrop/subcrop of the Back Creek Group, and to the eastern boundary defined as the Burton Fault, which has offset the Blackwater Group; and
- **Bottom inflow boundary** considered below the site. Model bottom elevations were determined from floor and roof elevation data in the geological model supplied by BMA. The no-flow boundary was assumed sufficiently far below the base of any mining (GMS and GLS) elevation based on available geological data.

7.3.3 Model Layers

Publicly available digital elevation data (STRM data) with a 90 by 90 metre grid spacing was used to represent the ground surface in the model outside of the refined area (400 metre grid area in **Figure 7-2**), and BMA topographical data was used to represent the ground surface within the refined area (100 metre grid in **Figure 7-2**). The model layer elevations in the refined-grid area were generated based on the BMA geological model; while the layer elevations outside the refined area were extrapolated based on available data (Bowen Basin digital geology, Bowen Basin regional contouring of the top of the Moranbah Coal Measures on 50 metre intervals, and coal seam gas well logs) and assumptions. These data sets were used to create layer elevations throughout the model domain.

Seventeen layers, representing the different lithological units across the survey area, were included in the model (**Table 7-1**). **Figure 7-3** presents a west-east cross-section through the centre of the model, illustrating the model layers (pre-mining).

It is important to note that faults can act as both conduits for groundwater flow, or in the case of coal seams, barriers to flow. The eastern boundary of the model is along the Burton Fault, where the Moranbah Coal Measures are significantly offset, and is considered a no flow boundary. Within the groundwater survey area, the Moranbah Coal Measures have undergone some minor to moderate faulting that may interrupt the continuity of the aquifer and act as boundaries to groundwater flow. In the model domain, the coal seams are simplified to allow continuous groundwater flow and to tie in with the interpolated levels beyond the EIS study area where data is limited. The effect of this simplification was to remove barriers to groundwater flow, which effectively extends the predicted drawdowns and increases groundwater inflows to the workings. The model is therefore considered to be conservative and would likely to be a 'worst case scenario'.



Note: This figure shows the 2011 mine plan used for surface and groundwater modelling.

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SITE TOPOGRAPHY AND CROSS-SECTION THROUGH NUMERICAL MODEL SHOWING MODEL LAYERS

GROUNDWATER

Figure: 7-3

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7 Numerical Modelling

Table 7-1 Numerical Model Layers

Model Layer	Unit
1 (top)	Tertiary, alluvium
2	Fort Cooper Coal Measures –
3	Fort Cooper Coal Measures FC1
4	Fort Cooper Coal Measures – Interburden
5	Fort Cooper Coal Measures FC2
6	Moranbah Coal Measures – Overburden
7	Moranbah Coal Measures - GUS
8	Moranbah Coal Measures – Interburden
9	Moranbah Coal Measures – Goonyella 'P' Seam GP1
10	Moranbah Coal Measures – Interburden
11	Moranbah Coal Measures – Goonyella 'P' Seam GP2
12	Moranbah Coal Measures – Interburden
13	Moranbah Coal Measures – GMS
14	Moranbah Coal Measures – Interburden
15	Moranbah Coal Measures –GLS
16	Moranbah Coal Measures – Underburden
17 (bottom)	Back Creek Group

7.3.4 Rainfall Recharge

Recorded site specific data, from the Moranbah weather station, is available for the period 1972 to 2011. However, for an extended period (120 years) of rainfall data, a statistical analysis of climate data from surrounding weather stations was compiled based on the Data Drill system. The rainfall and evaporation data for the period between 1889 and 2011 indicates an average 546.5 millimetre annual rainfall, and 2,093.8 millimetre annual evaporation rate.

Through a review of available data (AGE 2008; METServe 2010), recharge rates would be less than one per cent of mean annual average rainfall, and evapotranspiration was not considered due to the depth to groundwater observed for the deep aquifers.

7.3.5 Hydraulic Parameters

Probable ranges of hydraulic conductivity (K) and storativity values, as displayed in **Figure 7–2**, were derived from hydraulic test results (as described in **Section 6**) and literature values where onsite data was not available.

7 Numerical Modelling

Table 7-2 Ranges of Hydraulic Conductivity (K) and Storativity Values for Each Numerical Model Layer

	K(horizontal) (m/day)		K(vertical) (m/day)		Storage Coefficient		Specific Yield (/m)	
Layer	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	1.0E-02	1.0E+01	1.0E-03	5.0E-01	1.0E-06	1.0E-04	5.0E-02	2.0E-01
2	1.0E-04	1.0E-01	1.0E-05	1.0E-03	1.0E-06	1.0E-04	1.0E-02	1.0E-01
3	1.0E-04	1.0E-01	1.0E-05	1.0E-03	1.0E-06	1.0E-04	5.0E-03	5.0E-02
4	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01
5	1.0E-04	1.0E-01	1.0E-05	1.0E-03	1.0E-06	1.0E-04	5.0E-03	5.0E-02
6	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01
7	1.0E-05	2.5E-02	1.0E-06	2.5E-03	1.0E-06	1.0E-04	5.0E-03	5.0E-02
8	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01
9	1.0E-05	2.5E-02	1.0E-06	2.5E-03	1.0E-06	1.0E-04	5.0E-03	5.0E-02
10	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01
11	1.0E-05	2.5E-02	1.0E-06	2.5E-03	1.0E-06	1.0E-04	5.0E-03	5.0E-02
12	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01
13	1.0E-05	2.5E-02	1.0E-06	2.5E-03	1.0E-06	1.0E-04	5.0E-03	5.0E-02
14	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01
15	1.0E-05	2.5E-02	1.0E-06	2.5E-03	1.0E-06	1.0E-04	5.0E-03	5.0E-02
16	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01
17	1.0E-05	5.0E-02	1.0E-06	1.0E-04	1.0E-06	1.0E-04	1.0E-02	1.0E-01

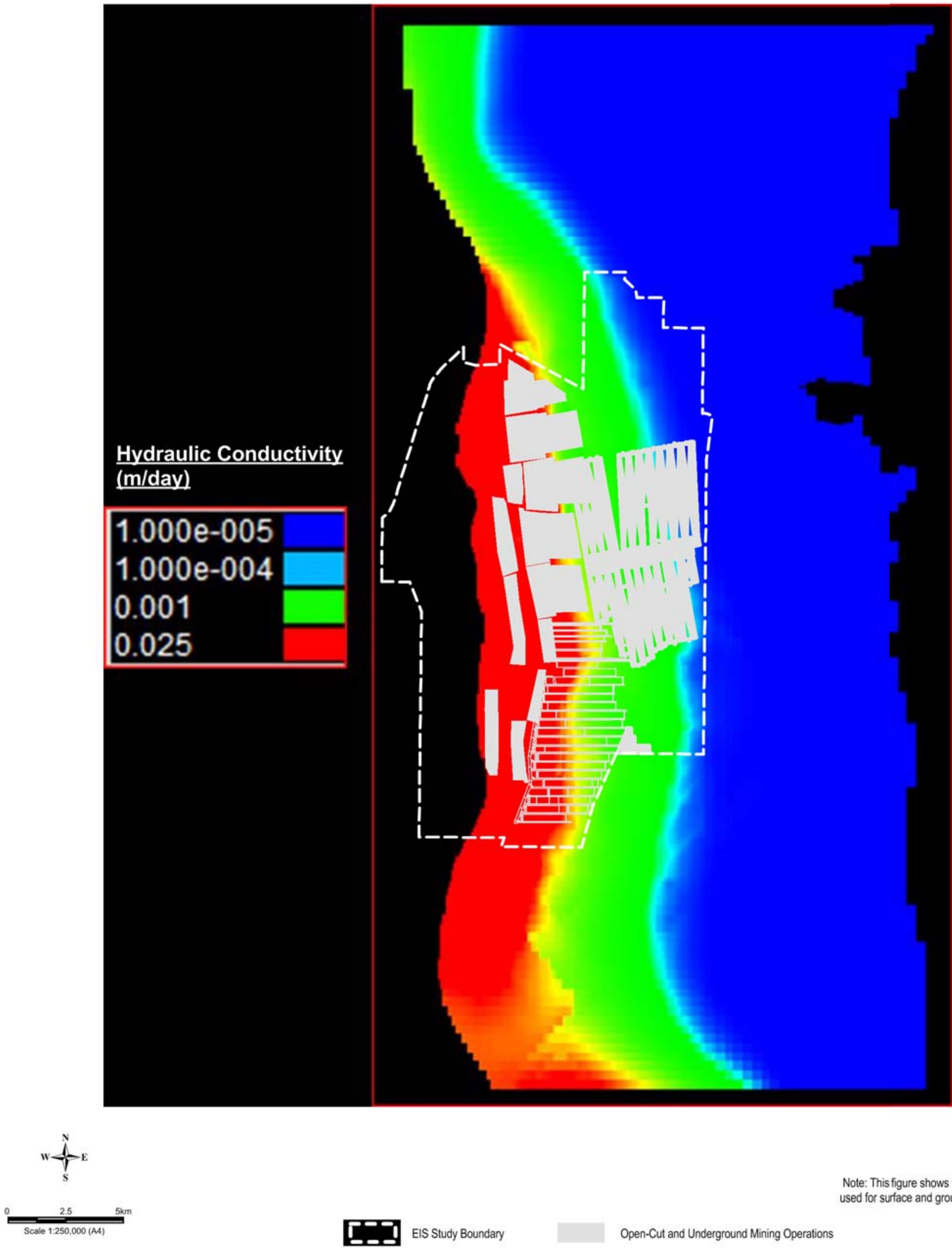
Parameterization

Following the principle of parsimony, model parameterization was kept as simple as possible while accounting for the system processes and characteristics that are evident in observations and important to predictions. For the numerical model, hydraulic conductivity (K) values were assigned as homogeneous values to the layers, except for the layers representing the Moranbah Coal Measure coal seams (layers 7, 9, 11, 13 and 15) to which a K distribution, allowing for the recognised permeability decrease with depth, was ascribed. This K distribution was based on the WDS (2011) study for coal seam gas depressurisation prior to mining. A regression formula from this study was derived as follows:

Permeability (m/day) = 233.52 x $e^{(-0.016 \text{ x depth})}$

Where depth is below land surface (metres)

Based on the regression formula horizontal K distributions were derived for the coal seam layers, within constraints of the K values not being higher than 0.025 metres per day and not lower than 1×10^{-5} metres per day (derived from filed data and literature values). The horizontal K distribution for the GMS (layer 13 in the numerical model), the target coal seam for mining in the proposed RHM, is shown in **Figure 7–4**. The vertical K distributions within these layers follows the same distributions as the horizontal K distribution but with values one order of magnitude lower (typical modelling assumption where limited data available).



Note: This figure shows the 2011 mine plan used for surface and groundwater modelling.

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HORIZONTAL K DISTRIBUTION FOR GMS (LAYER 13) OF NUMERICAL MODEL

URS | GROUNDWATER | Figure: 7-4

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As well as the K distribution for the five Moranbah Coal Measures coal seam layers, four horizontal and vertical K parameters were assigned to the remaining model layers as listed in **Table 7-3**, with the vertical parameters defined based on the ratio of Kh/Kv and tied to the horizontal parameters during the calibration.

Table 7-3 Relationship of Hydraulic Conductivity between Each Layer in the Numerical Model

Model Layer	Unit	K (horizontal) Parameter	K (vertical) Parameter
1	Tertiary, alluvium	K_1	K_{z1}
2	overburden	K_2	K_{z2}
3	FC1	K_3	K_{z3}
4	interburden	K_4	K_{z4}
5	FC2	K_3	K_{z3}
6	interburden	K_4	K_{z4}
7	GUS	K distribution	K distribution x 0.1
8	interburden	K_4	K_{z4}
9	GP1	K distribution	K distribution x 0.1
10	interburden	K_4	K_{z4}
11	GP2	K distribution	K distribution x 0.1
12	interburden	K_4	K_{z4}
13	GMS	K distribution	K distribution x 0.1
14	interburden	K_4	K_{z4}
15	GLS	K distribution	K distribution x 0.1
16	interburden	K_4	K_{z4}
17	Base	K_4	K_{z4}

7.3.6 Simulation of Mine Dewatering using Drains

In order to assess the potential zone of influence created around RHM due to mine dewatering, the MODHMS drain package was utilised. Using drains involved the setting of a reference (drain target) elevation (base of the target coal seam) and a conductance (leakage) term.

The bottom elevations of the drains were set at the base of the GMS coal seam to be mined. Groundwater levels in the model were compared to the elevation of the bottom of the drain in each model cell and when the groundwater level is above the bottom of the drain water was removed from the model domain at a rate determined by the head difference and the drain hydraulic conductance. The drains were activated according to the proposed mine plan (schedule and progression). Drain conductance was set at a high rate to ensure the groundwater level was lowered to the drain level (to simulate dry workings as required for mine safety).

This approach was adopted for the environmental impact assessment in order to estimate the total volume of groundwater to be removed during an estimated 25 year life of mine (LOM), and assess the resultant drawdown cone at the end of mine life.

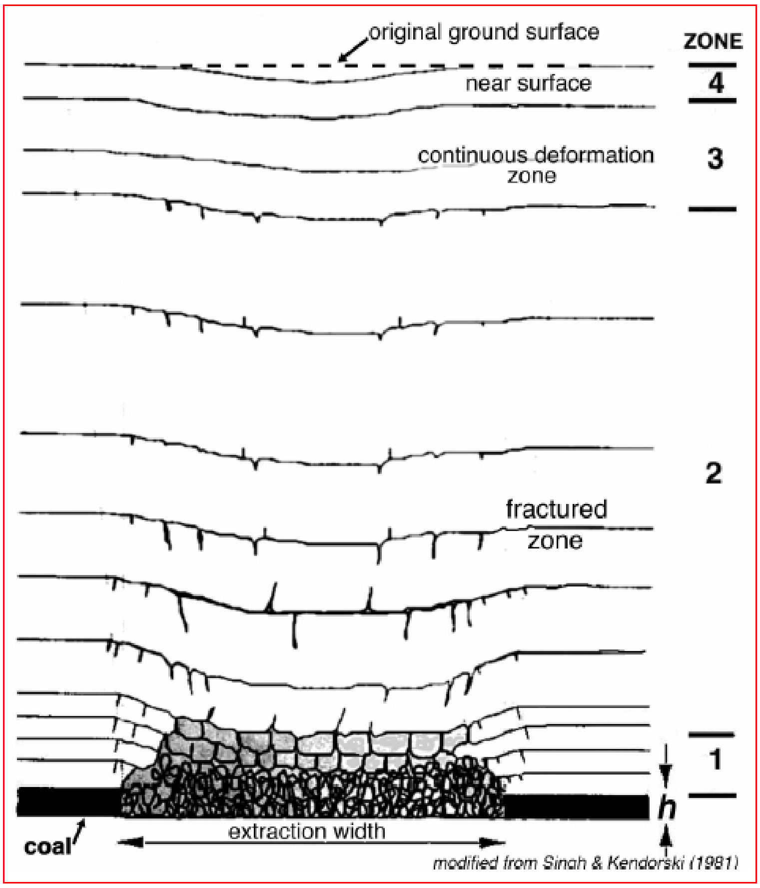
7.3.7 Simulation of Mine Dewatering considering Goaf Alteration

To further estimate mine impacts and estimates of groundwater ingress over the LOM, consideration and simulation of aquifer alteration (due to longwall mining (goaf)) was given.

As longwall mining progresses, goaf develops due to roof collapse in the mining retreat, resulting in a progressively upward collapse of the overburden and where propagation to surface, subsidence. The subsidence profile is divided into four distinct zones (Singh and Kendorski 1981) as shown in **Drawing 7-1**. In zone 1, the depth of strata directly affected by roof caving is 2 to 10 times the thickness of the mined out coal (up to six metres in the RHM area). In zone 2, the fractured zone, partial fracturing of strata occurs from 10 to 24 times the thickness of the mined out coal. In zone 3, the continuous deformation zone, buckling of strata occurs from 24 to 64 times the thickness of the mined out coal. The caved and fractured zones (zone 1 and 2) alter the natural groundwater flow system and can potentially introduce significant vertical leakage through fractures. The highest vertical leakage would occur in the caved zone (zone 1, 2 to 10 times the thickness of mined out coal), therefore it was envisaged that the range of zone 1 would be within the interburden between the GMS and GUS, which is layer 12 in the numerical model.

It was assumed (for groundwater modelling purposes) that goafing fully develops a year after the mine extraction.

Drawing 7-1 Typical Subsidence Profile (from Winters and Capo 2004)



7.3.7.1 Mine Dewatering Scenarios

Two approaches of estimating the additional groundwater inflow due to the development of goaf were adopted and compared.

The first approach was based on using the time-variant properties capabilities of MODHMS (2010) by assuming that vertical and horizontal K values were increased 10 times from the original values for the goaf area within layers 12 and 13, with this increase in K for these model layers remaining over the model run.

The second approach was based on using the drain package in MODFLOW to approximate additional inflows by adding drain cells to the goaf areas within model layers 12 and 13. Note that the drain conductance was determined through several trial runs and was estimated to be within the range of 0.1 to 1 rather than a large value used for freely drained cells.

7.4 Model Calibration

7.4.1 Calibration Data

Model calibration was to groundwater level data collected by BMA over time within the survey area and groundwater level information collected from the Eaglefield Expansion Project EIS (METServe 2010). Most of the observation locations had only one measurement record. Regional groundwater level data in this area were not available from the NRM registered bore database.

As mining commenced with the Goonyella mine in the 1970s and has been ongoing since that time, it is envisaged that significant groundwater level changes in the survey area would already have occurred due to mine dewatering. As mining pits progress and new mining areas were created over time, areas and impacts of dewatering would also vary with time. As time series groundwater level data were not available and historic records of dewatering rates and locations were not readily available, transient calibration of the model was not possible. Instead, a pseudo steady-state condition was calibrated, considering the length of mining in the area (40 years), in order to establish an initial condition for predictive simulations. This was done to assess the potential impacts of the project on groundwater already altered by approved mining.

7.4.2 Calibration Approach

Model calibration is a process of refining the model's depiction of the hydrogeological framework, aquifer hydraulic properties, and boundary conditions until a desired correspondence is achieved between the model simulated and measured field data. The end result of the model calibration process is a potential optimal set of parameter values and boundary conditions that minimise the discrepancy between simulated and observed data.

The major calibration target of the model was groundwater level data with constraints of reasonable ranges of hydraulic conductivity and other parameters (e.g. recharge). Transient calibration was not conducted due to limited available data.

The parameter estimation program PEST (Doherty 2008) along with detailed parameter output verification was used to calibrate the parameters of the regional groundwater flow model. PEST implements a nonlinear least-squares regression method to estimate model parameters by minimising the sum of squared weighted residuals of groundwater levels.

The calibration process was assessed against the Murray-Darling Basin Commission Groundwater Flow Modelling Guideline (Aquaterra 2000).

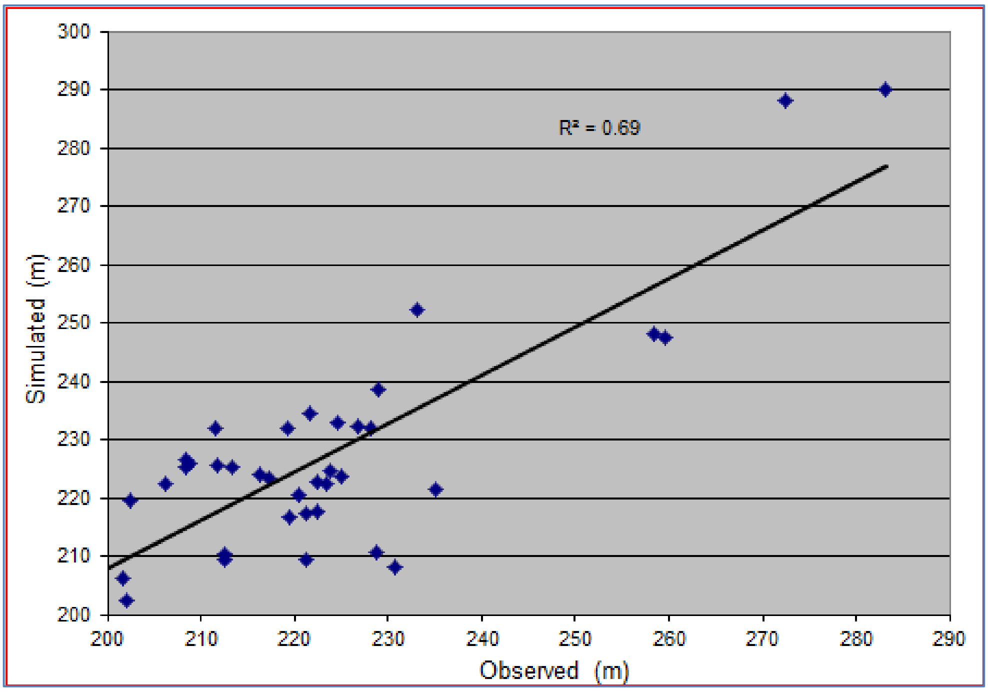
7.4.3 Calibration Assessment

The pseudo steady-state calibration aimed at representing an average state of groundwater levels. A total of 39 groundwater measurements from different monitoring points were used for the calibration process.

Parameter values of hydraulic conductivities, recharge, and drain conductance were estimated through PEST. Hydraulic conductivities were constrained by upper and lower limits and the spatial distribution as discussed in **Section 7.3.5**, while recharge rate was a single value for the model area.

The difference between the modelled and observed (measured) groundwater levels was the preferred indicator of model simulation error. A scatter plot of modelled versus observed groundwater levels is shown in **Chart 7-1** for steady-state calibration.

Chart 7-1 Modelled Versus Observed Head Values for Steady-State Calibration



Root-mean-square error (RMSE) was selected to evaluate the performance of the model calibration based on groundwater levels. Good agreements between modelled results and field measurements usually have RMSE less than 10 per cent of the difference between the observed maximum and minimum potentiometric heads within the model area. The RMSE for the steady-state calibration was 11.6 metres, which is 13.2 per cent of the approximate 87.7 metre range of groundwater levels.

Table 7-4 shows the calibration statistics for the steady-state calibration. These calibration statistics indicate that the model calibration is reasonable based on the parameter constraints (within site specific ranges) and data availability (impacted by mining).

7 Numerical Modelling

The 39 calibration head targets covered the period 1996 to 2009, with many of the measurements undertaken within discrete time intervals (e.g. eight groundwater bore levels were recorded on 12 October 1998). As discussed in **Section 7.4.1**, there are no pre-mining groundwater level data, and available groundwater level data would be largely impacted by mine dewatering. Since the pseudo steady-state model only reflects the existing mining conditions, close 'point-to-point' matching throughout the historic records was not possible, resulting in high residuals. Instead, the pseudo steady-state calibration was inclined to provide a regional flow pattern, which could be used as initial conditions for the predictive simulations.

Table 7-4 Calibration Statistics for Numerical Model Steady-State Calibration

Calibration Statistics	Steady-State Calibration (39 observations)
Mean Error (m)	-4.1
RMSE (m)	11.57
Standard Deviation (m)	10.97
Head Range (m)	87.73
Mean Error %	-4.6%
RMSE %	13.2%
Standard Deviation %	12.5%
R^2	0.69

The groundwater levels determined from the steady state simulation were contoured to provide an indication of groundwater level variations across the model domain. **Figure 7-5** presents the simulated pseudo steady state groundwater head distribution in the GMS. The calibrated parameters, which were then used for the predictive modelling, are presented in **Table 7–5**. Note that the K distribution for the Moranbah Coal Measure coal seams was adopted from the WDS regression formula (WDS 2011) without further calibration, as it is envisaged that these distributions include the best information available.

Table 7-5 Summary of Calibrated Parameters for Numerical Model

Model Layer	Unit	K (horizontal) (m/day)	K (vertical) (m/day)
1	Tertiary, alluvium	0.49	0.049
2	overburden	1.00E-03	1.00E-04
3	FC1	1.00E-03	1.00E-04
4	interburden	1.08E-04	1.08E-05
5	FC2	1.00E-03	1.00E-04
6	interburden	1.08E-04	1.08E-05
7	GUS	Distribution*	Distribution* x 0.1
8	interburden	1.08E-04	1.08E-05
9	GP1	Distribution*	Distribution* x 0.1
10	interburden	1.08E-04	1.08E-05
11	GP2	Distribution*	Distribution* x 0.1
12	interburden	1.08E-04	1.08E-05

7 Numerical Modelling

Model Layer	Unit	K (horizontal) (m/day)	K (vertical) (m/day)
13	GMS	Distribution*	Distribution* x 0.1
14	interburden	1.08E-04	1.08E-05
15	GLS	Distribution*	Distribution* x 0.1
16	interburden	1.08E-04	1.08E-05
17	Base	1.08E-04	1.08E-05
Recharge		1.00E-07 m/day	

* K distribution derived from the WDS regression formula- 233.52*EXP(-0.016 X depth)

7.4.3.1 Comments on Model Calibration

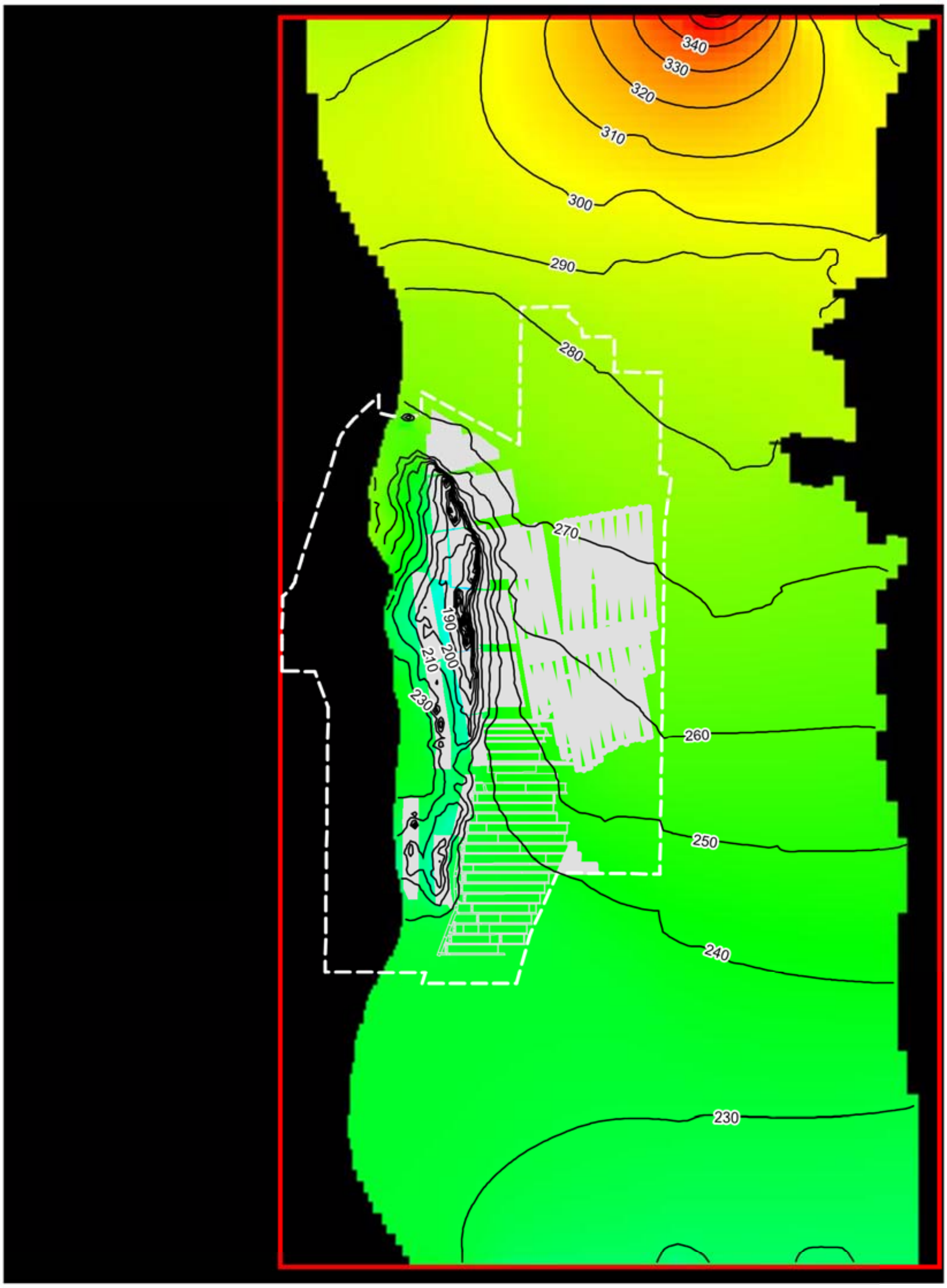
The model calibration statistical results indicate a moderate agreement between the field measured groundwater levels or assumed steady-state water levels (as discussed in **Section 7.4.1**) and the model simulated levels. This is due to the following:

1. There are no pre-mining groundwater levels to calibrate against, and since the mining is an ongoing process, there was no steady-state condition that really existed. The available measurements in the historical records are impacted by historic mine dewatering. Higher residuals (field vs. model) at certain points were expected as dewatering can easily cause drawdown to be more than 50 metres.

2. Consideration of reducing residuals, to within a desirable range, was given, i.e. using a zonation or the pilot point approach to calibration. This approach was recognised, however, to result in an over-calibrated model, i.e. calibrated to noise or dewatering effects. As historic mine dewatering extraction rates were unavailable it was not possible to accurately incorporate this (mine dewatering) stress into the modelled system during pseudo steady-state calibration. Instead, the rule of parameter parsimony was adopted. The best data available was the approach of K values varying with depth using the regression formula. Thus the main purpose of calibration was to capture the regional groundwater flow trend rather than "point-to-point" matching.

3. The purpose of the calibration was to obtain an acceptable starting condition that represented the regional trend for the predictive simulation and reasonable parameter ranges.

4. Consideration of uncertainty was given as, trying to calibrate too closely to observed heads was likely to result in calibration to dewatering impacts and no actual aquifer conditions. This would have resulted in the model comprising a wide range of hydraulic conductivity, both spatial and with depth, which is not considered to match site conditions. The only way of verifying reliability of the model was to conduct uncertainty analysis for the predictive model, which is discussed in **Section 7.5.3**.



Note: This figure shows the 2011 mine plan used for surface and groundwater modelling.

N
W E
S

0 2.5 5km
Scale

EIS Study Boundary

Open-Cut and Underground Mining Operations

—230— Groundwater Elevation Contour (mAHD)

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MODELLED EXISTING GROUNDWATER HEAD DISTRIBUTION IN THE GMS

GROUNDWATER

Figure: **7-5**

File No: **42627136-g-2104.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4

7.4.4 Model Limitations

The groundwater flow model was a simplification of a real system, so it is subject to limitations. Limitations result from the simplification of the conceptual model upon which the numerical model is based, the grid scale, the inaccuracies of measurement data, and the incomplete knowledge of the spatial variability of input parameters.

There are no pre-mining groundwater levels available, and since mining has been ongoing since the 1970's, there was no steady-state condition to calibrate against. Thus the available groundwater level measurements in the historical records are impacted by historic mine dewatering; however, dewatering rates are also unavailable so the model could not be developed with a transient calibration. Therefore, the rule of parameter parsimony was adopted.

The best data available is the hydraulic conductivity values from aquifer tests, core tests, and the spatial distribution with depth identified by WDS (2011). The groundwater model was thus calibrated to capture the regional groundwater flow trend identified from groundwater levels with the objective of obtaining an acceptable starting condition that represented the regional trend for the predictive simulation and reasonable parameter ranges. Verification of reliability of the model was conducted by undertaking uncertainty analysis for the predictive model.

7.5 Predictive Simulations

After the steady state model was calibrated to the available data, the model was then converted to transient flow conditions to undertake the predictive scenarios for impact assessment. Predictive simulation was conducted for the ongoing GRM, BRM (including the extension into MLA70421), and proposed RHM for the active period of mining for the total complex (until 2068, the expected end of mining at GRM). Calibrated model parameters were used for the predictive simulation, and the modelling drain package was used for simulating open-cut and underground mining, approved and proposed.

The calibrated hydraulic conductivity values in **Table 7–5** were used for the predictive simulation; while the storativity values were adopted from literature and hydraulic tests as transient calibration was not possible with the available data. The model parameters used during the simulations are presented in **Table 7-6**.

Table 7-6 Summary of Numerical Model Parameters Used in the Predictive Simulation

Model Layer	Unit	K (horizontal) (m/day)	K (vertical) (m/day)	Storage Coefficient	Specific Yield
1	Tertiary, alluvium	0.49	0.049	1.00E-05	0.1
2	overburden	1.00E-03	1.00E-04	1.00E-05	3.00E-02
3	FC1	1.00E-03	1.00E-04	1.00E-05	1.00E-02
4	interburden	1.08E-04	1.08E-05	1.00E-05	3.00E-02
5	FC2	1.00E-03	1.00E-04	1.00E-05	1.00E-02
6	interburden	1.08E-04	1.08E-05	1.00E-05	3.00E-02
7	GUS	Distribution*	Distribution* x 0.1	1.00E-05	1.00E-02
8	interburden	1.08E-04	1.08E-05	1.00E-05	3.00E-02
9	GP1	Distribution*	Distribution* x 0.1	1.00E-05	1.00E-02
10	interburden	1.08E-04	1.08E-05	1.00E-05	3.00E-02
11	GP2	Distribution*	Distribution* x 0.1	1.00E-05	1.00E-02
12	interburden	1.08E-04	1.08E-05	1.00E-05	3.00E-02
13	GMS	Distribution*	Distribution* x 0.1	1.00E-05	1.00E-02
14	interburden	1.08E-04	1.08E-05	1.00E-05	3.00E-02
15	GLS	Distribution*	Distribution* x 0.1	1.00E-05	1.00E-02
16	interburden	1.08E-04	1.08E-05	1.00E-05	3.00E-02
17	Base	1.08E-04	1.08E-05	1.00E-05	3.00E-02
Recharge		**1.00E-07 m/day**			

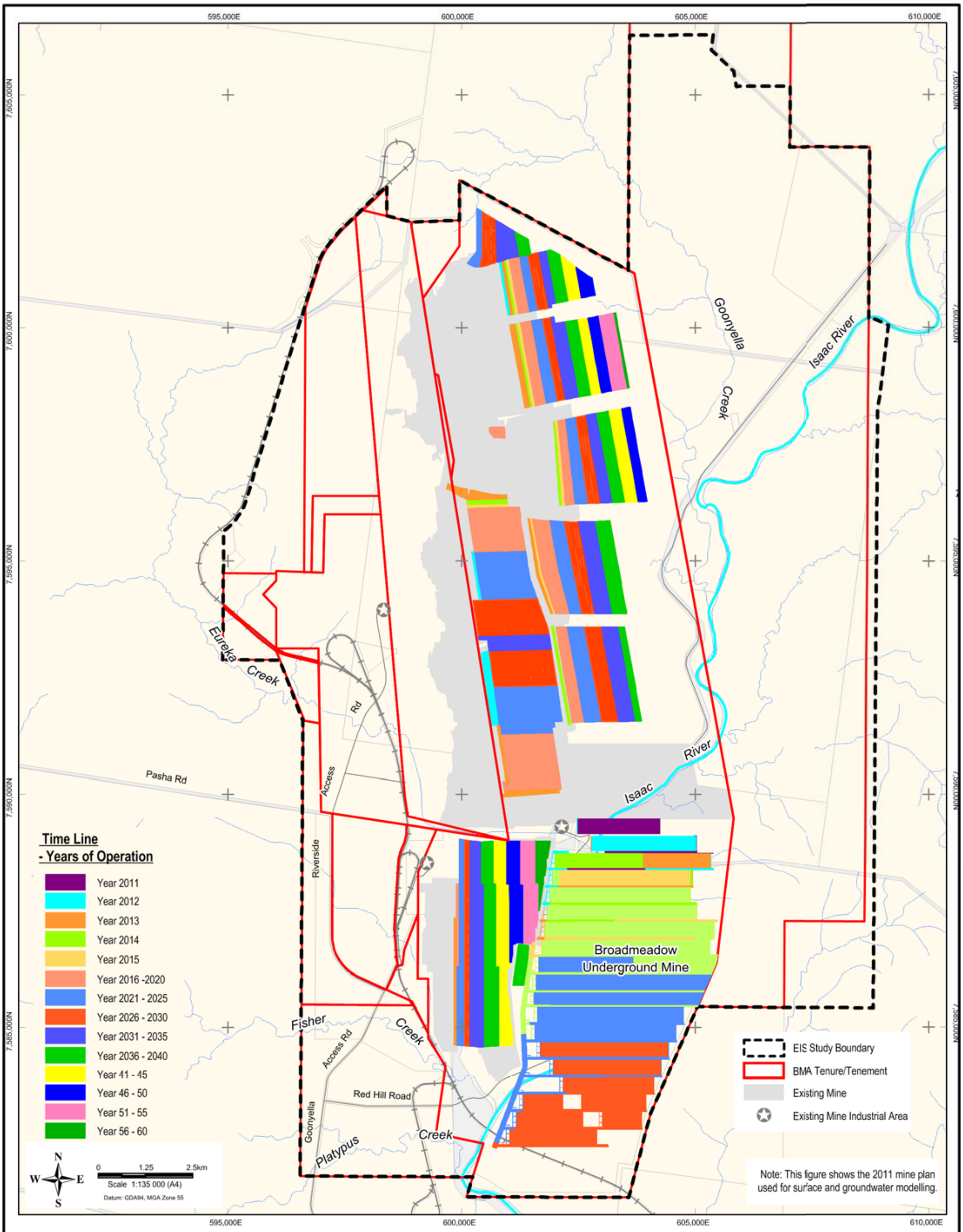
* K distribution derived from the WDS regression formula- 233.52*EXP(-0.016*depth)

7.5.1 Mine Progression Plans

Year-on-year mine plans for the existing GRM and BRM, as well as proposed mine plans for the RHM were simulated to assess the cumulative impacts of the proposed project. Several assumptions were made for the predictive simulation:

- Mining was assumed to progress on an annual time step as provided in the mine plans. Where the mine plans showed multi-year time steps, the mine plan was subdivided into equal (based on surface area) yearly time steps.
- Open-cut mining progress areas were assumed to be open for two years as backfilling occurs after mining.
- Underground mine areas will be maintained in a dewatered state for the life of each mine.
- Goafs were assumed to be formed in the year following mining (as discussed in **Section 7.3.7**).

GRM and BRM progression plans were provided with yearly progression to 2068 and 2030, the end of mining for each respectively. The mining progression plans for the proposed RHM were provided with yearly progression for the first four years and then five-yearly progression for the remainder on the LOM. The mine progression for the approved GRB mine complex is shown in **Figure 7-6**. The mine progression for the proposed RHM including the Broadmeadow extension is shown in **Figure 7-7**.



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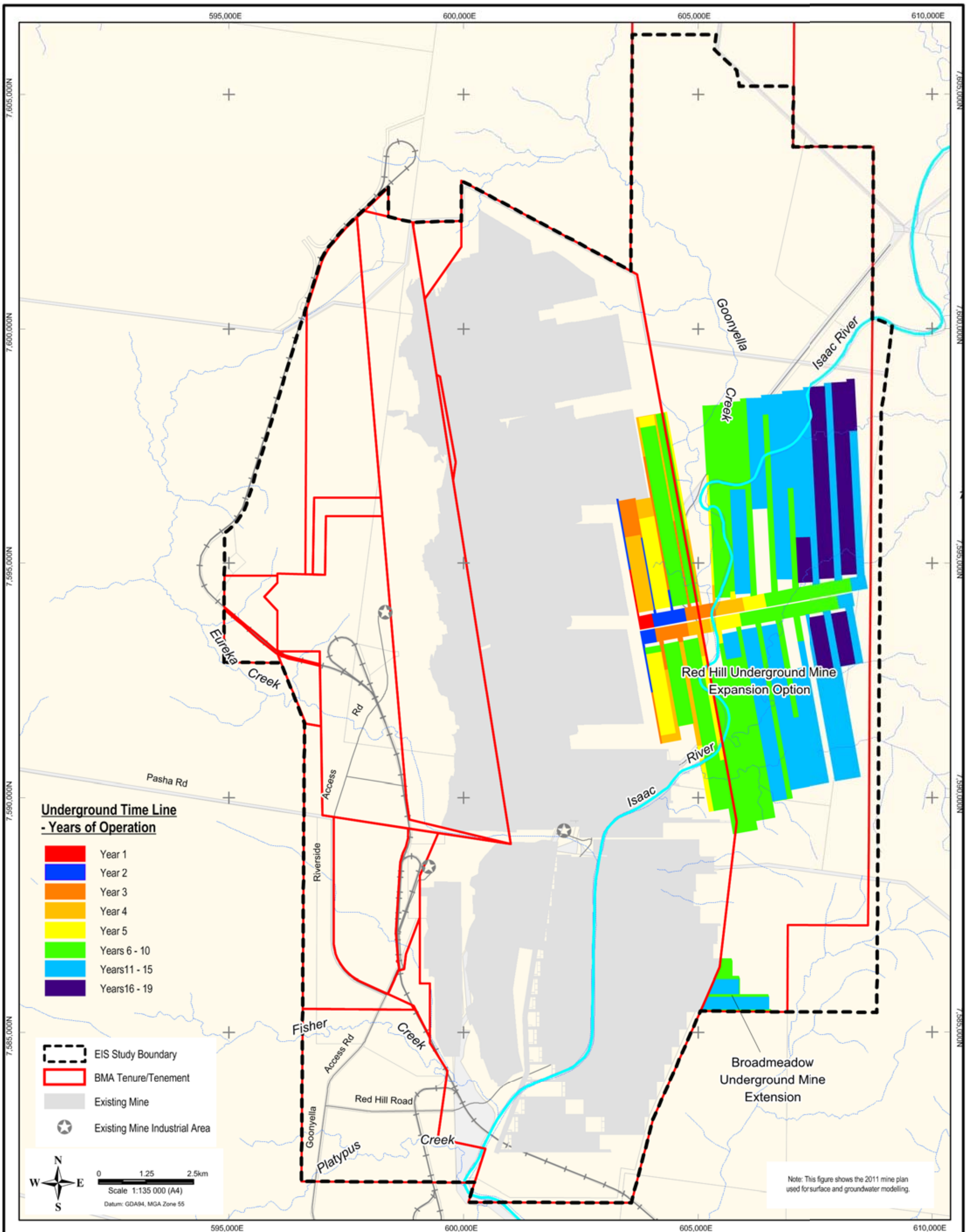
MINE PROGRESSION FOR EXISTING APPROVED GOONYELLA RIVERSIDE AND BROADMEADOW MINES

URS | GROUNDWATER | Figure: **7-6**

File No: **42627136-g-2105.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4



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MINE PROGRESSION FOR PROPOSED PROJECT

URS

GROUNDWATER

Figure: **7-7**

File No: **42627136-g-2106.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4

7.5.2 Predicted Groundwater Drawdown and Inflow

Groundwater drawdown predictions were modelled on the October 2011 mine plan. A new mining sequence has since been developed for the RHM, Broadmeadow extension and the existing approved BRM. Further, both the BRM and the proposed Broadmeadow extension footprints have been revised. This has the potential to alter groundwater volumes and drawdown over the life of mine. However, the mine plan and revised schedule are indicative only and sequencing of production and annual production rates are dependent on a range of factors and likely to vary. Regardless of this, the changes are not anticipated to have a significant impact on modelling predictions.

In order to assess the potential impact of the project on groundwater, in addition (cumulative) to the impact of the existing approved GRB mine complex, predictive simulations were performed for two scenarios (with and without the project). Total drawdown contours for cumulative impact (approved GRB mine complex and the project) and for the impact caused by RHM beyond the approved baseline (additional drawdown due to the project calculated by the difference in predicted impact of the GRB mine complex by itself and with the project), for the Tertiary/Quaternary Formations (Layer 1) and for the GMS (the mined seam, Layer 13) are shown in **Figure 7–8** and **Figure 7–9** for 2040 (the modelled end of mining for the RHM) and **Figure 7–10** and **Figure 7-11** for 2068 (the end of mining at GRM) respectively.

Prediction of groundwater volumes to be removed, either through mine dewatering and / or active dewatering for IMG drainage, were estimated through the use of zone budgets in the MODHMS model simulation. Groundwater extraction with time for the two approaches to goaf simulation, use of time varying properties and use of drain cells, are shown in **Chart 7–2** and **Chart 7-3**. It is noted that the results of the two approaches are comparable.

Groundwater extraction is predicted to peak at approximately two gigalitres (GL) per year using the time varying properties approach, and 3.5 GL per year using the drain cell approach. Some of this predicted extraction will not be extracted by IMG drainage or seepage collection, but will be lost from the mine water balance as embodied water in extracted coal or evaporation through the mine ventilation system. Note that extraction from the underground mines stop at the completion of mining, but that groundwater would continue to flow into the mine void and goaf with a consequent lag in groundwater drawdown as this storage is filled.

7 Numerical Modelling

Chart 7-2 Estimated Total Groundwater Ingress Using Time Varying Properties

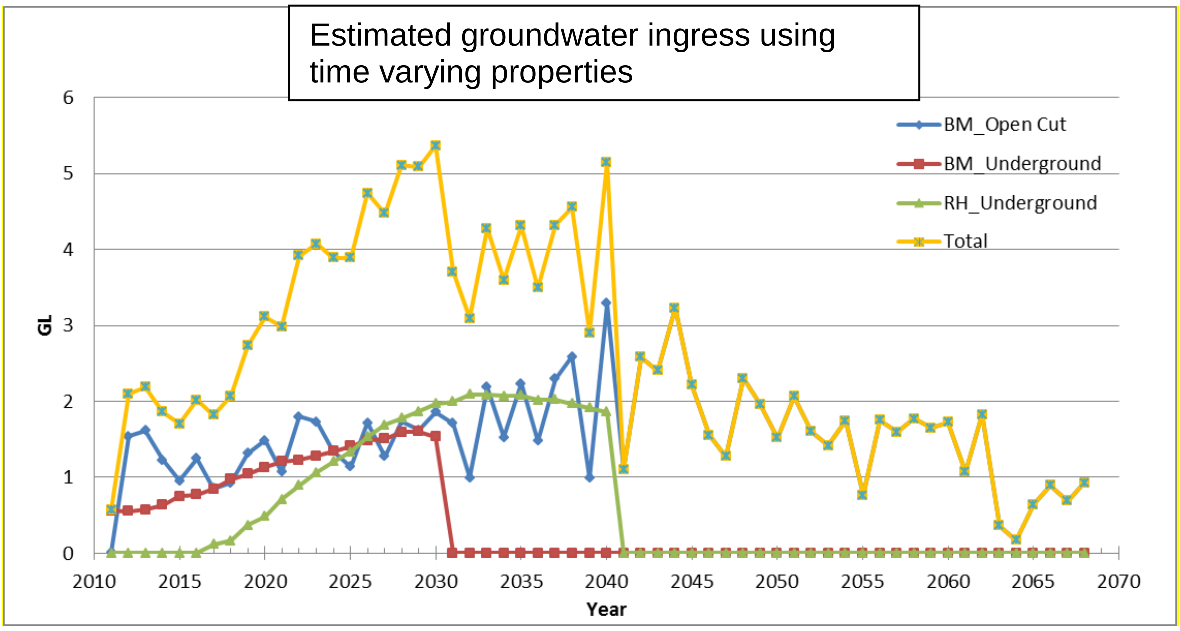
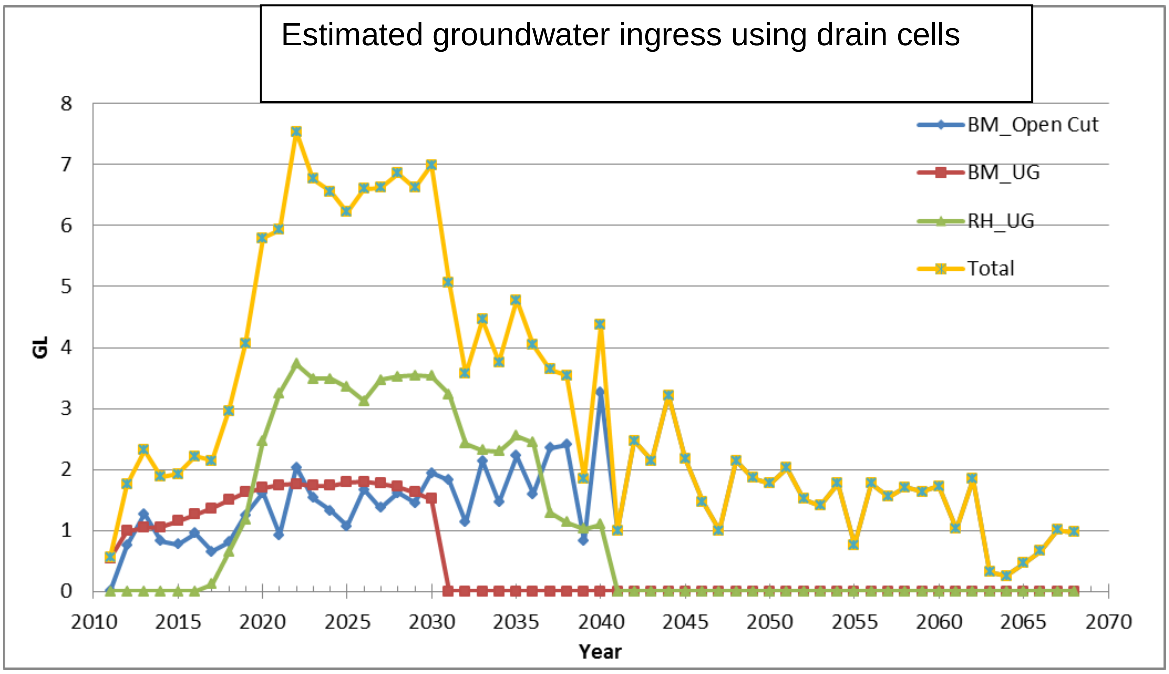
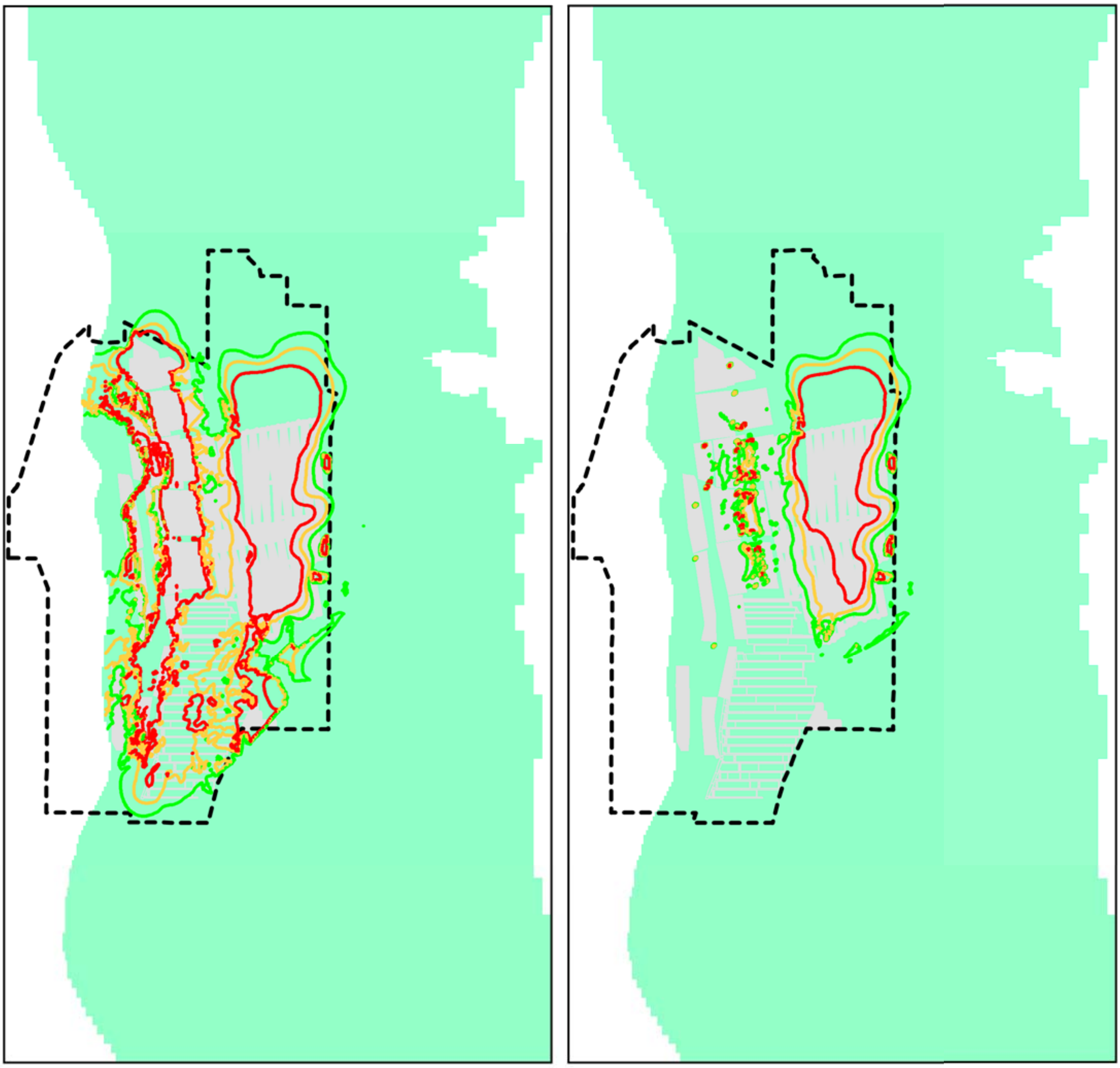


Chart 7-3 Estimated Total Groundwater Ingress Using Drain Cells





Drawdown modelled for Goonyella Riverside, Broadmeadow and proposed Red Hill Mine

Drawdown as a result of proposed Red Hill Mine

Note: This figure shows the 2011 mine plan used for surface and groundwater modelling.

N W E S

0 3.75 7.5km

Scale

Drawdown (m)

0.5

1

2

EIS Study Boundary

Open-Cut and Underground Mining Operations

Model Extent

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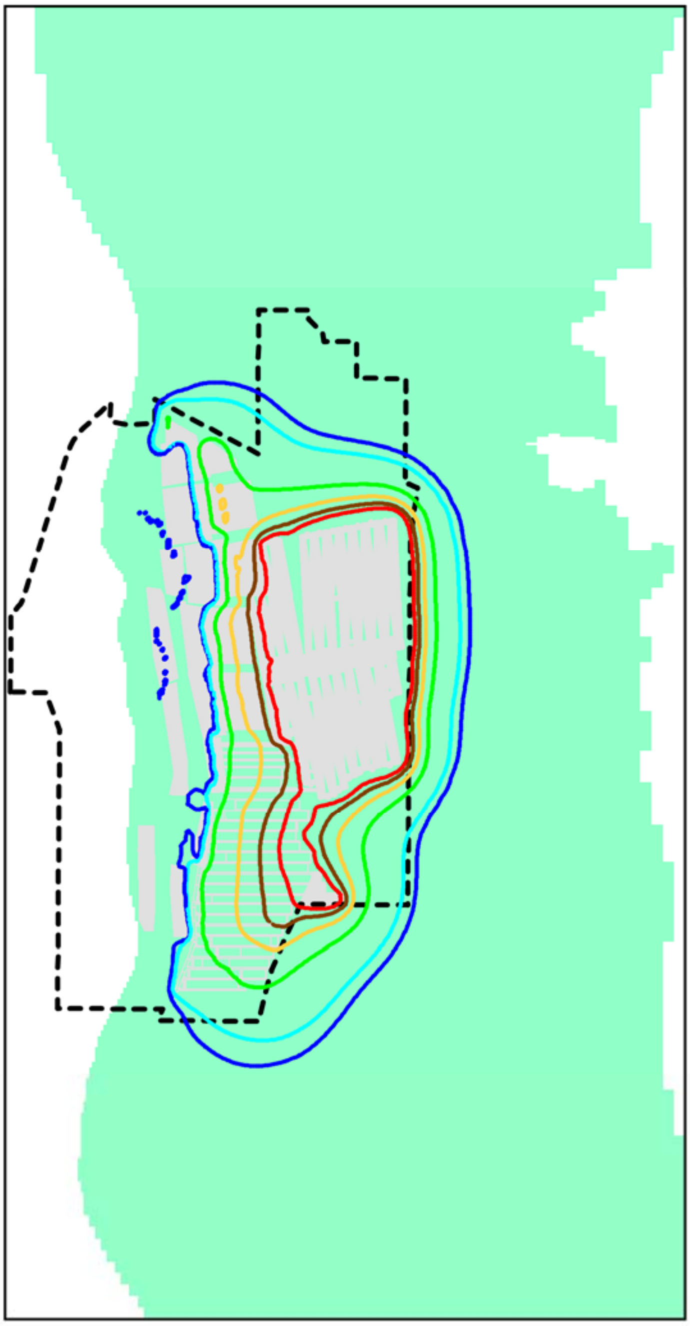
MODELLED DRAWDOWN IN TERTIARY/QUATERNARY FORMATIONS AT END OF 2040

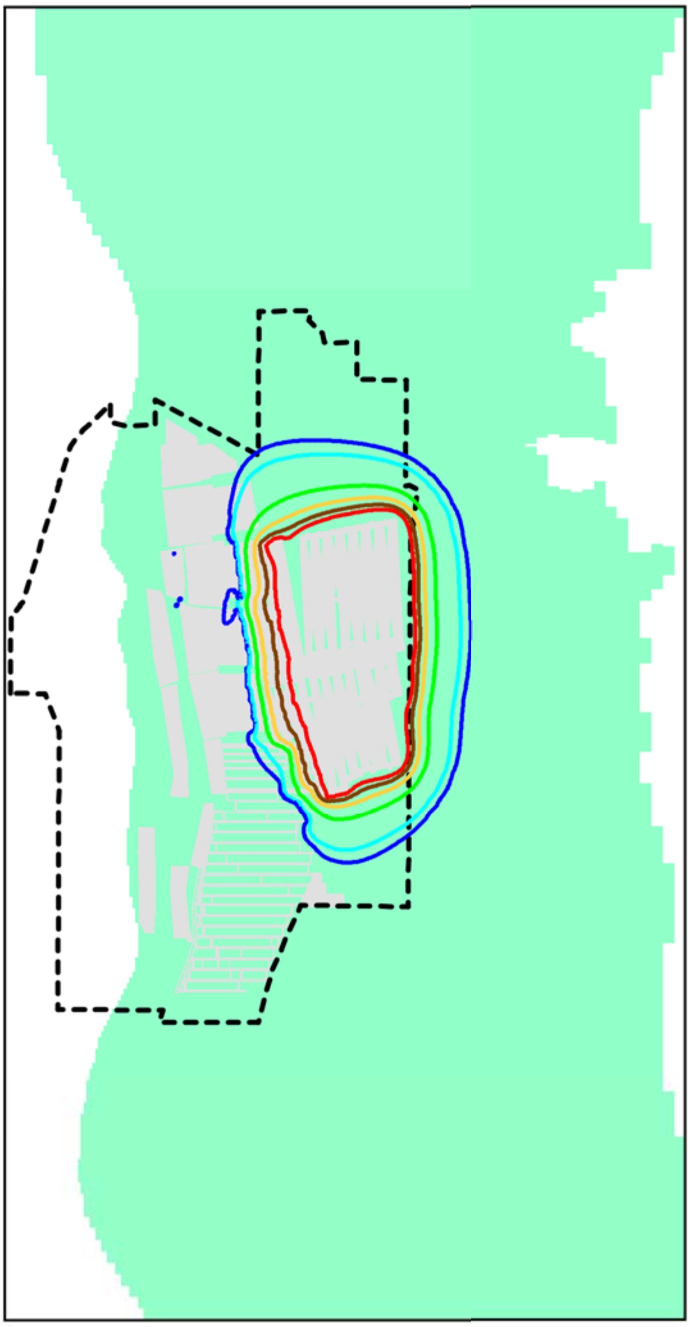
GROUNDWATER

Figure: **7-8**

File No: **42627136-g-2107.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4



Drawdown modelled for Goonyella Riverside, Broadmeadow and proposed Red Hill Mine



Drawdown as a result of proposed Red Hill Mine

Note: This figure shows the 2011 mine plan used for surface and groundwater modelling.

Drawdown (m)

- 5
- 10
- 50
- 100
- 150
- 200

N W E S

0 3.75 7.5km
Scale

- EIS Study Boundary
- Open-Cut and Underground Mining Operations
- Model Extent

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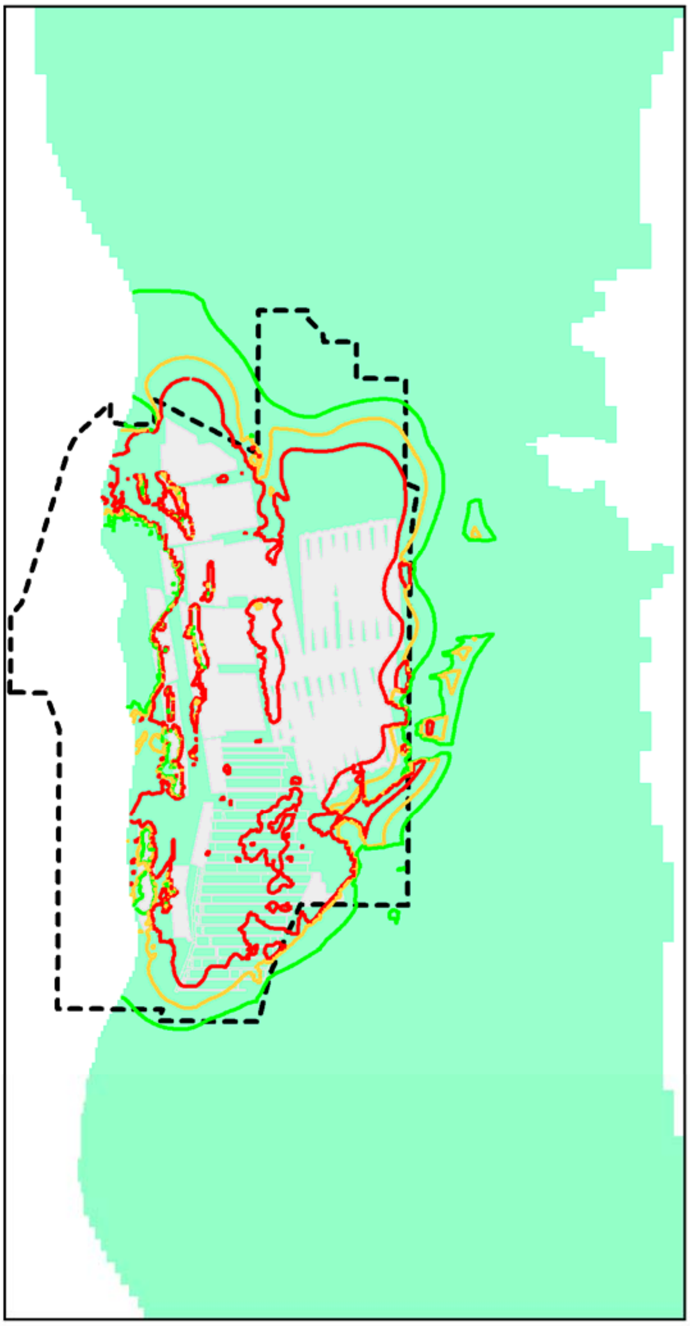
MODELLED DRAWDOWN IN GMS AT END OF 2040

URS

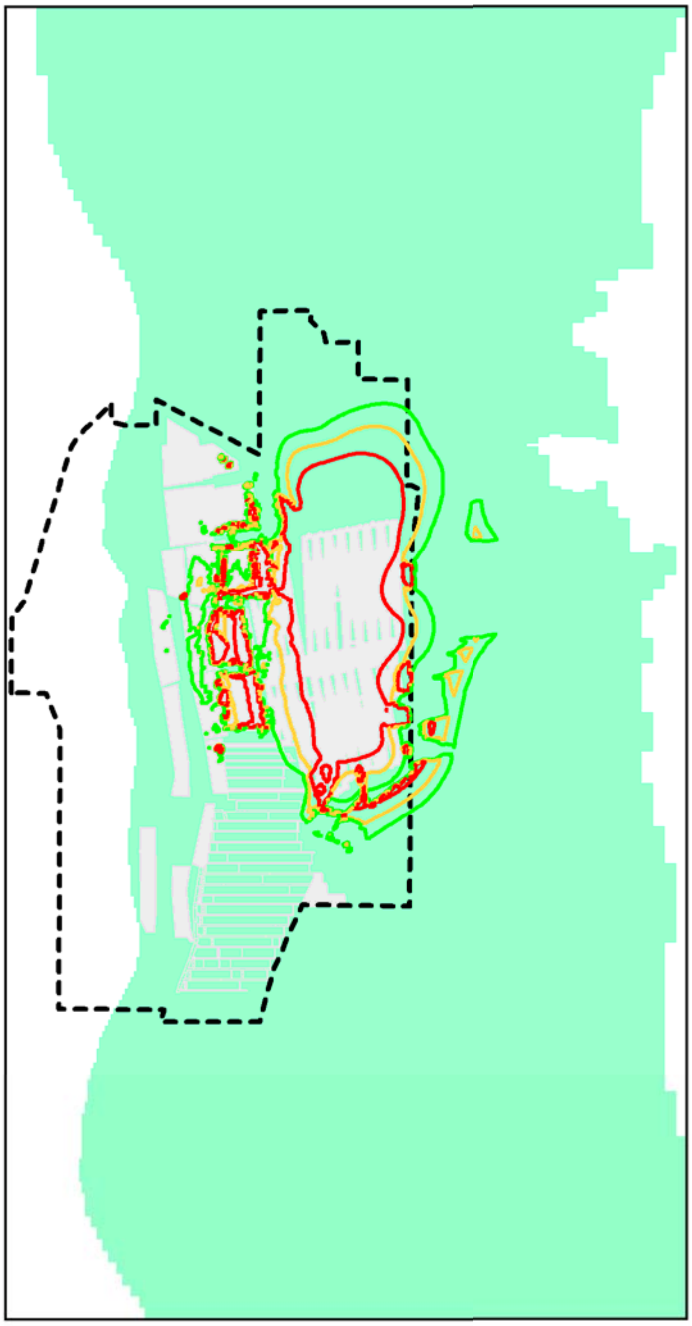
GROUNDWATER

Figure: **7-9**

File No: **42627136-g-2108.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4



Drawdown modelled for Goonyella Riverside, Broadmeadow and proposed Red Hill Mine



Drawdown as a result of proposed Red Hill Mine

Note: This figure shows the 2011 mine plan used for surface and groundwater modelling.

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GROUNDWATER IMPACT ASSESSMENT

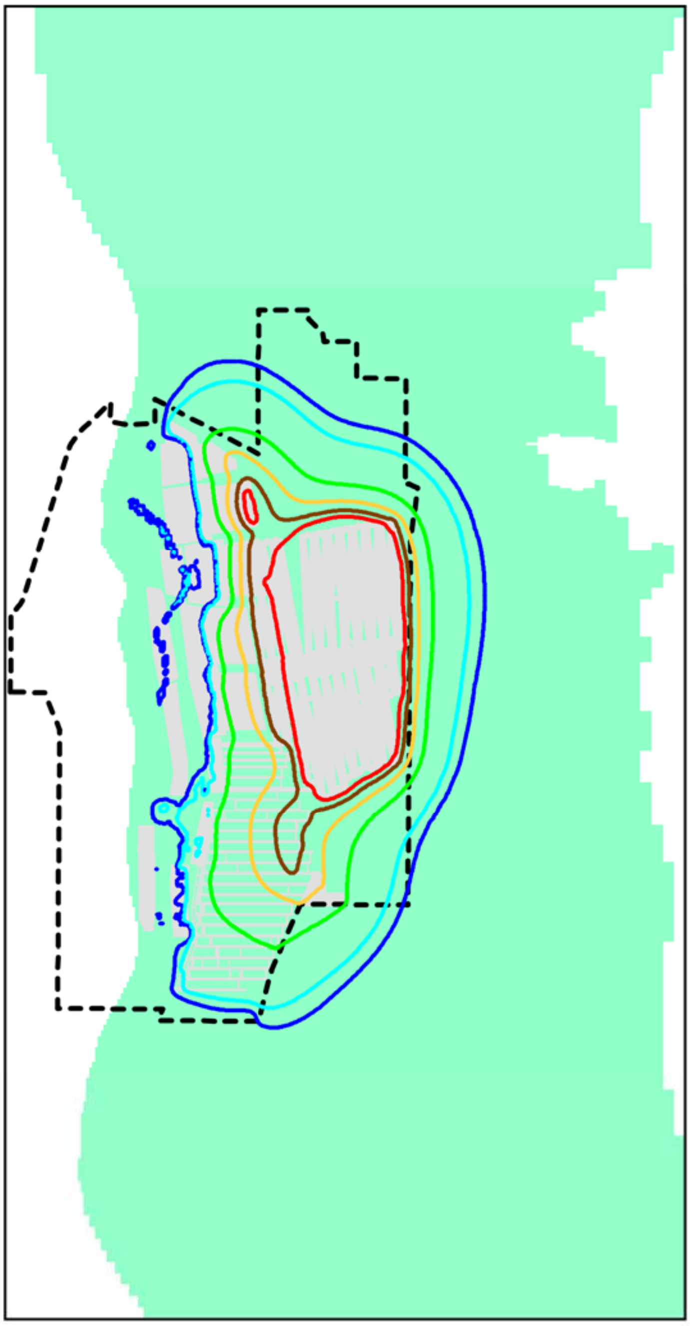
MODELLED DRAWDOWN IN TERTIARY/QUATERNARY FORMATIONS AT END OF 2068

URS

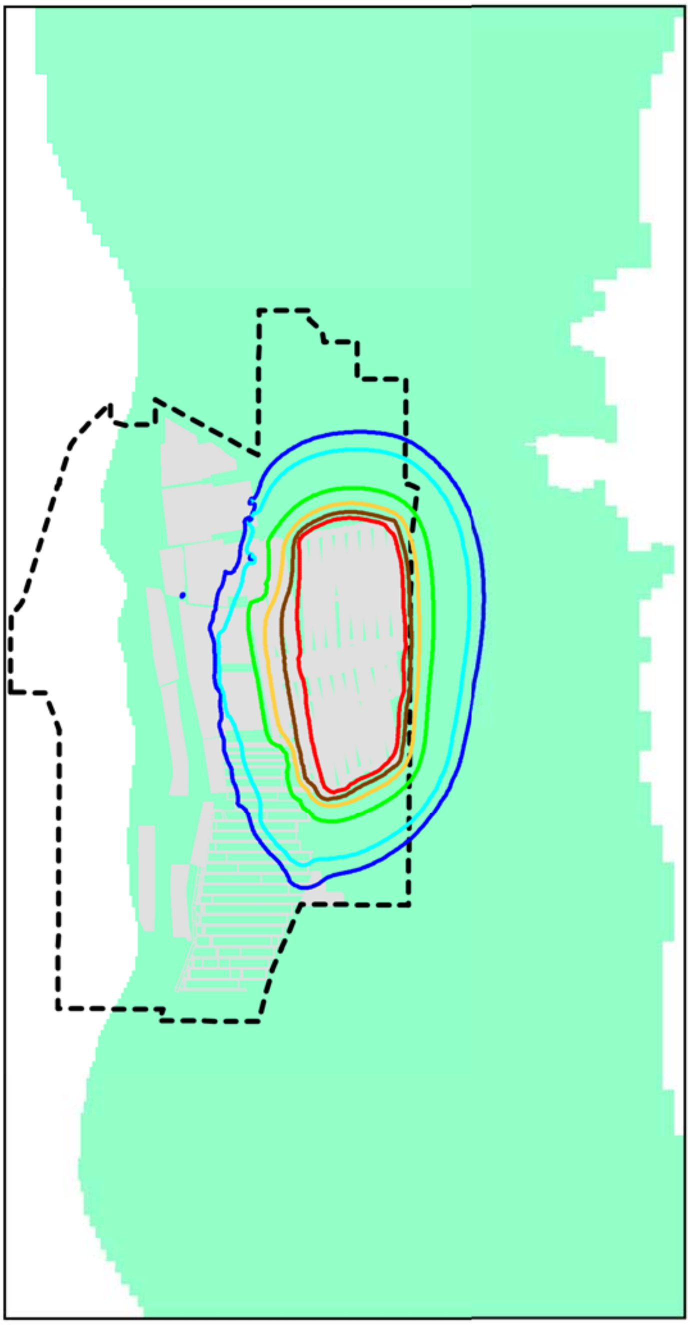
GROUNDWATER

Figure: **7-10**

File No: **42626730-g-2109b.wor** Drawn: **VH** Approved: **MS** Date: **24-06-2013** Rev.**B** A4

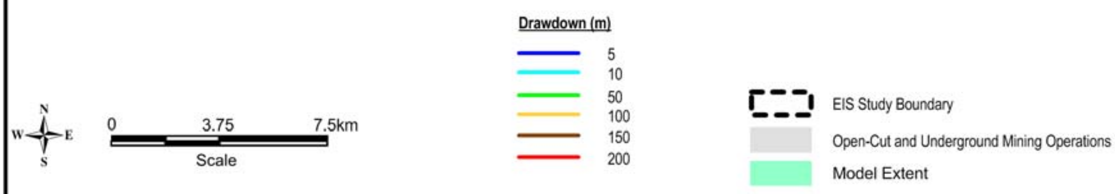


Drawdown modelled for Goonyella Riverside, Broadmeadow and proposed Red Hill Mine



Drawdown as a result of proposed Red Hill Mine

Note: This figure shows the 2011 mine plan used for surface and groundwater modelling.



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GROUNDWATER IMPACT ASSESSMENT

MODELLED DRAWDOWN IN GMS AT END OF 2068

URS

GROUNDWATER

Figure: **7-11**

File No: **42627136-g-2110.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4

7.5.3 Groundwater Ingress

Based on the model approach adopted to assess the potential impacts of mine dewatering, in terms of drawdown on the local and regional groundwater resources, conservative assumptions were included. This allowed for “worst-case” scenarios regarding potential impacts to be assessed.

The use of drains provided elevated groundwater ingress predictions, which were not suitable for inclusion in the mine water management assessment (Red Hill Mining Lease EIS Appendix I2), as this study requires a more realistic estimate of groundwater volumes for inclusion in the water balance.

The predictive model was revised to simulate year-on-year groundwater ingress volumes, considering impacts of longwall mining (goaf) resulting in the alteration of aquifers over time. The predictive model simulated cumulative dewatering of the GRM open cuts, the BRM, the Broadmeadow extension, and the RHM underground workings.

Table 7–7 presents the year-on-year volumes of groundwater associated with the proposed mine panels over the LOM for RHM and GRB mine complex mines. The estimates are predicted using the basecase set of aquifer parameters, determined during calibration. An estimated total groundwater volume of 35 GL will be removed during the RHM LOM (20 to 25 years).

The estimates for groundwater ingress into RHM range from 0.12 GL to 2,09 GL over the LOM. These data are shown in **Chart 7–2**.

Table 7-7 Groundwater Ingress Estimated for RHM (basecase) in cubic metres

Year	GRM	BRM	RHM	Total
2011	15,303	558,060	0	573,363
2012	1,542,580	554,985	0	2,097,565
2013	1,614,730	570,974	0	2,185,704
2014	1,227,470	633,868	0	1,861,338
2015	951,768	752,522	0	1,704,290
2016	1,244,380	771,574	0	2,015,954
2017	855,044	848,690	118,571	1,822,305
2018	930,070	977,918	165,444	2,073,432
2019	1,316,480	1,041,970	369,962	2,728,412
2020	1,488,760	1,134,290	487,836	3,110,886
2021	1,070,720	1,204,010	707,199	2,981,929
2022	1,796,650	1,226,570	891,687	3,914,907
2023	1,728,670	1,280,900	1,065,610	4,075,180
2024	1,342,020	1,342,580	1,205,810	3,890,410
2025	1,139,750	1,409,990	1,335,560	3,885,300
2026	1,716,190	1,488,220	1,533,330	4,737,740
2027	1,276,560	1,508,450	1,690,990	4,476,000
2028	1,740,780	1,591,900	1,777,100	5,109,780
2029	1,624,370	1,601,560	1,863,880	5,089,810
2030	1,859,850	1,533,980	1,969,540	5,363,370
2031	1,711,400	0	1,994,020	3,705,420

Year	GRM	BRM	RHM	Total
2032	996,491	0	2,093,040	3,089,531
2033	2,187,430	0	2,087,220	4,274,650
2034	1,524,260	0	2,070,090	3,594,350
2035	2,234,130	0	2,079,210	4,313,340
2036	1,479,800	0	2,016,940	3,496,740
2037	2,294,810	0	2,022,040	4,316,850
2038	2,589,180	0	1,968,360	4,557,540
2039	986,844	0	1,911,950	2,898,794
2040	3,289,370	0	1,860,960	5,150,330
2041	1,107,730	0	0	1,107,730
2042	2,582,380	0	0	2,582,380
2043	2,404,440	0	0	2,404,440
2044	3,229,910	0	0	3,229,910
2045	2,216,570	0	0	2,216,570
2046	1,554,660	0	0	1,554,660
2047	1,274,060	0	0	1,274,060
2048	2,301,260	0	0	2,301,260
2049	1,963,800	0	0	1,963,800
2050	1,517,800	0	0	1,517,800
2051	2,064,960	0	0	2,064,960
2052	1,603,870	0	0	1,603,870
2053	1,418,090	0	0	1,418,090
2054	1,742,260	0	0	1,742,260
2055	763,412	0	0	763,412
2056	1,751,760	0	0	1,751,760
2057	1,597,000	0	0	1,597,000
2058	1,773,450	0	0	1,773,450
2059	1,647,270	0	0	1,647,270
2060	1,722,730	0	0	1,722,730
2061	1,067,610	0	0	1,067,610
2062	1,825,650	0	0	1,825,650
2063	363,198	0	0	363,198
2064	170,852	0	0	170,852
2065	640,507	0	0	640,507
2066	891,452	0	0	891,452
2067	686,828	0	0	686,828
2068	928,758	0	0	928,758

7 Numerical Modelling

For the purposes of establishing a mine water balance for RHM, it has been assumed that around 2,200 KL/day or 800 ML/year of water will be produced from gas extraction wells. Thus over 25 years of mining the volume of groundwater extracted from IMG will be ~ 20 GL and from mine dewatering ~ 15 GL.

Table 7–9 below provides an indication of the possible range of groundwater ingress estimates, based on model parameter sensitivity and uncertainty analysis. As noted above, this analysis is based on the 2011 indicative mine plan. However, the revised mine plan is not expected to result in significant changes to these conclusions.

7.5.4 Uncertainty Analysis

Prediction uncertainty arises mainly as a result of uncertainties in model conceptualisation and model parameters. The effects of alternative conceptualisations on the calibrated model were not explored in this study because the alternatives were considered very limited as the model has been built based on the best available information and understanding of the groundwater regime through site specific studies.

Parameter uncertainty was explored through varying selected parameters (one at a time) to examine the impacts on predicted groundwater drawdown or extraction. The base case model used was the calibrated predictive model using the time varying properties approach for goaf simulation. Uncertainty was assessed by conducting 12 additional model runs with varying parameters as shown in **Table 7–8**. The horizontal hydraulic conductivity (Kh) and vertical hydraulic conductivity (Kv) distributions were scaled up with factors of two and five and scaled down with factors of 0.5 and 0.2 for sensitivity runs one to four. The specific yield (Sy) for coal seams in the base case was 0.01 and was considered at the lower end, so only the effect of higher Sy was considered in sensitivity run five. The variation of Kh values for interburden was considered in sensitivity runs six and seven. Only scaling up of Kv for interburden was considered in sensitivity run eight as Kv of the base case was at the lower end. The variation of Kh and Kv values for overburden was considered in sensitivity runs nine to 12.

Table 7-8 Parameter Variations Used for Model Sensitivity Assessment as a Product of Calibrated Base Case Parameters Displayed in Table 7–5

Sensitivity Run	Unit	K (horizontal)	K (vertical)	Specific Yield
1	Moranbah Coal Measures seams (layers 7, 9, 11, 13, and 15)	Base case × 2	Base case	Base case
2	Moranbah Coal Measures seams (layers 7, 9, 11, 13, and 15)	Base case × 0.5	Base case × 1	Base case × 1
3	Moranbah Coal Measures seams (layers 7, 9, 11, 13, and 15)	Base case × 1	Base case × 5	Base case × 1
4	Moranbah Coal Measures seams (layers 7, 9, 11, 13, and 15)	Base case × 1	Base case × 0.2	Base case × 1
5	All coal seams (layers 3, 5, 7, 9, 11, 13, and 15)	Base case × 1	Base case × 1	Base case × 2
6	Interburden (layers 4, 6, 8, 10, 12, 14, and 16)	Base case × 2	Base case × 1	Base case × 1
7	Interburden (layers 4, 6, 8, 10, 12, 14, and 16)	Base case × 0.5	Base case × 1	Base case × 1

7 Numerical Modelling

Sensitivity Run	Unit	K (horizontal)	K (vertical)	Specific Yield
8	Interburden (layers 4, 6, 8, 10, 12, 14, and 16)	Base case × 1	Base case × 5	Base case × 1
9	Overburden	Base case × 2	Base case × 1	Base case × 1
10	Overburden	Base case × 0.5	Base case × 1	Base case × 1
11	Overburden	Base case × 1	Base case × 5	Base case × 1
12	Overburden	Base case × 1	Base case × 0.2	Base case × 1

Mean drawdown of in the Alluvium/Tertiary layer and the GMS at the end of year 2068 is presented in **Table 7–9** for the base case model and sensitivity runs. For the base case, the mean drawdown was 8.26 and 64 metres respectively. The largest mean drawdown of 12.96 metres for the Alluvium/Tertiary occurred in sensitivity run eight, in which Kv of the interburden increased five times, allowing more drawdown to propagate upwards.

Table 7-9 Mean Drawdown from Sensitivity Runs for Alluvium/Tertiary and Goonyella Middle Seam, 2068

Sensitivity Run	Alluvium, Tertiary Mean Drawdown (m)	GMS Mean Drawdown (m)
Base Case	8.26	64.00
1	8.25	59.45
2	8.34	71.02
3	8.28	65.13
4	8.26	56.36
5	8.33	67.56
6	8.01	57.28
7	8.48	65.58
8	12.96	56.34
9	8.40	66.97
10	8.11	62.06
11	7.06	61.94
12	8.10	61.93

Total groundwater inflow for RHM and for RHM and the GRB mine complex are presented in **Table 7-10** for the sensitivity analysis. The highest groundwater inflow occurred in sensitivity run eight, where groundwater inflow was two times higher than the base case for RHM and was almost double the base case for RHM and GRB mine complex. Sensitivity run eight had a higher Kv value for the interburden, which allowed more leakage to the GMS.

Through the analysis of parameter uncertainty, it was identified that uncertainty of Kv of the interburden between coal seams could have marked impacts on predictive groundwater drawdown and inflow because the chosen sensitivity value of Kv value of 5×10^{-5} m/day (five times the base case value) was still within the reasonable parameter range.

7 Numerical Modelling

Table 7-10 Total Groundwater Inflows for each Sensitivity Run at the end of Mining

Sensitivity Run	Red Hill Mine Total Inflow (GL)	Red Hill Mine and GRB Mine Complex Total Inflow (GL)
Base Case	35.3	146
1	35.1	142
2	33.4	138
3	35.2	140
4	30.9	135
5	37.1	147
6	34.5	139
7	33.8	139
8	75.5	214
9	34.1	139
10	34.1	140
11	34.1	138
12	34.0	139

Of particular note, the greatest uncertainty identified surrounds the vertical permeability of interburden and goaf aquifer parameters and therefore corresponding groundwater inflows as there is no known published data for post goaf aquifer parameters. The uncertainty in the model results can be reduced through the collection of inflow data. If significant divergence is observed between the measured and model predicted inflows, revisiting the model and specifically re-calibration of the model parameters against the measured inflow data will reduce the model uncertainty and gain better predictions for the future. It is also recommended that model refinement and predictions be rerun (at intervals no longer than three years during the LOM based on monitoring data compiled.

Potential Impact of Project on Groundwater Regime and Mitigation Measures

The impacts on groundwater from the development, operation, closure and post-closure of the project have been evaluated. Potential impact of the mine on the regional groundwater regime was assessed by predictive groundwater modelling. The groundwater model was developed to estimate groundwater extraction (passive seepage and active dewatering for gas control) over the mine life, project drawdown in aquifers, evaluate the zone of influence and direct and indirect impacts of dewatering, and evaluate the possible impact on other groundwater users. The groundwater model was constructed using the geological model, hydraulic parameters determined on site and from literature, and groundwater level information within the survey area.

Mining within the GRB mine complex area commenced after the granting of the original Goonyella mining lease (ML1763) in 1971 and the Riverside mining lease (ML1764) in 1978. While the main aquifers within the area are the coal seams, inflow from the exposed seams to the current GRM pit voids have not been significant. Dewatering in advance of mining is generally not required for the current open pit or underground workings.

The Goonyella North mine is located along the strike of the Moranbah Coal Measures immediately north of the EIS study area, with the Moranbah North mine located immediately south. Given the close proximity of these coal mines, this assessment considers the additional and, where possible, the cumulative impact of the project on the current (mine influenced) groundwater resources in the survey area.

8.1 Potential Impacts during Development and Operation

8.1.1 Potential Impacts on Regional Groundwater Levels

The project is within the declared Isaac Connors GMA; however, there are few groundwater users locally. From a search of the NRM groundwater database, seven bores are registered within 10 kilometres of the EIS study area boundary for water supply purposes. Other bores are present but these are either monitoring bores or coal seam gas exploration bores) as discussed in **Section 6.3**.

During the LOM, groundwater inflow from the aquifers to the underground mine workings or extraction as part of gas depressurisation can lead to increased drawdown of the potentiometric surface in the vicinity of the mine workings when compared to drawdown from the existing approved coal mines in the area.

8.1.1.1 Impacts on Permian Formation Aquifers

Dewatering resulting from IMG drainage and groundwater ingress into the mine workings will cause drawdown of groundwater levels as discussed in **Section 7.5.2** and presented in **Figure 7-9** and **Figure 7-11**. Resultant variations in the current groundwater levels, which have already been altered due to existing mine dewatering, were predicted.

Groundwater modelling was used to project drawdown caused by dewatering and IMG drainage of the proposed RHM. Predictive modelling indicates that drawdown of five metres (from pre-RHM mining levels) will occur to a distance of up to four kilometres from the proposed RHM footprint. The drawdown predictions were simulated for the target GMS, allowing for the prediction of the largest zone of influence at the end of mining.

8 Potential Impact of Project on Groundwater Regime and Mitigation Measures

Groundwater drawdown will also occur in the units above the GMS due to induced flow towards the depressurised coal seam and the impact of the goaf resulting in increasing vertical permeability. The extent and degree of drawdown within the overlying units decreases with increasing distance above the dewatered seams.

The Goonyella North and Moranbah North mines are located along strike and also target the Moranbah Coal Measures to the north and south of RHM, respectively. The cumulative impact of these mines will be to superimpose the drawdown of each mine such that the Moranbah Coal Measures between the mines will be significantly dewatered. No groundwater users were identified between the mines.

Drawdown in bores of five metres or more is considered, in fractured rock aquifers, to have a material impact on bore yield. There are no identified groundwater supply bores within the predicted five metre drawdown zone. Thus no "at-risk" bores have been identified.

There are two production bores (Skeleton Bore (NRM Registration 81696), and Cleanskin Gully Bore) on the 'Broadmeadow' property are located outside the predicted five metre drawdown contours zone but still within the predicted cone of depression on the 'Broadmeadow' property (Skeleton Bore (NRM Registration 81696), and Cleanskin Gully Bore),as shown on **Figure 6–4** While it is expected that users of these two bores will still have access to groundwater and not realise a marked change in supply it is recommended that monitoring be conducted to validate predictions.

Additional bores that may potentially be affected by mine dewatering and IMG drainage are the CSG bores. These bores are, however, designed to remove groundwater to allow gas extraction, and hence, mine-induced drawdown should not cause any impacts on these bores.

8.1.1.2 Impacts on Tertiary and Quaternary Aquifers

All creeks and the Isaac River within the EIS study area are ephemeral and there are no perennial water holes or groundwater dependant environments present, as discussed in **Section 6.4**. Under dry season conditions, groundwater does not contribute or have any hydraulic connection with surface water resources within these drainages. In exceptionally wet years it is possible that the Quaternary alluvium and shallow Tertiary aquifers may contribute some groundwater to the surface water system along water courses for a short duration after rain events.

Where excavations required for the surface infrastructure and mine access portals encounter Quaternary alluvium near creeks or the Isaac River and / or Tertiary sediments, groundwater inflow may occur (i.e. direct drainage impacts). The aquifers in these units are typically ephemeral are not considered significant aquifers. Due to the expected low hydraulic gradients (one to two metres) and low conductivity, the drawdown zone of influence, as a result of the direct impacts, is considered to only extend some 10 to 100 metres around excavations. This area around the excavations will remain dewatered, as recognised in the GRB mine complex open cut pits, as evaporation exceeds recharge.

The Quaternary alluvium associated with the Isaac River is considered, based on permeability and water quality, to be the most significant aquifer within the survey area, but is unlikely to be significantly impacted by groundwater drawdown as there are no major excavations to take place in close proximity to the Isaac River and limited hydraulic connection between the perched water tables in the alluvium and the confined coal seam aquifers (which will be depressurised and dewatered).

Although the numerical model indicates the potential for drawdown of over two metres in the Tertiary/Quaternary (as shown in **Figure 7–8**), this is not considered to occur in reality due to the ephemeral nature of the Cainozoic units. The model simulations assume fully saturated conditions in the Tertiary sediments and Quaternary alluvium and that these units are in hydraulic connection with the underlying confined aquifers. In reality due to the short periods over which the aquifers are actually, saturated, drawdown due to mining will be much less than predicted.

Subsidence is predicted to create cracking at surface (IMC 2011), the clay-rich nature of the Tertiary sediments, Quaternary alluvium, and weathered Permian will, however, self-heal. This will reduce the potential of leakage from surface to the mine workings. Observations at the adjacent BRM appear to confirm this.

All creeks and the Isaac River within the EIS study area are ephemeral and there are no perennial water holes or groundwater dependant ecosystems present, as discussed in **Section 6.4.** On this basis, impacts on groundwater dependent ecosystems are not expected.

Incidental mine gas drainage activities are not expected to impact on the Tertiary or Quaternary aquifers as the bores will be sealed where they intersect these aquifers.

8.1.2 Impacts on Groundwater Quality

The groundwater quality of the Permian strata is brackish to saline and not suitable for human consumption or irrigation, but has some use for stock water according to the limits set in ADWG (2004) and ANZECC/ARMCANZ (2000) water quality guidelines.

During mining operations, groundwater quality within aquifers surrounding the site is not expected to change from pre-mining conditions. This would be a result of all RHM water and waste storage facilities infrastructure being designed, constructed, and managed to ensure little or no potential of seepage. In the event that groundwater contamination did occur contaminant migration off site in the groundwater will not occur. This is expected as during degassing and mining operations, groundwater will be continually extracted from bores or sumps in the underground workings to ensure a safe working environment. This drainage of groundwater will create a depression in the potentiometric (groundwater) surface around the workings such that the net movement of groundwater is towards the workings during mine operation. This will prevent the movement of water that may have been impacted by mining from moving away from the mine operation area and into the surrounding aquifers. The resultant drawdown, changing groundwater flow patterns, effectively limits the potential for contaminant plumes to migrate off site via groundwater.

Groundwater quality away from the influence of the project will not deteriorate as these resources will continue to receive recharge via the same processes that occurred pre-mining.

Groundwater quality data (with respect to major anions and cations and dissolved metals) indicate that groundwater in the alluvial aquifers and basalt is of similar or better quality when compared to the coal seam aquifers of the Moranbah Coal Measures. Hence, any inadvertent mixing of groundwater (during and post mining) by induced downward movement from the upper to lower aquifers is unlikely to result in a deterioration of groundwater quality in the Permian aquifers.

Another potential source of contamination for groundwater is through contact with mine waste materials which may be acid forming or leach salt or metal contaminants to groundwater. A geochemical assessment of the coal and mine wastes (waste rock and tailings) was undertaken for the project (URS 2012a). The study indicates that the overburden (excavated for mine access) and rejects generated by the proposed mining and coal processing operation is predominantly

8 Potential Impact of Project on Groundwater Regime and Mitigation Measures

geochemically benign. Any possible seepage and /or surface run-off is expected to be slightly alkaline and have low-to-moderate salinity following surface exposure. Overburden and reject materials are unlikely to generate acid given the lack of oxidisable sulphur content, excess acid neutralising capacity and existing alkaline pH of these materials. As the direction of groundwater flow will be towards the mine workings, the buffering capacity of the groundwater is expected to neutralise any oxidation products of the coal seams due to mine dewatering, and any potential for the development of acid mine drainage is low.

The expected water quality of overburden and coal reject materials (runoff and seepage) and the water quality of the coal seam aquifers indicate that groundwater seeping into the underground mine will require dilution or treatment to reduce the salinity prior to reuse. The acid-base classification of coal samples found that most coal samples were potentially acid forming, although the potential for acidification of groundwater in contact with exposed coal seams is expected to be relatively low. This is due to the low sulphur concentration of coal and the significantly greater proportion of pH-neutral material and in the roof and floor of the underground mine compared to coal.

The waste rock dumps, waste placement areas, CHPP and coal stockpiles are located over the relatively saline aquifers of the Permian formations (Moranbah Coal Measures or Back Creek Group), not the fresh water aquifers of the Isaac River Quaternary alluvium or Tertiary sediments. Thus any potential seepage or runoff is unlikely to result in a marked alteration to groundwater quality of the underlying Permian formations.

The quality of the groundwater in the shallow Cainozoic groundwater resources that may exist within the project footprint (i.e. Quaternary alluvium and Tertiary sediments) have the potential to be impacted by spills and seepage from the MIA, and waste disposal and fuel storage areas where these are in sufficient quantities to leach through the soils to groundwater. Any spills from these areas are typically localised and not regionally significant in terms of groundwater impacts. The risks of groundwater contamination from chemical or fuel spills will be minimised by storage and handling of fuels, oils and other chemicals in accordance with Australian standards and requirements of Material Safety Data Sheets. The design of storage and handling facilities will provide full containment, and procedures for immediate clean-up of spills will be available. These measures are standard practice or a legislated requirement at mine sites. Areas of hydrocarbon and chemical storage will have spill control measures in place and a regular inspection regime will be required in order to monitor activities that could potentially lead to contamination of groundwater. Any accidental spills will be assessed on a case-by-case basis and remediated, which may include excavation and disposal of any contaminated soil, in accordance with NRM requirements.

During mining, mobile and stationary machinery including excavators, cranes, trucks and other vehicles will be required. There is potential for hydrocarbon contamination of the soil associated with leaks or spills from this machinery (or fuel storage areas for the maintenance of machinery). Dissolved and free-phase hydrocarbon may impact on the shallow aquifers underlying and down-gradient of areas of fuel spillage.

During mine operation, groundwater quality within aquifers surrounding the mine areas will continue to be suitable for the same purposes applicable during the pre-mining period. The groundwater quality within the aquifers surrounding the EIS study area will be monitored to ensure no marked deterioration in groundwater is occurring as a result of the proposed mining activities.

8.1.3 Additional Potential Impacts

8.1.3.1 Reduced recharge

Compression and/or sealing of the ground surface associated with the construction of roads and building foundations and IMG infrastructure is not expected to greatly alter the permeability of strata immediately beneath the site and, as such, will not markedly reduce rainfall recharge of the underlying aquifers. Works will be limited in the vicinity of the Isaac River, further limiting potential impacts on the Quaternary alluvial aquifer.

8.1.3.2 Subsidence

Underground mining using the thick seam mining method (longwall top coal caving) will result in subsidence of the overlying strata in the mined-out areas behind the longwall, with fracturing extending from the extraction horizon toward the surface. This caving and subsidence can cause fractures and joints in the overlying strata. AGE (2002) state that following the passage of longwall panels and stabilisation of subsidence, fracturing in the bulk of the strata will generally close up, allowing strata permeability to return to near to the pre-mining levels. Within the tensile zone above and adjacent to the longwall panels the vertical and horizontal strata permeability will be markedly and permanently altered due to sub-surface fracturing. The vertical extent of these fractures is dependent on numerous factors, such as mine design, geological conditions, surface topography, and the distance between the mine workings and the ground surface and in the RHM is predicted to extend up to 10 metres above the mine workings (IMC 2011).

8.1.3.3 Gas removal

To allow safe underground mining of the coal, degassing of the coal seams in advance of mining is required. Methods of degassing the coal are currently being developed for the project, and are likely to include installation of gas drainage wells (vertical or surface to in-seam). The drilling and installation of gas drainage wells has the potential to impact on groundwater (through water quality mixing, gas migration (pathways if not sealed correctly), and resulting in composite potentiometric heads) by creating potential pathways for leakage between formations.

Standard gas drainage well construction techniques, including fully cased and grouted wells and undertaking cement bond logs, will minimise the potential for inter-aquifer transfer through the bore. The IMG water production dam, where groundwater removed during the IMG drainage will be temporarily stored en-route to the mine water management system, will be fully lined with an impermeable lining, removing the potential for seepage to groundwater.

Permanent subsurface structures such as building foundations and road embankments can impede shallow groundwater flows and cause localised groundwater restrictions and waterlogging due to the build-up of pressure in the up-gradient area. The project does not require extensive subsurface structures in the vicinity of the Isaac River and associated alluvial aquifer. Detailed design will need to assess the need for engineering solutions such as pressure head relief.

8.2 Potential Impacts Post Mining

The main features of the final landform after mining ceases will comprise partially to totally filled mine voids in the underground workings, and subsidence troughs on the surface.

As with the impacts during mining, the increased permeability and storage for groundwater in the goaf will remain after mining.

8.2.1 Impacts on Regional Groundwater Levels

The remnants of the mine void will collect and accumulate water from groundwater ingress through the walls and goaf of the final workings. There is also the potential for groundwater ingress to occur from surface through leakage down the ventilation shafts, the mine access drift, old exploration holes or abandoned bores. These pathways facilitate groundwater rebound post mining

Typically, the mine workings will fill up and groundwater levels recover over time. The groundwater modelling, which does not take account of these leakage sources, indicates that a lag effect will persist after groundwater extraction is stopped, with residual drawdown in the GMS persisting until 2068. The groundwater system will re-adjust to the new (altered and enhanced) aquifer conditions surrounding and within the mined area. Groundwater levels and piezometeric pressures within the regional aquifers will, over time, attain a new equilibrium level. This new equilibrium for the groundwater system will have a different potentiometric surface from that which was present pre-mining owing to the presence of the mined workings and the different hydrogeological parameters of the goaf.

A detailed study of groundwater level recovery within RHM has not been conducted as part of the EIS because the closure requirements for the GRM will have a significant impact on recharge to groundwater and the rate of groundwater recovery. Groundwater levels are expected to recover within RHM after closure during the period of continued operation of GRM (2040 to 2068), and further work will need to be undertaken throughout the GRM mine life to determine the hydrological regimes, and the expected water quality of the mine voids. It is considered that the groundwater levels will recover in RHM, over time, to the base of the GRB mine complex open pits. The GRB mine complex final voids will, based on size and climate conditions (evaporation exceeding rainfall), permanently alter groundwater flow patterns towards the GRB mine complex final voids.

8.2.2 Impacts on Groundwater Quality

A rise in the groundwater salinity within the RHM void may occur as a result of atmospheric weathering of the exposure of wall, roof and floor rock during mining. However as discussed in **Section 8.1.2**, any increase in groundwater salinity is expected to be minor compared to the natural salinity of the groundwater in the Permian formations. Current and previous geochemical analysis in the Moranbah Coal Measures lithology show that there is low acid generation potential, with the roof and floor strata having excess buffering capacity, thus there is a low risk that metals will be mobilised into the groundwater.

Post-mining water quality within all aquifers surrounding the EIS study area is expected to remain similar to pre-mining water quality.

8.3 Mitigation Measures for Potential Impacts

8.3.1 General Groundwater Monitoring Program

A network of groundwater monitoring bores were previously installed around the EIS study area as shown in **Figure 6-3**. Additional groundwater monitoring bores and vibrating wire piezometers (VWPs) were also installed by BMA in early 2012. Further groundwater monitoring bores are to be installed down-gradient of mine water and waste storage facilities with locations to be determined after finalisation of the site layout. Further monitoring will be undertaken prior to the commencement of mining of the RHM underground expansion option to enable the long term monitoring of groundwater levels and groundwater quality, as well as to provide data for updates of the groundwater model.

Routine monitoring during the mining operation will provide early warning of any variation in response of the groundwater system to that predicted. This will enable BMA to undertake mitigation measures to minimise impact on surrounding groundwater users and the environment, such as the implementation of make good measures. In addition, the groundwater monitoring will enable the identification of any cumulative groundwater level drawdown impacts as a consequence of other mining operations in the area.

The monitoring bores are required to be completed in accordance with the Minimum Construction Requirements for Water Bores in Australia (Land and Water Biodiversity Committee 2003), the Water Act and undertaken by a licensed water bore driller. They must be surveyed for elevation levels of ground surface and monitoring measurement point to allow future groundwater levels to be measured to a consistent, known, datum and allow groundwater sampling as required.

Groundwater level and quality monitoring will be undertaken regularly to enable the detection of seasonal fluctuations and any groundwater level or quality trends or impacts. In turn, the monitoring data (level and chemistry) will be entered into a BMA environmental monitoring database to enable a regular assessment and interrogation to evaluate potential groundwater impacts.

A groundwater monitoring network and program will be developed and implemented for the RHM underground expansion option to detect any marked change to ground water quality due to activities. This will be consistent with the current suitability of the groundwater for agricultural use (stock watering), limited domestic use, and any discharge to surface waters that may occur after significant wet weather events.

Prior to commencement of mining for the RHM underground expansion option, at least 12 groundwater monitoring events will be undertaken, evenly spread across wet and dry seasons for at least two years. The monitoring events will record:

- groundwater levels; and
- groundwater quality with analysis of the parameters: - pH, electrical conductivity (EC), total dissolved solids (TDS), major cations and anions, nutrients (total nitrogen, nitrous oxides, ammonia, phosphorous), selected dissolved metals (aluminium, arsenic, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, and zinc), and total petroleum hydrocarbons (for bores monitoring potential fuel spill / seepage sources).

In addition, continuous groundwater level monitoring will be conducted across at least two wet and dry seasons using vibrating wire piezometers automatically recording water levels at regular intervals.

8 Potential Impact of Project on Groundwater Regime and Mitigation Measures

The background groundwater monitoring program will consist of 12 sampling events evenly spread over a two year period to determine background groundwater quality as far as practicable in order to determine groundwater contaminant and trigger limits for comparison to the EPP (Water) groundwater quality objectives for the Isaac River sub-catchment (zone 34) (as shown in **Table 6-3**)

On completion of monitoring, groundwater trigger levels, based on the 85th percentile value of groundwater quality results and groundwater contaminant limits based on the 99th percentile of groundwater quality results will be determined.

During mining operations, groundwater monitoring will continue, including:

- Monitored of groundwater levels in standpipe monitoring bores and VWPs.
- Groundwater quality sampling undertaken at least once very wet season and once every dry season with analysis of the parameters: - pH, EC, TDS, major cations and anions, nutrients, selected dissolved metals (aluminium, arsenic, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium and zinc), and total petroleum hydrocarbons (for bores monitoring potential seepage sources).
- Additional monitoring in one or more bores may be undertaken in the event of a significant spill of fuels or other contaminants with potential to cause groundwater contamination.
- Measurement of daily precipitation, evaporation, and gas drainage and mine dewatering volumes will be undertaken through operations.

Groundwater monitoring and sampling will be conducted by a suitably qualified and experienced professional in accordance with the current edition of the DERM Monitoring and Sampling Manual, or subsequent updated versions; and the AS/NZS 5667.11:1998 Australian/New Zealand Standard for water quality – sampling Part 11; guidance on sampling groundwater.

Monitoring data (level and chemistry) will be entered into a BMA environmental monitoring database to enable a regular assessment and interrogation to evaluate groundwater trends.

If groundwater quality results exceed trigger levels set out in the environmental authority, monitoring will be repeated within 60 days. If concentrations exceed trigger levels in the second sampling event then an investigation into cause, optimum response, and the potential for environmental harm must be conducted and mitigation measures developed and implemented to address the outcome of the investigation.

An annual review of the monitoring program will be conducted by a suitably qualified and experienced hydrogeologist. This annual review of the monitoring program will be conducted to evaluate the effectiveness of each monitoring location, to assess where new locations and modifications to the monitoring program may be needed, and to evaluate impacts that may be occurring. These data will, on a regular basis (no longer than three years), be used to validate model predictions.

Post-mining groundwater monitoring will be subject to detailed closure/relinquishment conditions. It is expected that during the operational phase of the project, the groundwater data collected for the region will be comprehensive enough to accurately predict the long term recovery of the aquifers. This will assist in the development and implementation of the closure strategy and the refinement of post-mining groundwater monitoring programs.

8.3.2 Impacts on Nearby Groundwater Users

While groundwater model predictions do not indicate any significant impacts on adjacent groundwater users, should a detrimental impact on landholder groundwater supplies be detected, and shown to be related to the project operations, then BMA will seek to reach mutually agreeable arrangements with affected neighbouring groundwater users for the provision of alternate water supplies. To this end, BMA will update its groundwater census of bores on properties within the predicted drawdown cone prior to commencement of mining, and enter into make-good agreements with landholders specifying trigger levels and appropriate responses.

Regular groundwater monitoring will enable groundwater level drawdown to be identified prior to any impacts being experienced in surrounding landholder bores. In turn, alternative water supplies can be put in place before supplies from relevant existing landholder bores are adversely affected. Options for alternate supplies include:

- installations of new pumps capable of extracting groundwater from greater depth within existing bores;
- deepening of existing bores;
- installation of a new bore at another location on the property; and / or
- provision of piped water sourced from the mine (i.e. surplus water from the gas depressurisation program, depending on quality).

The specific arrangements for affected properties will be discussed with each relevant landholder with a view to reaching a mutually acceptable agreement.

8.3.3 Seepage from Stockpiles and Surface Water Control Structures

Good environmental practice requires that reasonable effort be made to minimise seepage from stockpiles and surface water control structures wherever this may affect the groundwater system. All mine water storages will be constructed in accordance with the NRM (2002) dam guidelines. These guidelines include requirements for management of seepage from mine water storages.

The surface water runoff collection system from the MIA and CHPP will be managed as a non-release system with water stormwater returned to the mine water management system. Raw and product coal stockpiles will be contained within hardstand or compacted areas and drainage will be directed to the mine water management system.

Early detection of significant seepage will enable management of any potential problems. Potential seepage from the project surface water management system (such as the IMG water production dam for gas drainage works) will be regularly assessed through the installation and monitoring of the monitoring bore network on-site, including down-gradient of all potential seepage sources. Management of surface water will include monitoring of water at selected locations for potential contaminants.

Installation of monitoring bores down-gradient of potential seepage sources is proposed to enable early detection of any leachate entering the shallow Quaternary alluvial or Tertiary sediment aquifers. The key indicator parameters of seepage will be monitored including (but not restricted to) standing water level, salinity (as TDS), dissolved metals, and major ions initially on a quarterly basis.

8 Potential Impact of Project on Groundwater Regime and Mitigation Measures

In the unlikely event of groundwater impact, mitigation strategies will include some or all of the following measures (depending on the specific requirements):

- investigation of water management system integrity;
- removal of contaminant source and repair / redesign of any water management structures as required;
- installation of and pumping from, groundwater interception wells; and / or
- installation of and pumping from groundwater interception trenches.

8.3.4 Hydrocarbon and Chemical Contamination

Areas of hydrocarbon and chemical storage and handling will be designed to contain spills and procedures will be in place to minimise likelihood of spills and provide a rapid response in the event that spills occur. Spill kits and spill clean-up training will be available on site.

Installation and monitoring of the monitoring bore network on site, including down-gradient of all potential spill areas, will enable early detection of any contaminated seepage.

Further information on the prevention and management of spills is provided in the Red Hill Mining Lease EIS Section 5.4.

8.3.5 Installation of Gas Drainage Bores

Any gas drainage wells will be designed and constructed in accordance with industry standards, with the goal of maintaining hydraulic isolation between discrete water-bearing formations, and will therefore inherently mitigate the risk of gas migration into overlying aquifers and/or releases at the surface. In addition, the integrity of the wellhead and casing will be monitored as part of normal operations.

8.3.6 Closure and Post Closure

There are no specific groundwater management requirements in relation to closure and post closure. If significant groundwater drawdown has occurred, groundwater levels may continue to be monitored to track recovery.

Glossary

ALLUVIUM - Sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on river beds, floodplains, and alluvial fans.

ALLUVIUM AQUIFER - A deposit of detrital material - mostly sediment - formed by river, stream and floodplain processes that store and transmit water in spaces between sediments grains. Stored water can be extracted and used.

ANISOTROPY - The condition under which one or more of the hydraulic properties of an aquifer vary according to the direction of flow.

AQUICLUDE - A low-permeability unit that forms either the upper or lower boundary of a groundwater flow system.

AQUITARD – These are geologic units that are of low permeability. Aquitards usually form a layer in a geologic sequence. They may contain water, but would not yield reasonable volumes of water to bores or wells. An example of an aquitard would be a saturated clay layer that is overlying a saturated sandy aquifer.

AQUIFER - A geological structure of formation or part thereof, permeated with water or capable of- (a) being permeated permanently or intermittently with water; and (b) transmitting water.

AQUIFER, CONFINED - An aquifer that is overlain and underlain by impervious layers. The water level in bores tapping confined aquifers rises within the bore to a level above the top of the aquifer, and may result in an artesian or sub artesian bore. Confined aquifers tend to occur in the central and deeper parts of the Basin.

AQUIFER, PERCHED - Perched Aquifers occur in the upper catchments. They sit over a thick layer of clayey weathered sediments and have no connection to the fractured rock aquifers beneath the clay. This lack of connection means that their ecosystems are highly dependent on rainfall runoff, lateral subflow, from unconsolidated sediments overlying the clay or upstream flow contributions. These systems are more sensitive to surface water changes. Development of surface water resources or disruptions to subsurface flow will have the greatest impact on flora and fauna in this setting.

AQUIFER, SEMICONFINED - An aquifer confined by a low-permeability layer that permits water to slowly flow through it. During pumping of the aquifer, recharge to the aquifer can occur across the confining layer. Also known as a leaky artesian or leaky confined aquifer.

AQUIFER TEST - A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resource available for development from the well.

AQUIFER, UNCONFINED - An aquifer which has the water table as its upper surface which may be recharged directly by infiltration from the groundwater surface.

AUSTRALIAN HEIGHT DATUM (AHD) - The Australian height datum, adopted by the National Mapping Council of Australia, for referencing a level or height back to a standard base level.

BORE (WELL) - Any bore, well or excavation or any artificially constructed or improved underground cavity used or to be used for the purpose of—(a) the interception, collection, storage or extraction of groundwater; or (b) groundwater observation or the collection of data concerning groundwater; or (c) the drainage or desalination of any land; or (d) in the case of a bore that does not form part of a septic tank system, the disposal of any matter below the surface of the ground; or (e) the recharge of an

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aquifer— but does not include a bore that is used solely for purposes other than those specified in paragraphs (a), (b) and (d).

BOUNDARY CONDITIONS - Specified Head (or Fixed or Constant Head). Refer to Dirichlet Condition (also known as First Type Boundary). Specified Flow. Refer to Neumann Condition (also known as Second Type Boundary). Head-dependent Flow. Refer to Cauchy Condition (also known as Third Type Boundary).

CAUCHY CONDITION - Also known as Head-dependent Flow or Third Type Boundary Condition. A boundary condition for a groundwater model where the relationship between the head and the flow at a boundary is specified, and the model computes the groundwater flux for the head conditions applying.

CALIBRATION - Calibration of a model is the process where parameters in the model are fine tuned to get the best possible match between actual and modelled data over a defined period.

CALIBRATION, INITIAL CONDITIONS - The initial hydrologic conditions for a flow system that are represented by its aquifer head distribution at some particular time corresponding to the antecedent hydrologic conditions in that system. Initial conditions provide a starting point for transient simulations.

CALIBRATION, STEADY STATE - The calibration of a model to a set of hydrologic conditions that represent (approximately) an equilibrium condition, with no accounting for aquifer storage changes.

CALIBRATION, TRANSIENT - The calibration of a model to hydrologic conditions that vary dynamically with time, including consideration of aquifer storage changes in the mathematical model.

COMPEXITY - The degree to which a model application resembles, or is designed to resemble, the physical hydrogeological system. A hierarchical classification of three main complexities in order of increasing complexity: Basic, Impact Assessment and Aquifer Simulator. Higher complexity models have a capability to provide for more complex simulations of hydrogeological process and/or address resource management issues more comprehensively. In this guide, the term complexity is used in preference to fidelity.

COMPLEXITY – Basic Model - With limited data availability and status of hydrogeological understanding, and possibly limited budgets, a Basic model could be suitable for preliminary quantitative assessment (rough calculations), or to guide a field program.

COMPLEXITY – Impact Assessment Model - More detailed assessments are possible with an Impact Assessment approach, which usually requires more data, better understanding, and greater resources for the study.

COMPLEXITY – Aquifer Simulator - An Aquifer Simulator is a high complexity representation of the groundwater system, suitable for predicting the response of a system to arbitrary changes in hydrogeological conditions.

CONCEPTUAL MODEL - A simplified and idealised representation (usually graphical) of the physical hydrogeologic setting and our hydrogeological understanding of the essential flow processes of the system. This includes the identification and description of the geologic and hydrologic framework, media type, hydraulic properties, sources and sinks, and important aquifer flow and surface-groundwater interaction processes.

CONE OF DEPRESSION - The radial decline of potentiometric levels or underground water levels around a point of water extraction from an aquifer.

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DARCY'S LAW - An empirical equation developed to compute the quantity of water flowing through an aquifer. Usually expressed as Q=kiA, where Q=flow, k=hydraulic conductivity, I=hydraulic gradient, A=aquifer cross-sectional area.

DEWATERING - Removing underground water for construction or other activity. It is often used as a safety measure in mining below the water table or as a preliminary step to development in an area

DIRICHLET CONDITION - Also known as a Specified, Fixed or Constant Head Boundary, or Third Type Boundary Condition. A boundary condition for a groundwater model where the head is known and specified at the boundary of the flow field, and the model computes the associated groundwater flow.

DRAWDOWN - Refers to a lowering of the surface that represents the level to which water will rise in cased bores. Natural drawdown may occur due to seasonal climatic changes. Groundwater pumping may also result in seasonal and long-term drawdown.

EXTRACTION - In relation to any bore includes withdrawing, taking, using or permitting the withdrawing, taking or using of water from that bore.

EVAPOTRANSPIRATION - The sum of evaporation and transpiration.

FINITE-DIFFERENCE MODEL - A particular kind of numerical model based upon a rectangular grid that sets the boundaries of the model and the nodes where the model will be solved.

Gigalitre (GL) - A volumetric measure equal to one million kilolitres or one billion litres.

GROUNDWATER - (a) Water occurring naturally below ground level (whether in an aquifer or otherwise); or (b) water occurring at a place below ground that has been pumped, diverted or released to that place for the purpose of being stored there; but does not include water held in underground tanks, pipes or other works.

GROUNDWATER FLOW MODEL - An application of a mathematical model to represent a site-specific groundwater flow system.

GROUNDWATER-DEPENDENT ECOSYSTEMS (GDE) - Ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater.

HETEROGENEOUS - A medium which consists of different (non-uniform) characteristics in different locations.

HOMOGENEOUS - A medium with identical (uniform) characteristics regardless of location.

HYDRAULIC CONDUCTANCE - A term which incorporates model geometry and hydraulic conductivity into a single value for simplification purposes. Controls rate of flow to or from a given model cell, river reach, etc.

HYDRAULIC CONDUCTIVITY - A measure of the ease of flow through a pore space or fractures. Hydraulic conductivity has units with dimensions of length per time (e.g. m/s, m/min, or m/d).

HYDRAULIC GRADIENT - Spatial variation in the effective elevation of water table and/or potentiometric level, which drives lateral flow of underground water.

HYDRAULICALLY LINKED - In relation to sub artesian water, means there is a direct connection between the sub artesian water and surface water to the extent that— (a) if the aquifer is full and surface water is removed, sub artesian water begins, within approximately 1 day, to flow to the

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surface, replacing the surface water removed; and (b) if the aquifer is not full, surface water begins, within approximately 1 day, to seep into the aquifer causing the water level in the aquifer to rise.

HYDROLOGIC EQUATION - An expression of the law of mass conservation for purposes of water budgets. It may be stated as inflow equals outflow plus or minus changes in storage.

INFILTRATION - The flow of water downward from the land surface into and through the upper soil layers.

ISOTROPY - The condition in which hydraulic properties of the aquifer are equal in all directions.

LEAKANCE - Controls vertical flow in a model between cells in adjacent layers. Equivalent to effective vertical hydraulic conductivity divided by the vertical distance between layer midpoints.

MODEL CALIBRATION - The process by which the independent variables (parameters) of a numerical model are adjusted, within realistic limits, to produce the best match between simulated and observed data (usually water-level values). This process involves refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve the desired degree of correspondence between the model simulations and observations of the groundwater flow system.

NEUMANN CONDITION - Also called a constant flux boundary. The boundary condition for a groundwater flow model where a flux across the boundary of the flow region is known and specified, and the model computes the associated aquifer head.

NON-UNIQUENESS - The principle that many different possible sets of model inputs can produce nearly identical computed aquifer head distributions for any given model.

NUMERICAL MODEL - Refers to a mathematical representation of a physical system intended to mimic the behaviour of a real system, allowing description about empirical data and prediction about untested states of the system.

OBSERVATION WELL - A non-pumping well used to observe the elevation of the water table or the potentiometric surface. An observation well is generally of larger diameter than a piezometer and typically is screened or slotted throughout the thickness of the aquifer.

PARSIMONY – A principle that states that the simplest explanation that explains the greatest number of observations is preferred to more complex explanations.

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.

PIEZOMETERIC SURFACE - Is a surface that represents the level to which groundwater will rise in cased bores intersecting confined aquifers.

POROSITY - The ratio of the aggregate volume of the spaces between grains or fractures in a rock, sediment or soil to its total volume, generally expressed as a percentage.

RECHARGE - Is the addition of water, usually by infiltration, to an aquifer.

RECHARGE BOUNDARY - An aquifer system boundary that adds water to the aquifer. Streams and lakes are typically recharge boundaries.

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RESIDUAL - The difference between the computed and observed value of a variable at a specific time and location.

SATURATED ZONE - The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.

SEDIMENTARY AQUIFERS - These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest groundwater resources.

SENSITIVITY ANALYSIS - The measurement of the uncertainty in a calibrated model as a function of uncertainty in estimates of aquifer parameters and boundary conditions.

SIMULATION - One complete execution of a groundwater modelling program, including input and output.

SPECIFIC CAPACITY - The ratio of the rate of discharge of water from the well to the drawdown of the water level in the well. Specific capacity should be described on the basis of the number of hours of pumping prior to the time the drawdown measurement is made. It will generally decrease with time as the drawdown increases.

SPECIFIC STORAGE - The amount of water per unit volume of a saturated formation that is expelled from storage due to compression of the mineral skeleton and the pore water.

SPECIFIC YIELD - The ratio of the volume of water that a given mass of saturated soil or rock will yield by gravity to the volume of that mass.

SPRING - A spring of water naturally rising to and flowing over the surface of land, but does not include the discharge of underground water directly into a watercourse, wetland, reservoir or other body of water.

STOCHASTIC - A description of a parameter or a process with random qualities. A stochastic parameter has a range of possible values, each with a defined probability. The outcome of a stochastic process is not known with certainty.

STORAGE COEFFICIENT (STORATIVITY) - Is the volume of water released or taken into storage per unit plan area of aquifer per unit change of head. It is a dimensionless value. In an unconfined aquifer, it is equal to specific yield.

SUB-ARTESIAN - Groundwater that does not rise above the surface of the ground when accessed by a bore and must be pumped to the surface.

TOPOGRAPHIC DIVIDE - The boundary between adjacent surface water boundaries. It is represented by a topographically high area.

TRANSMISSIVITY - Aquifer hydraulic parameter used to indicate the ease of groundwater flow through a metre width of aquifer section.

UNCERTAINTY ANALYSIS - The quantification of uncertainty in model results due to incomplete knowledge of model aquifer parameters, boundary conditions or stresses.

VADOSE ZONE - Also known as the zone of aeration and the unsaturated zone. The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe.

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The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater, may exist in the unsaturated zone.

VERIFICATION - A test of the integrity of a model by checking if its predictions reasonably match the observations of a reserved data set, deliberately excluded from consideration during calibration.

WATER BUDGET - An evaluation of all the sources of supply and the corresponding discharges with respect to an aquifer or a drainage basin.

WATER TABLE - Is the upper surface of an unconfined aquifer.

YIELD, SAFE - The amount of naturally occurring groundwater that can be economically and legally withdrawn from an aquifer on a sustained basis without impairing the native groundwater quality or creating an undesirable effect such as environmental damage. It cannot exceed the increase in recharge or leakage from adjacent strata plus the reduction in discharge that is due to the decline in head caused by pumping.

YIELD, SUSTAINABLE - An accepted working definition of sustainable yield is (Kalaitzis et al, 1999): “Sustainable yield is that proportion of the long term average annual recharge which can be extracted each year without causing unacceptable impacts on groundwater users or the environment”.

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