Prepared for
BHP Mitsubishi Alliance
ABN: 67096412752

AECOM

Transitional Progressive Rehabilitation and Closure Plan - Goonyella Complex

Hydrogeology assessment

21-Nov-2024
BMA Hydrogeology Assessment for Closure Plans
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Transitional Progressive Rehabilitation and Closure Plan - Goonyella Complex

Hydrogeology assessment

Client: BHP Mitsubishi Alliance

ABN: 67096412752

Prepared by

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1.0 Introduction

BHP Mitsubishi Alliance Pty Ltd (BMA) appointed AECOM Australia Pty Ltd (AECOM) to undertake hydrogeological assessments to support the transitional Progressive Rehabilitation and Closure Plan (PRC Plan) for the Goonyella Complex (GRB). The GRB comprises of the Goonyella, Riverside, and Broadmeadow mines, located about 30 kilometres (km) north of Moranbah, Queensland (see Figure 1).

The GRB metallurgical coal mining complex includes both open cut (Goonyella Riverside Mine) and underground (Broadmeadow Mine) operations, across eighteen (18) Mining Lease (ML) tenures within the geological Bowen Basin. Existing operations at GRB are executed under the conditions of Environmental Authority (EA) EPML00853413, for the extraction of coal via open cut strip mining from the Goonyella Riverside Mine and underground extraction of coal from the Broadmeadow Mine.

Mine workings of relevance for the Project are located primarily on ML 1763 and ML 1764, which include existing open cut pits: Thiess Pit, Airstrip Pit, Isaac Pit, Broadmeadow Pit, Red Hill Pit, Denham Pit, Cleanskin Pit, Riverside Pit, and Eureka Pit as depicted on Figure 2. This hydrogeological assessment was undertaken in accordance with the relevant requirements of the Queensland Department of Environment and Science (DES) Guideline – Progressive Rehabilitation and Closure Plans (PRC Plans), reference ESR/2019/4964, Version 3.1 (16 September 2024), 'the Guideline'. The groundwater assessment will be utilised to assist in the development of rehabilitation strategies and selection of post-mining land uses (PMLUs) and non-use Management Areas (NUMAs) within the GRB PRC Plan.

The BMA Red Hill Mine (RHM), an undeveloped hard coking coal underground mine, is located immediately adjacent and down dip of the GRB. The mine will be accessed through the open cut pit highwall of the GRB and utilise existing disturbance areas and infrastructure. The RHM is designed to be an extension of the GRB operational life and capacity of operations at the GRB. RHM is operated under a separate EA (EPML03337715) from the GRB and, as such, will have a separate PRC Plan. However, it is noted that, due to the interconnectivity of the hydrogeology, this groundwater input into the GRB PRC Plan incorporates both the GRB and RHM.

The terms 'GRB', 'Goonyella Complex', and 'Project area' throughout this report are defined as:

- GRB and Goonyella Complex are both defined as the collective Goonyella Riverside and Broadmeadow mines and the terms are interchangeable
- The Project area is defined as the regional area surrounding the GRB considered in detail within this assessment, to inform the understanding of the local and more regional scale groundwater system/s.

Figure 1 Project locality plan

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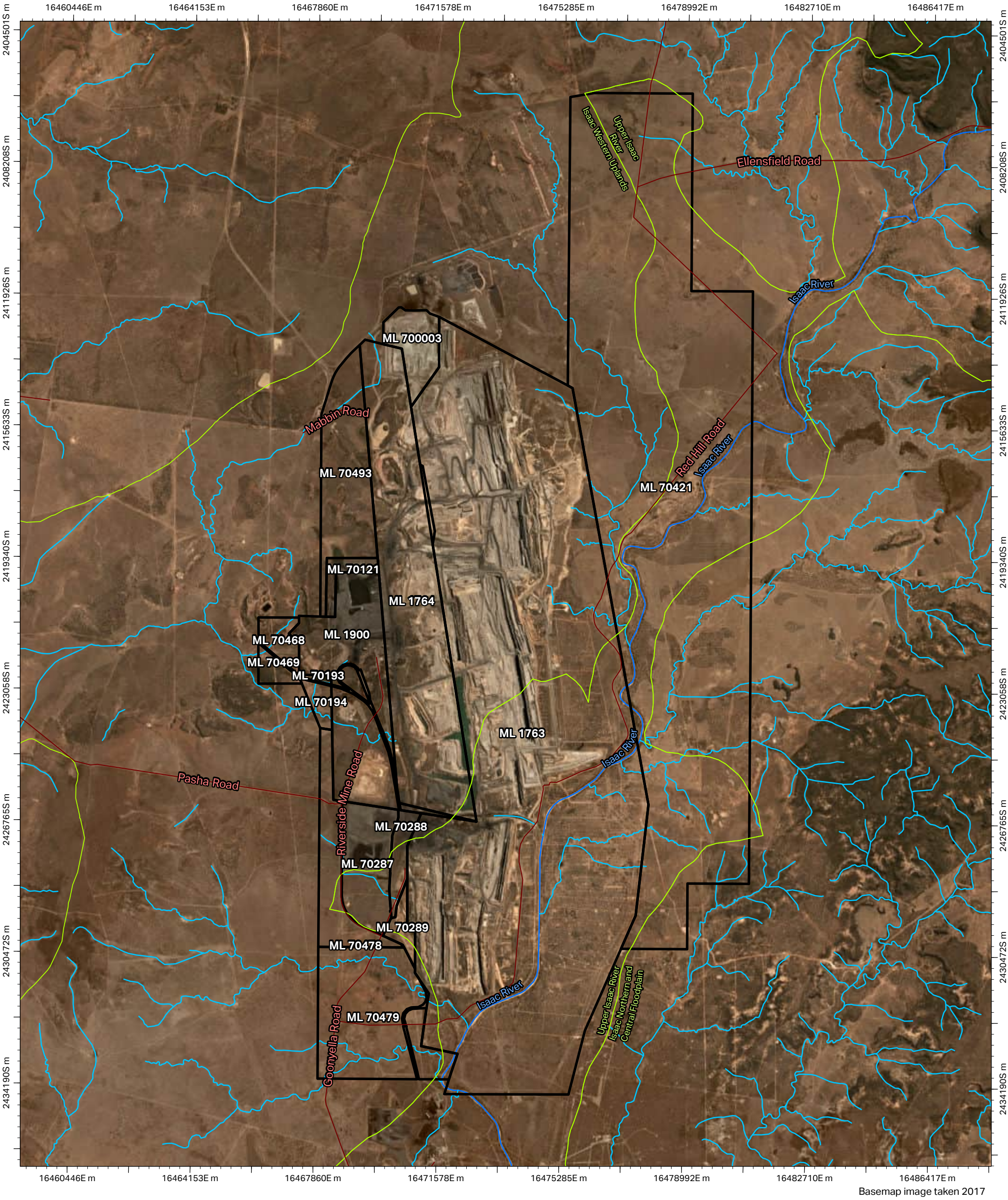

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Locality Plan

GDA 1994 MGA Zone 55

0 1 2 3 km

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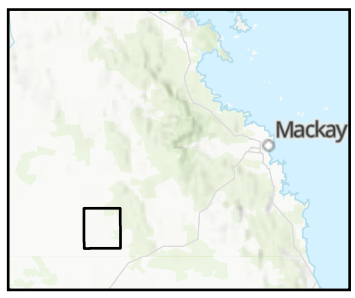

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)

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1.1 Background

The Goonyella open pit coal mine commenced operations in 1971, while the adjacent Riverside underground longwall mine was brought into production in 1982. The mines were merged into a single operation in 1989. The open pit mine targets three coal seams of the overall late Permian-aged Moranbah Coal Measures (MCM): the Goonyella Upper (GUS), Goonyella Middle (GMS), and Goonyella Lower (GLS) seams. The average thicknesses of these target coal seams are 3.9 m, 7.5 m, and 8.5 m, respectively. Comprising sandstones, siltstones, mudstones, claystone, and coal, the MCM extends more than 300 m below ground surface.

Operations began at Broadmeadow Mine as an underground longwall mine, which now includes top coal caving mining (TCC) methods, in 2005 under the ownership of BHP Billiton Mitsubishi Alliance. The TCC mining method is defined as “a special type of longwall mining applicable to very thick seams”. This method reduces the amount of good quality coal that can be left using ‘conventional’ longwall equipment. Implementing this method at Broadmeadow increased productivity and offers safety advantages.

The introduction of the longwall top coal caving method, alongside an expansion of the Broadmeadow Mine eastwards, increased the productive capacity at the mine from 0.4 million tonnes per annum (Mtpa) to a new total capacity of 4.8 Mtpa and extended the life of the mine by 21 years. This expansion began producing coal in 2013 as part of the Goonyella Riverside Mine Expansion Project.

The neighbouring Goonyella Riverside mine has two coal handling and processing plants (CHPP) where mined coal is sorted and washed. Coal from Broadmeadow mine utilises these CHPPs. After being processed, the coal is transported by rail to the BMA-owned Hay Point Terminal.

Figure 2 GRB Mine areas (source: BMA)

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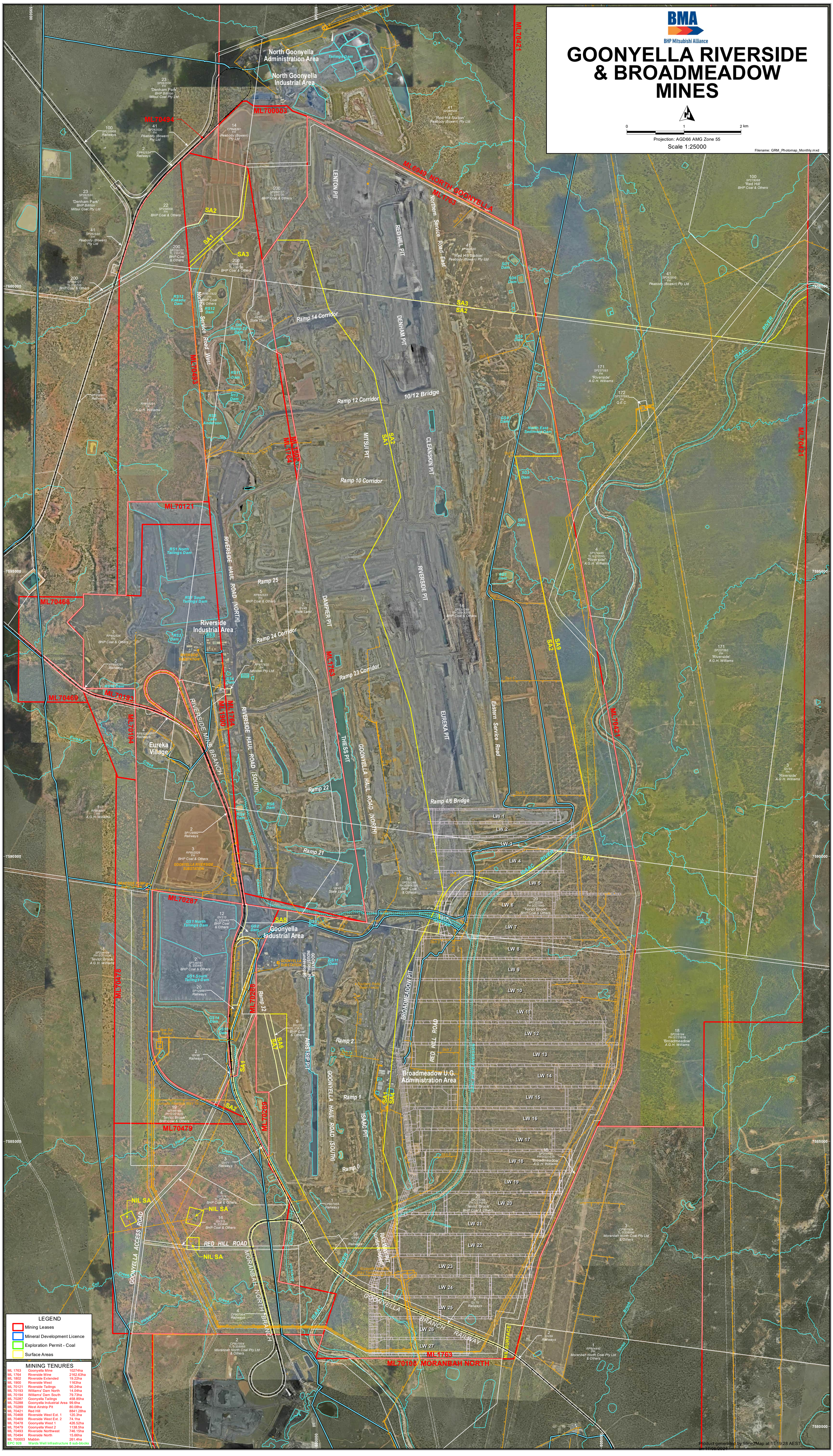
BMA
BHP Mitsubishi Alliance

GOONYELLA RIVERSIDE & BROADMEADOW MINES

0 1 2 km

Projection: AGD66 AMG Zone 55
Scale 1:25000

Filename: GRM_Photomap_Monthly.mxd



LEGEND

- Mining Leases
- Mineral Development Licence
- Exploration Permit - Coal
- Surface Areas

MINING TENURES

ML 1763	Goonyella Mine	10274ha
ML 1764	Riverside Mine	2162.63ha
ML 1802	Riverside Extended	19.22ha
ML 1900	Riverside West	1163ha
ML 70121	Riverside Tailings	90.24ha
ML 70193	Williams' Dam North	14.04ha
ML 70194	Williams' Dam South	79.73ha
ML 70287	Goonyella Tailings	458.85ha
ML 70288	Goonyella Industrial Area	99.6ha
ML 70289	West Airstrip Pit	80.08ha
ML 70421	Red Hill	8841.28ha
ML 70468	Riverside West Ext. 1	120.3ha
ML 70469	Riverside West Ext. 2	74.1ha
ML 70478	Goonyella West 1	426.52ha
ML 70479	Goonyella West 2	1138.5ha
ML 70493	Riverside Northwest	746.15ha
ML 70494	Riverside North	15.66ha
ML 700003	Mabbin	261.4ha
EPC 928	Wards Well Infrastructure	8 sub-blocks

Product generated by Mine2Map at 11:19:28 AEST on 17/05/2024

2.0 Final Landform #2.3

The post-mining final GRB landform relevant to this hydrogeological assessment was provided by BMA (denoted Landform #2.3) and is shown as Figure 3. The final landform comprises six planned residual final voids: Goonyella Pit (comprising Redhill Void, Denham Void, Cleanskin Void, Riverside Void), Thiess / Ramp 21 Pit, Ramp 32 East, Ramp 32 South, Broadmeadow Pit, and Isaac Pit (Plate 1). Ramp 32 East and Ramp 32 South are residual voids derived from the airstrip pit (Figure 2), where airstrip pit will be backfilled and rehabilitated for cattle grazing.

It is noted that Landform #2.3 was utilised in the predictive modelling included in the groundwater study, as reflected in Figure 21.

The final landform was a (2nd iteration) final landform provided by BMA to assess the suitability of BMA's intended post mining land use (PMLU) at GRB, that includes 'Cattle grazing', 'Woodland habitat', Water storage' and 'Watercourse' as defined within Table E1 of the EA.

Plate 1 GRB final landform residual voids

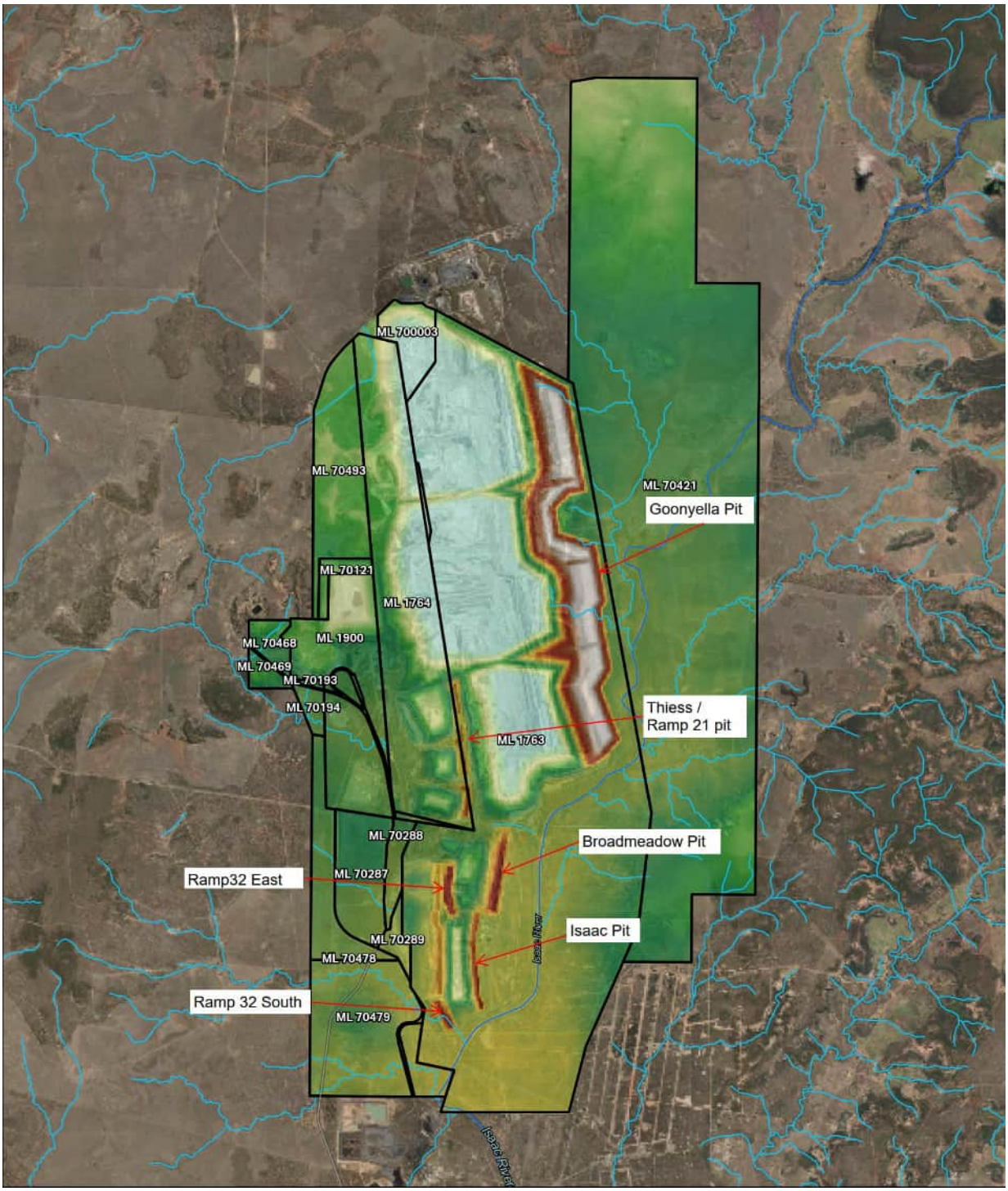


Figure 3 Landform #2.3

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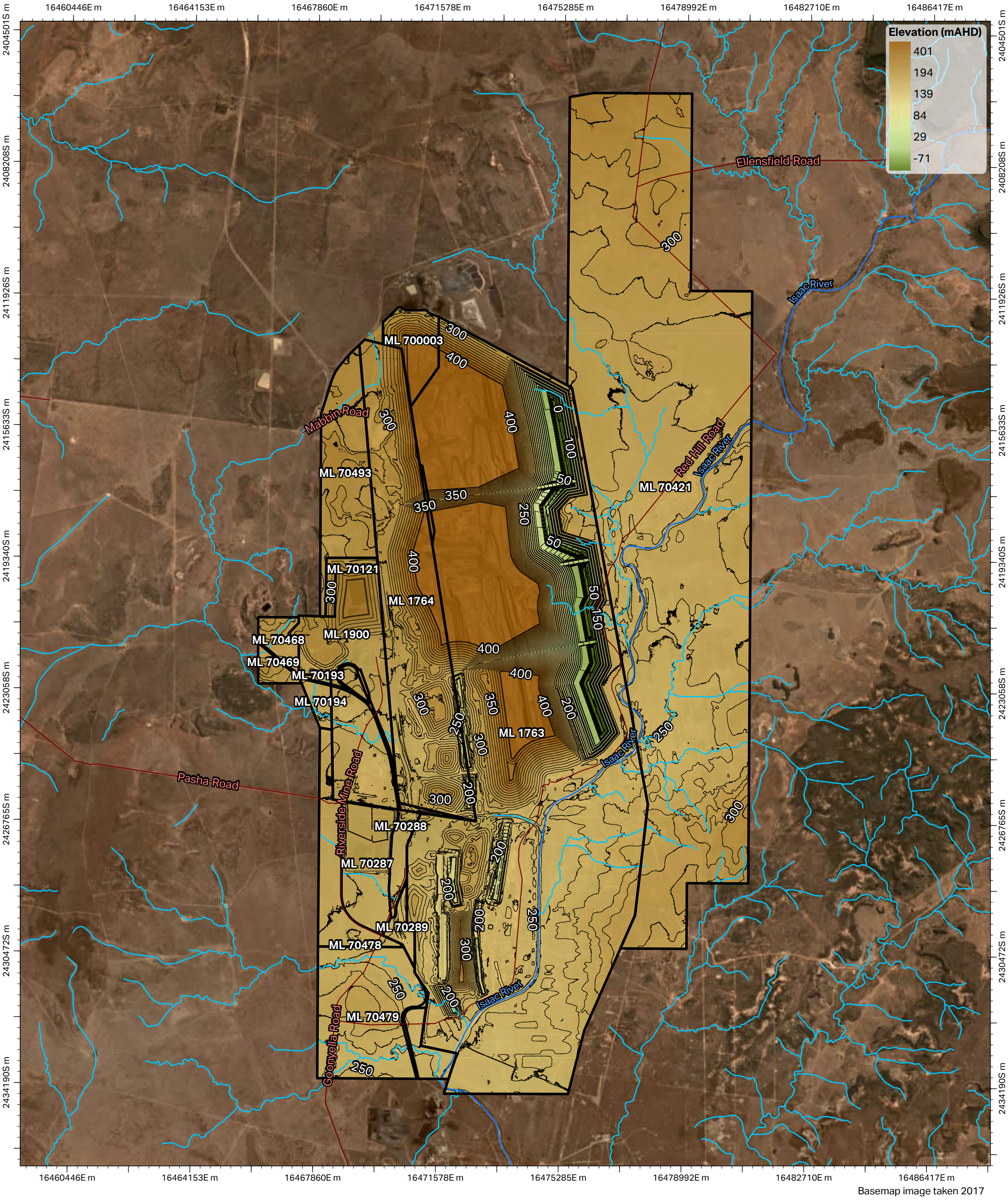

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Post Mining Landform (Landform #2)

Mine Lease

Watercourse (Major)

Watercourse (Minor)

GDA 1994 MGA Zone 55

0 1 2 3 km

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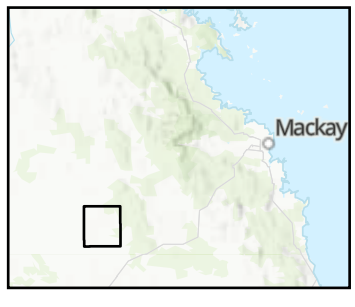

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3.0 Objectives

The main objective of the hydrogeological assessment is to assess the potential groundwater related impacts at GRB at completion of mining and until conditions stabilise post rehabilitation (i.e. groundwater equilibrium).

A focus of the hydrogeological assessment is demonstrating suitability of the landform for the intended PMLUs with respect of the GRB groundwater system. As such, the key specific objectives adopted in this assessment to demonstrate this suitability include:

- That the final landform is non-polluting with respect to groundwater:
  - The Goonyella Pit (final void) is recognised, through predictive groundwater and water balance modelling, to act as sink for groundwater, including groundwater contained within spoil.
  - The residual void pit water levels within the Goonyella Pit remain below groundwater bearing units, (i.e. there is sufficient freeboard to negate risk of void water discharge off site within a groundwater system).
- That there are minimal (little or no) additional impacts to groundwater receptors post-closure caused by the final landform that have not already occurred as a result of approved mining:
  - Little to no additional groundwater drawdown at potential groundwater dependant ecosystem (GDE) locations.
  - Little to no additional groundwater drawdown at anthropogenic bore users.

3.1 Guideline Criteria

A Progressive Rehabilitation and Closure Plan (PRC Plan) is a crucial component of ensuring that an Environmental Authority (EA) holder plans progressive rehabilitation of the land properly and provides conditions to which the land will be rehabilitated before surrendering the EA.

This hydrogeological assessment is undertaken in accordance with the relevant requirements of the Queensland Government Department of Environment and Science (DES) Guideline: Progressive Rehabilitation and Closure Plans (DES Reference: ESR/2019/4964, version 3.01, 16 September 2024).

Note: Guideline section 3.6.4 requires an assessment of groundwater interactions and potential lowering of groundwater levels that includes: consideration of the potential exposure of previously saturated geological formations to air - leading to AMD generation. Potential AMD generation and migration potential is not discussed in the hydrogeological assessment report, as a geochemical assessment has been compiled separately.

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Table 1 Statutory guidelines requirements addressed in the PRC Plan groundwater study

Guideline Section 3.6.1 Hydrogeology Requirements	Report Sections
Determining the groundwater occurrence including the existence of, and depth to, aquifers and aquitards	Section 7.0
Locating groundwater recharge and discharge locations locally and regionally	Sections 7.3, 11.0, 13.0, and 17.0
Groundwater quality within each of the aquifers and from surface expressions (i.e. seeps and springs)	Section 8.0
Current and potential future uses of groundwater including existing groundwater extraction bores	Section 9.1
Groundwater flow direction and velocity, including field tests to determine hydraulic conductivity	Section 7.2 and Section 13.0
The development of potentiometric mapping and hydro stratigraphic cross sections	Sections 7.3, 6.0,11.0, and 17.0
Groundwater modelling to determine contaminant transport and potential changes to groundwater level from dewatering or waste storage	Section 13.0, 14.0, 15.0, and 16.0
Guideline Section 3.6.3 Voids Requirements	**Report Sections**
Groundwater modelling to determine whether the void is acting as a sink or a source for groundwater	Section 15.0
A water balance study including an assessment of void surface and groundwater interactions such as:	
• groundwater lowering/reduction in hydraulic head	Section 15.4.3
• cones of depression and associated impacts	Sections 15.4.3, 15.6, and 15.7
• a conceptual model that incorporates all projected inflows, outflows, and recharge rates	Section 11.0, Section 15.4
• each of the major water fluxes into and out of the void	Section 16.3.1
Guideline Section 3.6.4 Underground Mining Requirements	**Report Sections**
• the development of a hydrogeological conceptual model	Section 11.0 and Section 17.1
• changes to the hydrogeological regime as a result of new cracks in the rock mass which can provide new flow paths in what could have previously been impermeable rock	Section 7.3.4
• potential for vertical connections between previously separated aquifers	Section 7.3.4

4.0 Project area description

The GRB complex is located within the Isaac River sub-basin of the Fitzroy Basin. The Isaac River sub-basin spans an area of about 22,000 square kilometres (km^2). Several tributaries join the Isaac River around the Project.

Eureka and Goonyella creeks are located immediately west and east of the GRB, respectively, and drain into the Isaac River. The Eureka Creek was modified with a man-made diversion drain and weir just upstream of where it joins the Isaac River. Eureka Creek is a partially regulated system for runoff from mining activities and is authorised as a discharge point to the Isaac River.

The Isaac River diversion is detailed in Section 5.2.

4.1 Climate

The climate around the Project area is sub-tropical, characterised by high variability in rainfall, temperature, and evaporation. Summer is between December and February and Winter is between June and August. The maximum daily temperature averages between 29.8 and 30.7 °C.

Climate data has been collected from two Bureau of Meteorology (BoM) weather stations around the project site. The weather stations used are:

- Moranbah Airport, QLD (Station 034035) – this station is situated about 36 km south of the project site. The station has been in operation since February 2012 to present day.
- Wentworth, QLD (Station 034015) – this station is situated approximately 43 km southwest of the project site. The station has been in operation since January 1963 to present day.

Average annual rainfall around the Project area is between 500 mm and 560 mm. High rainfall and evaporation occur in the summer months (December to February). Monthly evaporation rates are higher than monthly rainfall amounts throughout the year, indicating a net loss due to evaporation (i.e., a negative climate balance which has implications for final void water levels).

Summary of the average temperature and rainfall from the Moranbah Airport and Wentworth weather stations are presented in Table 2 and Table 3, respectively. Evaporation data was only available from the Wentworth weather station.

Table 2 Moranbah Airport (Station 034035) Temperature and Rainfall Averages

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Min Temp (°C)	21.5	21.4	20.3	16.9	12.8	10	8.8	8.9	12.7	16.3	18.9	20.6	15.9
Mean Max Temp (°C)	34.5	33.7	32.8	30.3	26.9	24.4	24.3	26.8	30.1	33.2	34.5	34.9	30.7
Mean Rainfall (mm)	103.1	82.6	76.8	25.7	30.6	23.1	38.7	12.2	14.5	22.8	66.3	64.3	560.8

Table 3 Wentworth (Station 034015) Temperature and Rainfall Averages

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Min Temp (°C)	21.7	21.5	20.0	16.7	12.8	9.4	8.1	9.5	12.9	16.7	19.3	21.0	15.8
Mean Max Temp (°C)	33.8	33.0	32.0	29.7	26.4	23.8	23.6	25.8	29.2	32.1	33.6	34.3	29.8
Mean Rainfall (mm)	88.6	77.0	50.2	28.8	28.6	18.4	19.6	18.3	9.9	25.9	54.8	82	499.3
Mean Evaporation (mm)	226.6	185.1	189.1	150.7	119.3	95.7	104.7	138.5	181.3	226.5	235.7	246.9	2,085.2

Rainfall data for the Project area were examined for rainfall patterns. Rainfall data was collected across the GRB for the period from 2014 to 2024. The coordinates for the rain gauges are provided in Table 4.

Table 4 Rainfall Stations Provided by BMA

Gauge Name	Commenced	Easting (GDA94)	Northing (GDA94)
GRM North AWS 2014 - 2024	2014	599688	7601004
BRM AWS 2014 - 2024	2014	602574	7588265
Eureka Village TEOM 2015 - 2024	2015	596976	7591840
GRM South AWS 2016 2024	2016	601182	7583820

The rainfall data indicates an average annual rainfall ranging from 510 to 560 mm, similar to the more regional weather stations.

Table 5 Average Rainfall Data (GRB)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
GRM North AWS 2014 - 2024	108.5	66.9	62.9	16.6	36.1	18.9	35.3	11.3	19.	21.7	45.8	73.9	517.2
BRM AWS 2014 - 2024	100.0	63.9	64.3	21.1	30.7	19.5	40.8	12.6	40.9	19.4	60.1	82.4	555.9
Eureka Village TEOM 2015 - 2024	85.6	86.6	90.9	21.4	38.1	25.1	44.6	9.78	17.5	28.8	54.5	73.0	575.8
GRM South AWS 2016 2024	94.2	64.7	75.3	19.1	42.0	13.1	39.6	6.7	14.7	15.2	41.9	87.6	514.0

4.2 Topography

The Project area comprises undulating with gently sloping valleys influenced by three main topographic controls. These include the sloping terrain in the northeast which is controlled by the Burton Range, the low-lying Isaac River floodplains in southwest, and the subtle hills and ridgelines in the west.

Elevation across the Project area ranges from approximately 520 m around the Burton Range to approximately 230 m south of the mines.

Figure 4 provides the topography and drainages across the Project area.

Figure 4 Topography and drainage

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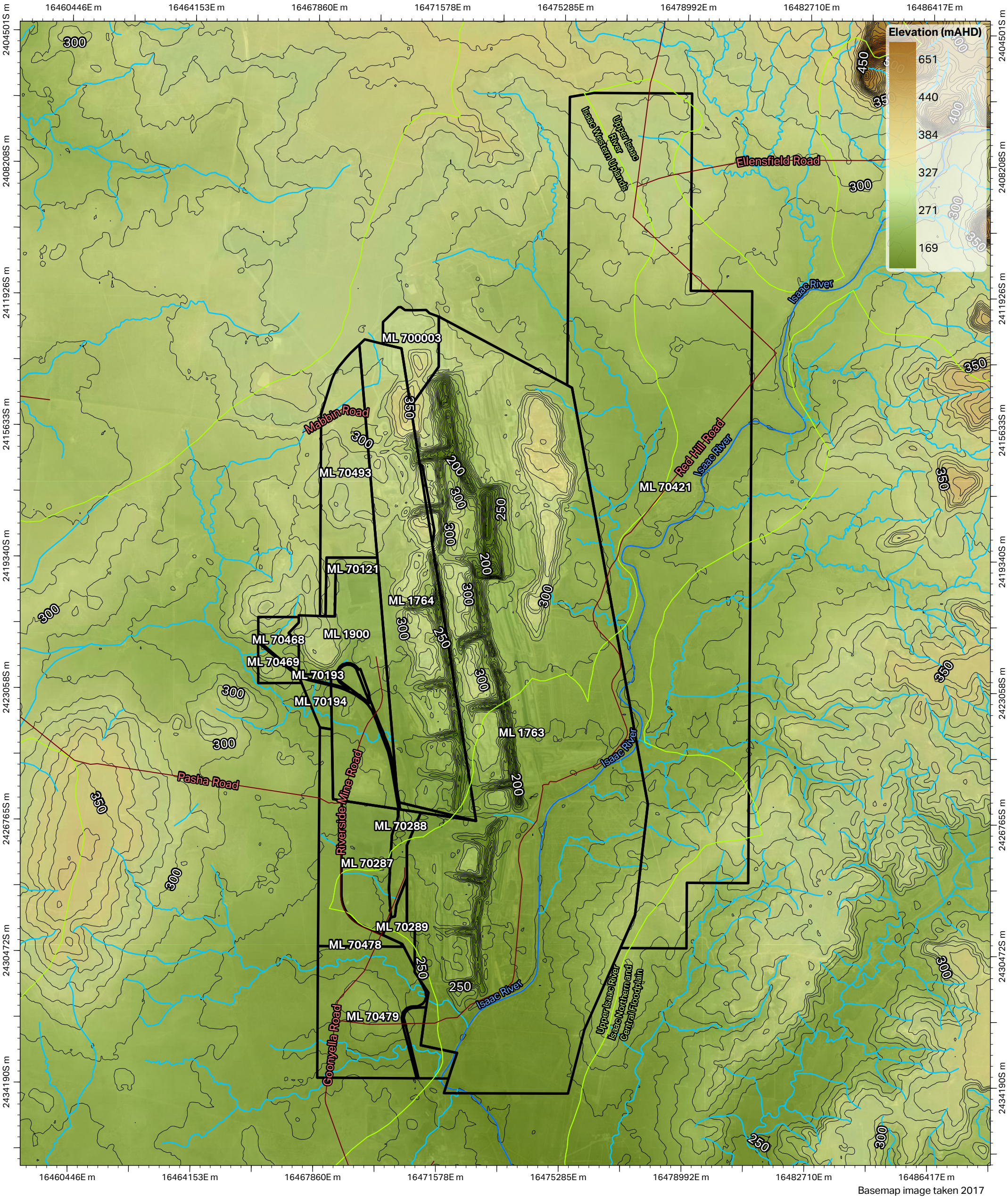

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Topography and Drainage

GDA 1994 MGA Zone 55

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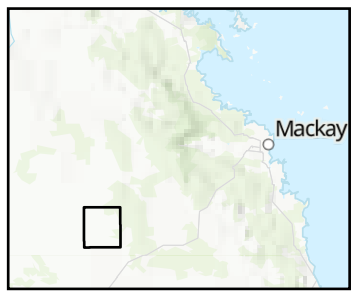

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)

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4.3 Cumulative Rainfall Departure

Cumulative rainfall departure (CRD) from long-term monthly rainfall records from the Moranbah and Wentworth weather stations are presented in Figure 5. The trends in this plot may provide an indication of water level response to rainfall recharge. A positive trend indicates periods of above average rainfall where increased groundwater recharge can occur. A negative slope indicates periods of below average rainfall where decreased groundwater recharge may occur.

Historic rainfall data from Wentworth, from 1964 to 1972, indicates a period of decreased rainfall. This was followed by a period of above-average rainfall (wet cycle) that lasted until 1991. After that, a period of below-average rainfall occurred until 1998, marking a dry cycle. There was an above the average level from 1998 to 2000, indicating an increase in rainfall. Rainfall levels fell below the average from 2000 to 2006 and then increased to above average from 2006 to 2012. A period of low rainfall was observed from 2012 to 2020. Since 2020, rainfall levels have remained above average rainfall.

Both CRD curves, for Moranbah and Wentworth, from 2016 to 2020, indicate a decrease in monthly rainfall in the Project area, leading to a reduction in groundwater recharge. The period from 2020 to 2024 saw a resurgence of wet weather, with rainfall levels surpassing the average and leading to an increase in groundwater recharge (Figure 5).

The CRD data during the period from 2016 to 2024 indicates similar rainfall patterns recorded for both Wentworth and Moranbah weather stations (Figure 5).

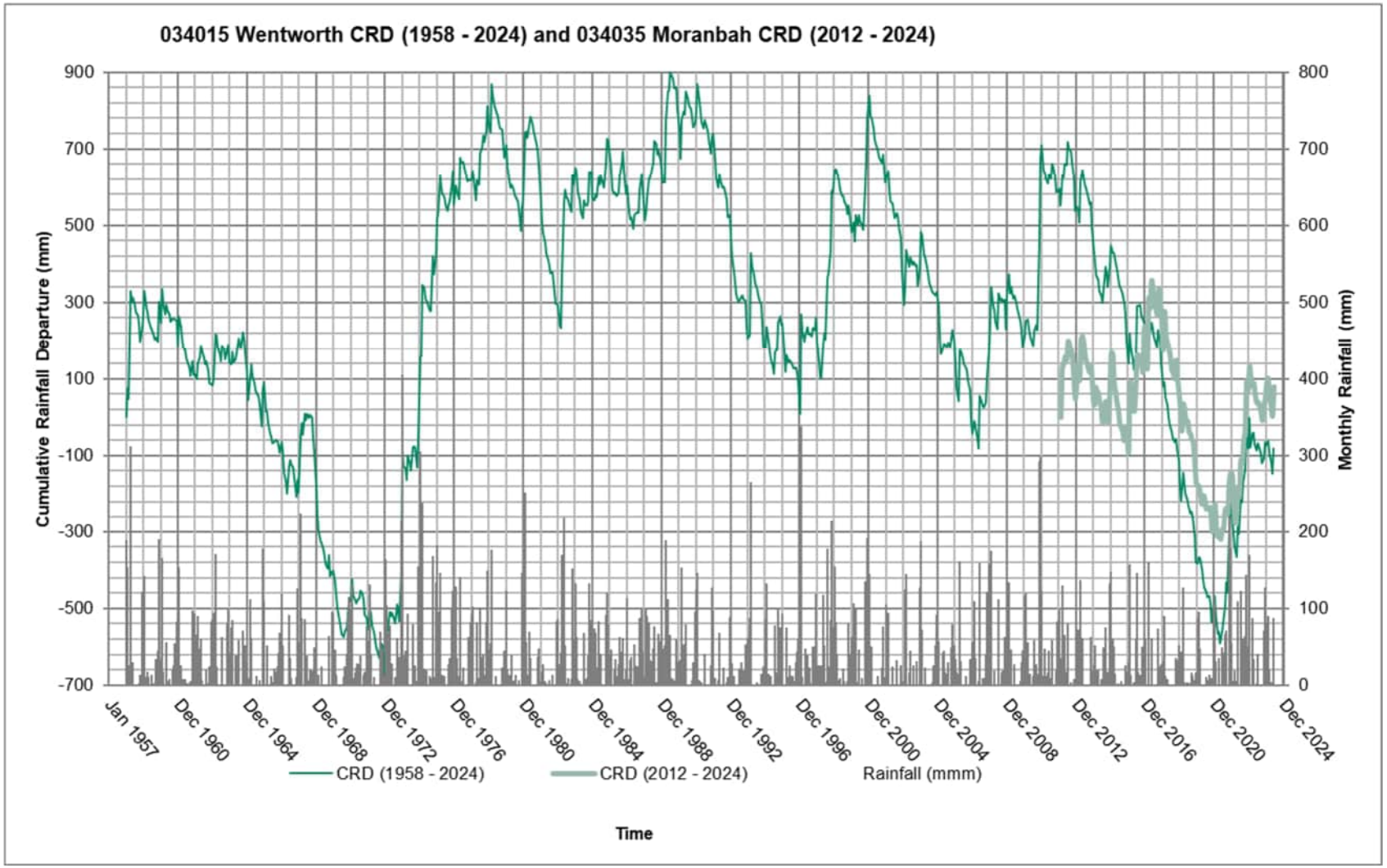


Figure 5 Wentworth (Station 034015) 1958 to 2024 and Moranbah Airport (Station 034035) 2012 to 2024 Cumulative Rainfall Departure curves

5.0 Surface Water and drainage

5.1 Overview

The Project area includes the headwaters of the Isaac-Connors sub-basin of the Fitzroy Basin. The mining activities span from near Eureka Creek to just west of Goonyella Creek and Isaac River. The Isaac River bisects the southwestern Project area, across the Goonyella and Broadmeadow mines, in a north-south direction (Figure 4). Other tributaries located south of the Project site include the Fisher Creek and the Eureka Creek. All these tributaries are considered to be ephemeral and drain into the Isaac River (Plate 2).

Plate 2 Tributaries across the Project area (Qglobe)

Drainage and surface water runoff mimic topography and flow from northeast to southwest across the project area, flowing into the Isaac River and tributaries, within and around the project. Baseflow originates from water stored in bedrock, valley soils, and riparian zones rather than distinct groundwater as water levels recede rapidly after rain events. Baseflow is typically limited to a few days up to approximately one or two weeks after surface runoff (quick flow) has drained from contributing sub-catchments (URS, 2013).

The Isaac River is an ephemeral sand bed stream that is largely alluvial downstream of the Burton Gorge. Geomorphologically, the Isaac River has a channel that is moderately winding and is primarily composed of sand and sediment, with minimal bedrock. Flooding has created a narrow alluvial terrace next to the channel, followed by a larger floodplain that is often flooded during major events.

Goonyella Creek is an ephemeral, slightly-to-moderately winding channel located largely at the Isaac River terrace-valley margin. The channel is relatively narrow and deep and features some bedrock upstream of Red Hill Road. Downstream, the channel merges with the Isaac River

Eureka Creek is also ephemeral and moderately winding (Plate 2).

A number of drainage lines feed into the waterways. Drainage lines consist of narrow channels and broader overland flow, and a series of ponds that remain as flows recede. These water bodies are temporal for short periods after flow.

5.2 Isaac River Diversion

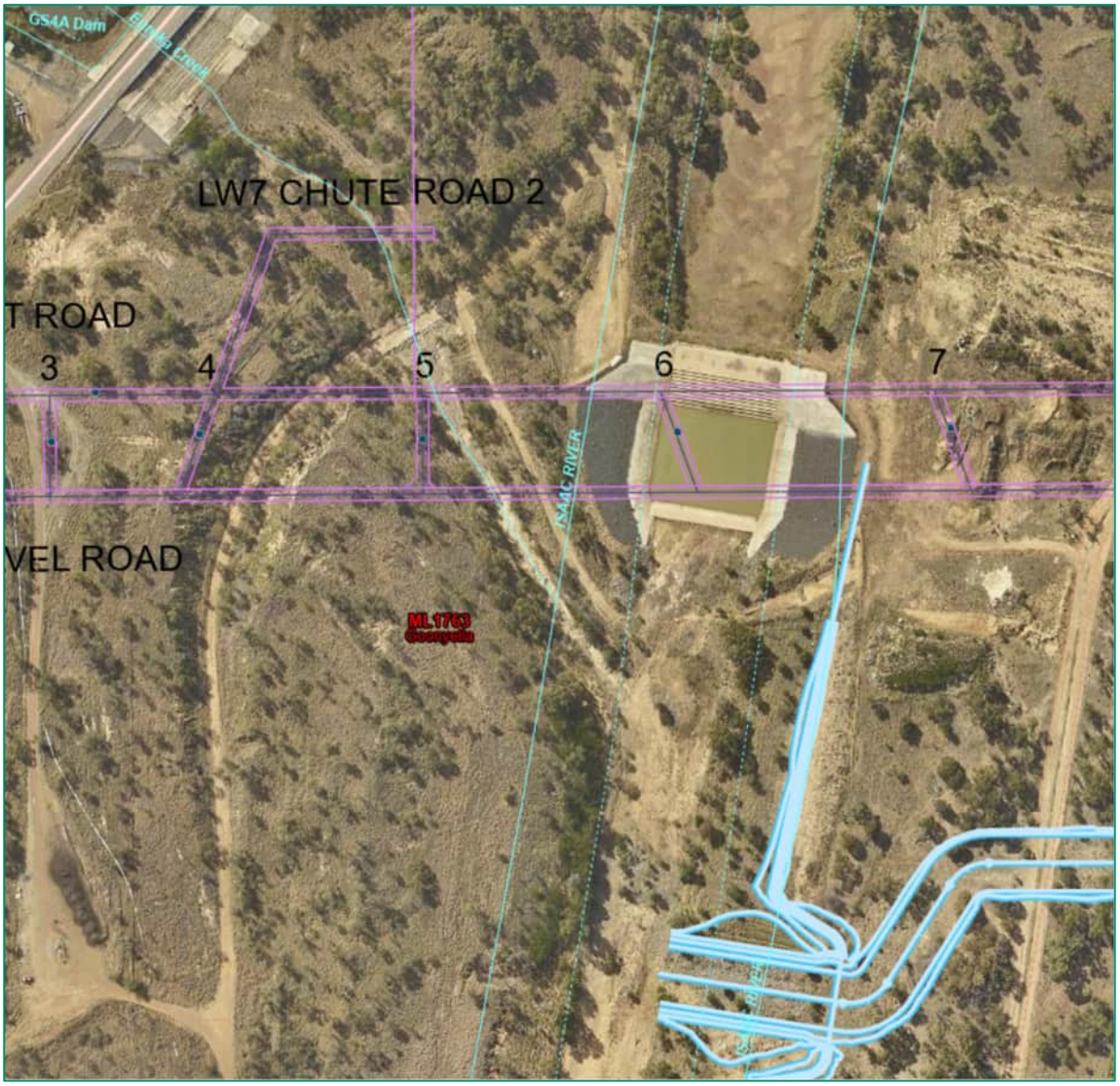
The Isaac River was diverted between 1985 and 1987 to allow access to coal deposits by open cut mining in the Project area. The diversion begins at the same location as Broadmeadow long wall panel, LW105, and replaces approximately 11 km of river channel with 7.8 km of diversion channel including two drop structures of around 2 m in height each, which were designed to manage the bed grade due to shortening of the channel. One drop structure is located immediately upstream of Eureka Creek confluence (Plate 3).

The diversion has bends at its upstream and downstream ends, however, the majority of the diversion is a near linear north-south channel. The diversion is largely cut through the Isaac River terrace, it is presently typically 8 to12 m deep with a top width of 80 to 100 m.

The Isaac River channel is incised into its floodplain by four to eight metres; the floodplain is inset within the broader terrace by a further two to four metres. The terrace, which is essentially a paleo-floodplain, is the dominant feature within the Project area. It has low relief with a gentle slope often away from the channel and in a downstream direction. The Isaac River diversion has been constructed within the Isaac River terrace and has no contemporary floodplain around the channel.

The excavated sediment from the diversion channel forms an embankment up to six metres above the surrounding terrace along the western bank of the diversion channel. To the east of the terrace, smooth hill slopes of reasonably low gradient rise up to a local catchment boundary near the eastern extent of the GRB mining area. There are only a few incised gully systems toward the upper limit of the local catchment. Two minor tributaries from beyond the mine plan area toward the upstream end of the mine plan, only the southern of these two will be over the mine footprint of GRB.

Plate 3 Drop structure



6.0 Geology

6.1 Regional Geology

6.1.1 Introduction

The Project area is located on the western flank of the northern part of the Bowen Basin, a sedimentary basin that covers an area of approximately 60,000 km^2. The Bowen Basin is a north-northwest to south-southeast orientated basin which extends from Collinsville in the north to beyond the New South Wales border in the south. It is overlapped by the Surat Basin in the southern region. The Bowen Basin a sedimentary sequence of Permian to Triassic age clastics, which attain a maximum thickness of 9,000 m in the depocentre of the Taroom Trough.

The Bowen Basin is divided into a number of tectonic units that comprise of platforms or shelves trending in the NNW to SSE direction, and are separated by sedimentary troughs. The main geologic feature of the project site is the Collinsville Shelf, which is a stable tectonic environment with sediment accumulation that gently dips and thickens towards the east.

Folding in the basin tends to be gentle and was largely a result of compression by thrust faults along the eastern margin. The area where the Collinsville Shelf meets the Nebo Synclinorium, an extension of the Taroom Trough, is defined by the Jellinbah Thrust Fault Zone. The lack of significant structures distinguishes the Collinsville Shelf sediments from the more disturbed formations of the Nebo Synclinorium.

The regional stratigraphic sequence of the geology can be summarised as Permian to Triassic sedimentary rocks that are overlain by Tertiary age deposits of the Duaringa and Suttor Formations that are separated by olivine-rich basalt remnants. The thin unconsolidated Quaternary alluvium and colluvium overlie the tertiary deposits.

The Permian age Back Creek Group, which generally comprise of fine-grained clastic sedimentary rocks deposited in a fluvial to shallow marine environment. The Back Creek Group is unconformably overlain by the Blackwater Group, which include the Rangal Coal Measures (RCM), the Fort Cooper Coal Measures (FCCM), and the Moranbah Coal Measures (MCM). The Permian deposits outcrop in the eastern and western margins and are unconformably overlain by the Triassic age sedimentary rocks of the Rewan Group. The RCM are the shallowest seams; they have been extensively mined along the eastern and western flanks.

The regional stratigraphy is summarised in Table 6 and presented in Figure 6, which depicts the solid geology as complied in 1:100,000 scale geological maps as downloaded from QSpatial. Figure 7 presents the surface geology mapped across the Project area (Queensland Government, 2024).

6.1.2 Crustal Extension

Development of the Bowen Basin initiated during the early-Permian as East-West extension generated a series of half graben sub-basins. Subsequent partial filling of the sub-basins occurred in the form of volcanic and sedimentary (lacustrine and fluvial) deposits (i.e. the Reid's Dome Beds (Esterle et al 2002).

6.1.3 Thermal Subsidence

Rapid subsidence due to continued thermal sag and continental erosion led to a marine transgression. From this point onwards, deposition within the basin became dominated by coastal and shallow marine sedimentation (e.g. the Back Creek Group).

6.1.4 Foreland Loading

Evolution of the Bowen Basin continued into the Late Permian, as further basin opening occurred with uplift and renewed volcanism in the east of the basin. During this period the half graben sub-basins became interconnected with continuing burial by a series of transgressive and regressive events.

Table 6 Regional Lithostratigraphy

Age	Stratigraphic Unit	Lithology	Typical Thickness (m)	Occurrence
Quaternary	Alluvium	Clay, silts, sand, gravel, and floodplain alluvium	15 - 35	Confined to present day stream alignments, floodplains, alluvial fans, high terraces and paleochannels. Localised along the Isaac River, Eureka and Goonyella Creeks, and floodplains
Tertiary	Undifferentiated Tertiary sediments	Clay, silt, sand, gravel, colluvium, fluvial, and lacustrine deposits including cross-bedded.	15 m	Underlying alluvium or as surficial cover
	Suttor Formation	Quartz sandstone, clayey sandstone, mudstone and conglomerate; fluvial and lacustrine sediments; minor interbedded basalt.	0 - 120	Most extensive in the mine areas and to the east. Sparsely distributed around the Project area
	Basalt	Olivine-rich weathered basalt remnants, moderately weathered and fresh basalts	0 - 80	Isolated outcrop and subcrop/s, inferred dykes, and flow remnants in the norther regions of the Project site
	Duaringa Formation	Mudstone, sandstone, conglomerate, siltstone, some oil shale, lignite, and basalt	0 - 50	The formation does not outcrop in the area of the Project site
Triassic	Moolayember Formation	Mudstone, lithic sandstone, interbedded siltstone, mudstone, sandstone, and thin coal seams	0 - 200	Outcrop farther east of the Project site
	Clematis Sandstone	Quartz sandstone, some quartz conglomerate, minor reddish brown mudstone	0 - 300	Isolated outcrops/subcrop/s in the east and north
	Rewan Formation	Lithic sandstone, pebbly sandstone, conglomerate, red and green mudstone, siltstone, quart sandstone, and shale	200 - 800	Outcrops east of the Project site; increasing in thickness as it proceeds east
Late Permian*	Rangal Coal Measures	Coal seams, carbonaceous shale and mudstone, tuff, siltstone, and mudstone	25 - 200	Isolated outcrops in the east and north
	Fort Cooper Coal Measures	Coal, brown and green sandstone, labile sandstone, quartzose sublabile sandstone, calcareous and tuffaceous sandstone, mudstone, siltstone, conglomerate, carbonaceous shale, tuff, volcanic conglomerate	100 - 600	Isolated outcrops in the east and north
	Moranbah Coal Measures	Coal, quartzose to sublabile, locally argillaceous sandstone, siltstone, mudstone, carbonaceous mudstone	100 - 700	Underlies the Project site
Middle Permian	Back Creek Group	Quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal, and sandy coquinite	400 – 1,200	Outcrop west and extends under mined areas to the east

*Three coal-bearing formations are recognised in the Blackwater Group: the Moranbah, Fort Cooper, and Rangal Coal Measures

Figure 6 Solid Geology

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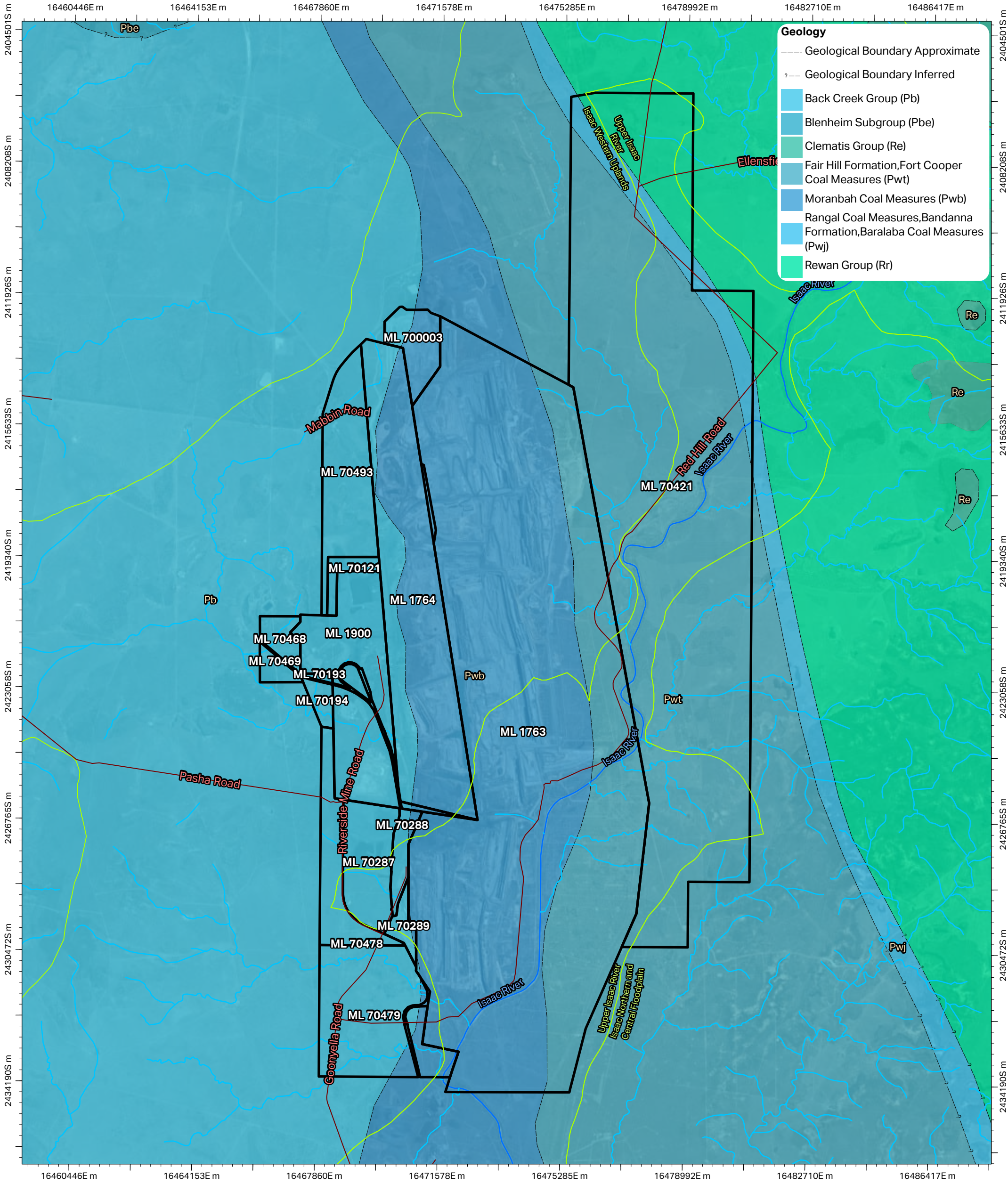

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Solid Geology

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)

GDA 1994 MGA Zone 55

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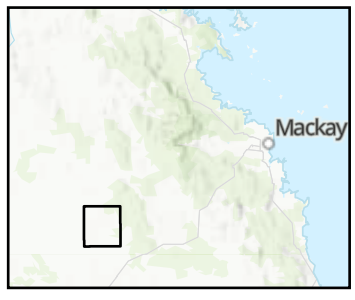

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Figure 7 Surface geology

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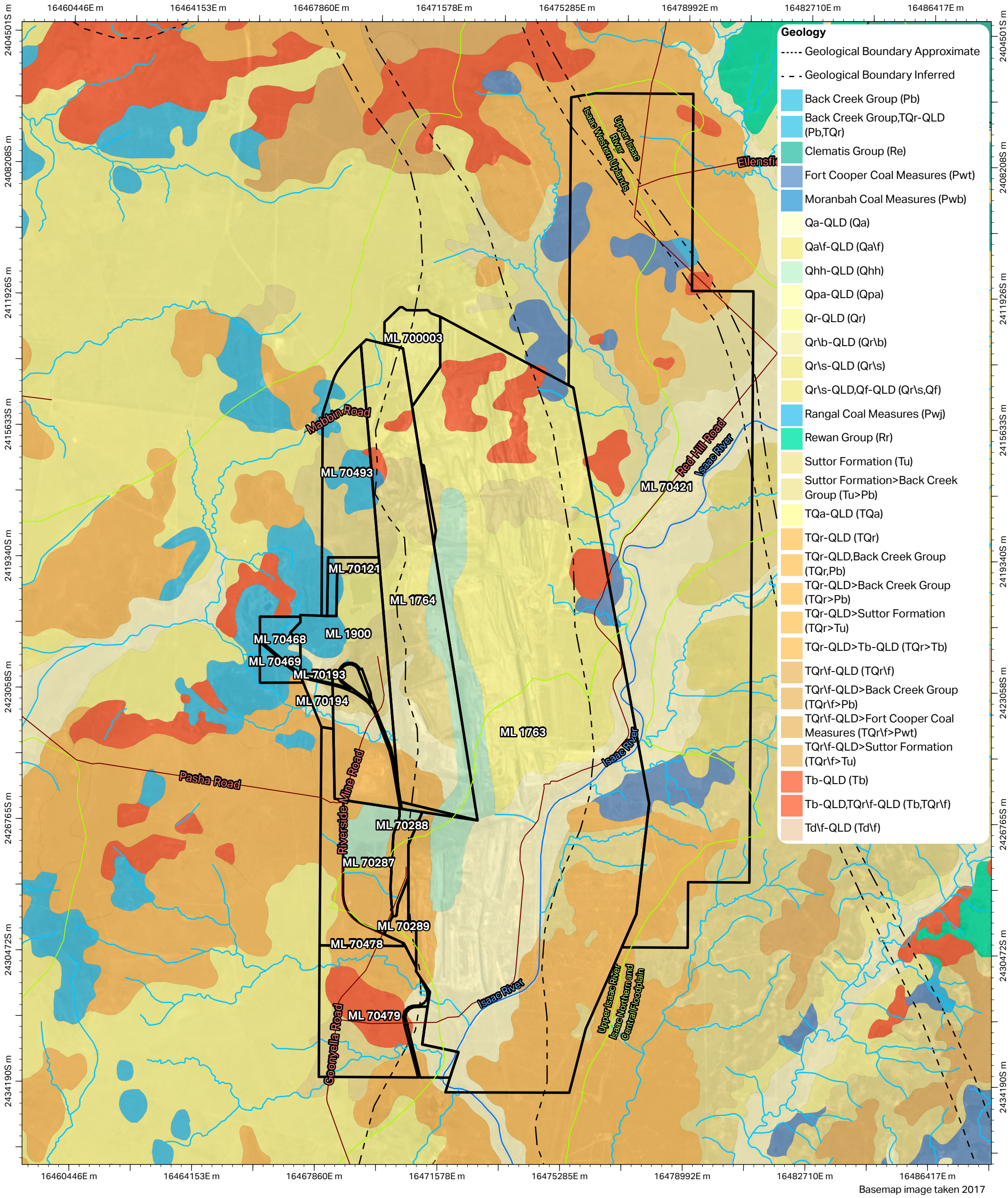

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Surface Geology

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)

GDA 1994 MGA Zone 55

0 1 2 3 km

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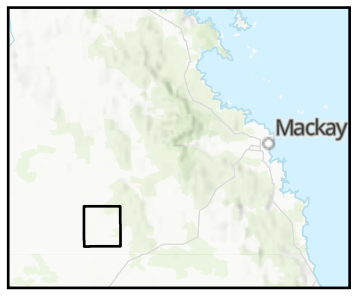

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6.1.5 Basin Closure

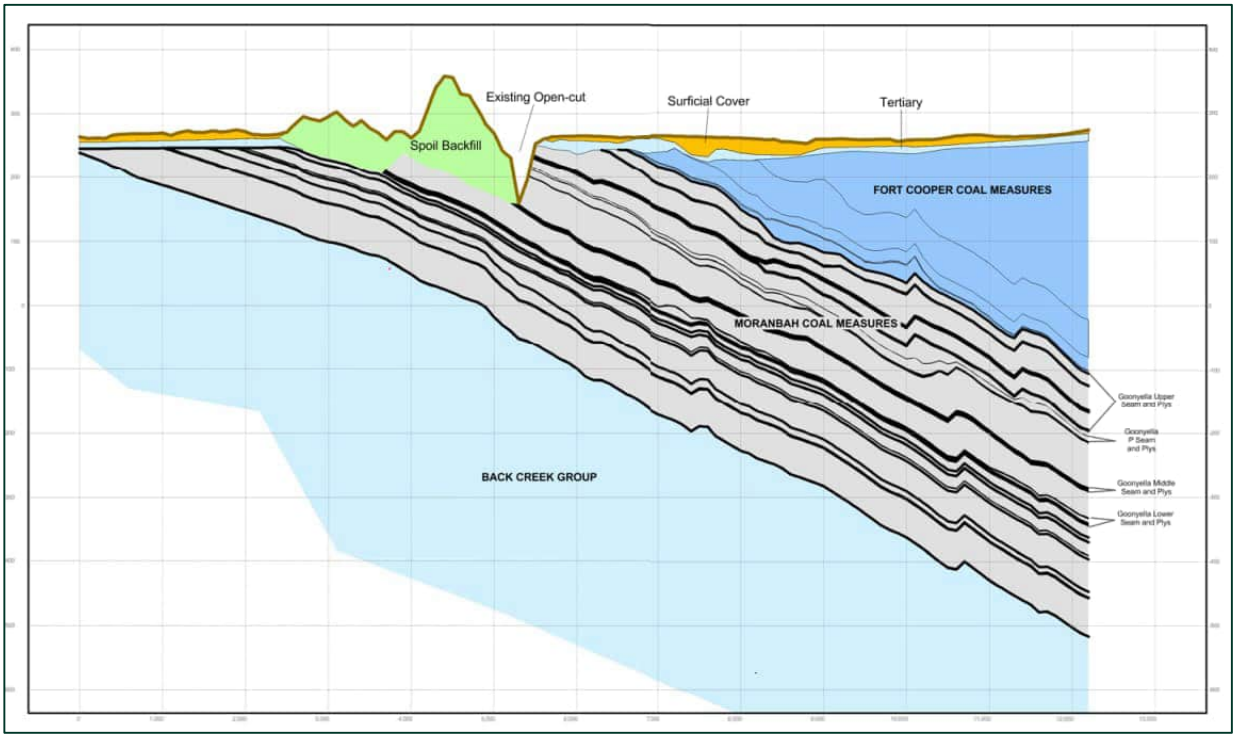
A period of tectonic compression in the Middle to Late-Triassic terminated any further sedimentation within the basin resulting in gentle folding and regional faulting (e.g. The Jellinbah Thrust). The regional area is mantled by an irregular cover of poorly consolidated Tertiary sedimentary strata and basalt (fresh and weathered). The Tertiary cover unconformably overlies the sediments and main coal-bearing units of the Late Permian Blackwater Group.

6.2 Local geology

The geology in the Project area, as included in the geological section, includes (from youngest to oldest):

- Quaternary Alluvium
- Tertiary Suttor Formation
- Tertiary Basalt
- Triassic Rewan Formation
- Permian Coal Measures (RCM, FCCM, MCM)
- Permian Back Creek Group.

Geological section through GRB



6.2.1 Structural description

The regional tectonic setting is mainly characterised as a compressive environment, which led to the development of thrust faults and folds, particularly along the eastern margin. Majority of the thrust faults dip towards the east and propagate into the Permian sediments. The thrust fault system aligns with the northwest-trending synclinal axis of the Basin, as most fault segments trend in a northwest direction, indicating the continuation of earlier basement structures.

The Project area is located on the Collinsville Shelf in the north-west of the Bowen Basin. The Collinsville Shelf is an area that has undergone a period of major deposition and is characterised by low

structural disturbance. Formations dip east at approximately 5° with small-scale and wide-spaced normal and reverse faulting showing small displacement.

The Project area is located approximately 30 km west of the Jellinbah Fault system (also known as the Isaac Thrust Fault system). Jellinbah Fault system represents a major regional structure that extends along a northwest – southeast orientation. The fault is typically steeply dipping, with a significant vertical displacement of throws that range from 100 to 500 m. Individual faults are typically 10 to 80 km long. The vertical displacement has resulted in contact of significantly different geological units.

Approximately 16 km east of the active mines are fault splays that are from the Jellinbah Fault system. These splays have north and northwest orientations. The Jellinbah Fault system splays have resulted in throws within the Permian coal measures of approximately 50 and 100 m.

Igneous intrusions present as dykes and sills are rarely found intruded through coal seams, causing coking and heat-affected coal.

6.2.2 Quaternary Alluvium

The Quaternary alluvial deposits unconformably overlie the Suttor Formation, Tertiary Basalt, and Rewan Formation in places (Figure 7). Quaternary alluvium is comprised of irregular sequences of clay, silt, sand and gravel that have been unconformably deposited in an eroded, valley-fill setting. Alluvium exists predominantly around rivers, creeks, and floodplains. The composition of the alluvium reflects a depositional environment that is dominated by meandering and braided river. The typical thickness of the alluvial deposits is between 15 and 35 m.

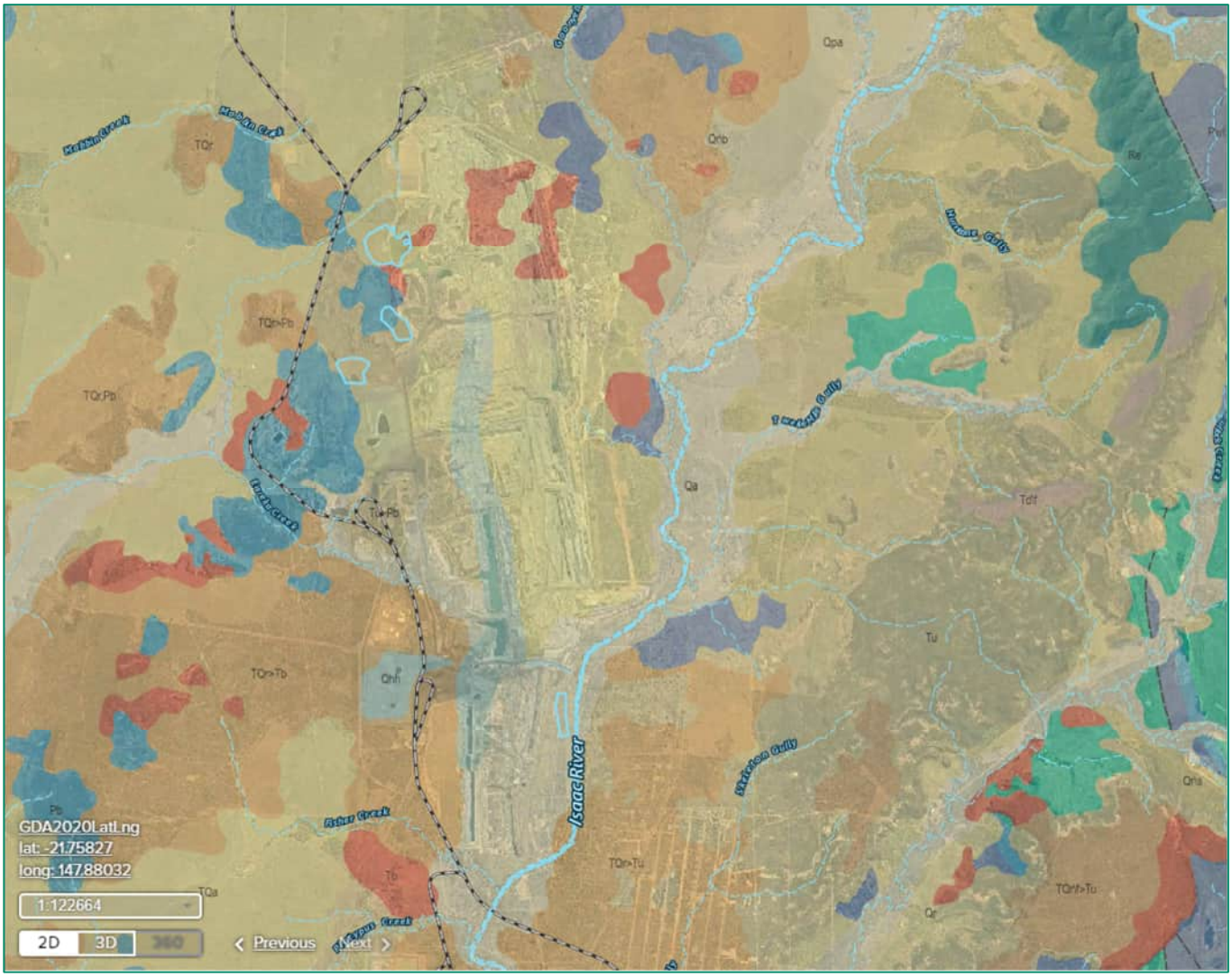
6.2.3 Tertiary age units

Tertiary age units mapped across the Project area (Figure 7) include the Suttor Formation (Tu), which comprises quartz sandstone, conglomerate, and sandy claystone, and the undifferentiated Tertiary sediments. These sediments consist of clay, silt, sand, gravel, colluvium, fluvial, and lacustrine deposits including cross-bedded.

The Tertiary age sediments, mainly colluvium, overlie Permian-Triassic bedrock. The thickness of the Tertiary sediments have an average thicknesses of 15 m. The Suttor Formation is mapped to the east adjacent to the Jellinbah Fault system (Plate 4).

Minor Tertiary age basalt (Tb) is mapped within or adjacent to the Project, as included in Plate 4.

Plate 4 Tertiary basalt (Tb) and Suttor Formation (Tu) within the Project area



6.2.4 Permian Coal Measures

The Permian coal measures comprise, from youngest to oldest, the RCM, FCCM, and MCM. The Blackwater Group is the collective term for these coal bearing units.

6.2.4.1 Rangal Coal Measures

The RCM are comprised of up to 200 m of lithic sandstones, mudstones and at least two discrete coal seams of economic importance. The low ash upper-most Leichhardt seam displays few stone bands and generally lies up to 50 m above the Vermont seam, the latter seam distinct due to the presence of the Yarrabee Tuff, which separates the upper and lower plies. The Yarrabee Tuff is a basin-wide geo-chronological marker; the top of which is often regarded as the base of the RCM formation. Both the Leichhardt and Vermont Seams are subject to splitting and merging.

The RCM sub-crop to the eastern side of the area and dip east to a maximum depth, of approximately 400 m where the formation is juxtaposed the Burton-Jellinbah Fault Zone. Locally net coal thicknesses for the formation can be up to 8.0 m with the Leichhardt seam containing up to 4.0 m.

The RCM overlie the FCCM and comprise both fractured and well-cleated coal seams. The RCM outcrops and subcrops strike generally in a north-south direction, and dip at a shallow angle to the east. The transition between the RCM and FCCM is generally indicated by the Yarrabee Tuff.

The RCM are separated by fine to medium grained sandstone, siltstone, carbonaceous shale, and mudstone layers. These units are competent and effectively limit vertical seepage between coal seams. The FCCM has a thickness range from 25 to 200 m, with the average estimated at 150 m.

6.2.4.2 Fort Cooper Coal Measures

Comprising up to 450 m of interspersed sandstones, mudstones, tuff-bands, and high-ash coaly packages. The coal measures comprise at least seven main seam intervals of variable resource potential. These packages can be up to 80 m gross thickness and consist of a series of thin, high-ash coal bands, stone bands, and carbonaceous units with a low net-to-gross coal ratio.

The FCCM lie directly below the RCM and are contiguous across the Project area. The maximum depth to the top of the formation is approximately 800 m with the Fairhill seam showing most local potential with up to 57 m gross coal thickness.

The FCCM is made up of alternating layers of coal seams, with thin vitrinite-rich coal seams mixed with carbonaceous shale, and are interspersed with tuffaceous sandstone, lithic sandstone, and mudstone. The measures overly the MCM and are regarded as laterally continuous. Outcrops and subcrops of the FCCM are found in the east of the Project area and extend underground, dipping beneath the RCM.

6.2.4.3 Moranbah Coal Measures

The MCM subcrop to the west of the Project area and are contiguous eastwards. The maximum depth to the top of the formation is approximately 700 m. Comprised of Permian sandstones, mudstones and tuffs interspersed with at least six discrete coal seams, the MCM form a 250 m to 350 m thick formation underlying the FCCM. Coal resources relate to regionally continuous GU, P, GM, and GL seams. Together these seams can total a net coal thickness approaching 30 m, with the GM capable of contributing in excess of 10 m.

The MCM are the lowermost coal-bearing sequence of the Blackwater Group and form the key coal resource targeted by BMA. The lithic sandstone, siltstone, mudstone, conglomerate, and coal of the MCM overly the Back Creek Group.

The MCM contains thick coal seams interspersed with several thin minor seams. The main target seams, along with their plies, include the following:

- Goonyella Upper (GU) Seam - The GU seam and its associated splits range in thickness from 2 – 7 m with an average of approximately 3 m in the Project area. It is the equivalent to the Q-seam.
- P Seam - Formed of three main plies, the GP1, GP0, and the GP4, the P-seam package averages approximately 5 m in net coal thickness. The package is rich in tuff bands, most notably the P-tuff, which is recognisable across the basin by its distinctive gamma signature.
- Goonyella Middle (GM) Seam - The GM seam is the thickest coal seam in the MCM averaging 8 m in thickness locally. Thinning of the GM seam is seen to the southeast of the Project area due to seam splitting. The lower half of the seam hosts two tuff bands – the Penny and Tonstein bands.
- Goonyella Lower (GL) Seam - The GL seam is located approximately 50 m below the GM seam. The GL seam has an average thickness of 6 m with characteristic thinning to the south of the exploration area.

6.2.5 Back Creek Group

The Back Creek Group underlies the Blackwater Group, and outcrops immediately west of the Project area. This unit consists of quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite. The consolidated fine-grained sedimentary rocks are considered semi-permeable, acting as a confining layer to the overlying the Blackwater Group.

7.0 Hydrogeology

Based on the understanding of the geological setting presented in Section 6.2, the hydrogeological regime relevant to GRB comprises the following key hydrostratigraphic units with enhanced groundwater potential:

- Quaternary alluvium – unconfined aquifer (sporadic discontinuous water-bearing strata of permeable unconsolidated sand or gravel) localised at and near to GRB along the Isaac River, Eureka Creek, and Goonyella Creek, and more regionally along the Isaac River where it is particularly well developed
- Permian age coal measures:
  - Low permeability interburden units with aquitard properties
  - Coal seams that exhibit water bearing properties associated with secondary porosity through cleats and fracturing.

The coal seams within the MCM are the primary aquifer at GRB. The coal seams can be characterised as confined aquifers (above and below by low permeable interburden), with the GUS, GMS, and GLS forming the main hydrostratigraphic units locally. The MCM overburden and interburden function as aquitards and are typically dry, or low yielding.

This section discusses hydrogeological units, which are recognised to be relevant to GRB closure planning, covering hydraulic properties, groundwater occurrence, hydraulic gradients, recharge, discharge, groundwater quality, and water use.

7.1 Groundwater monitoring network

The GRB groundwater monitoring network comprises a total of 46 monitoring sites. Water levels in 18 of the monitoring bores have not been measured since 2023.

The monitoring network was established in 2012 as part of the Red Hill mining project approvals study (URS, 2013) the context of supporting further environmental approvals. The network's monitoring bores intersect a range of hydrostratigraphic units, including:

- Alluvium
- Tertiary
- MCM
- Back Creek Group

Groundwater monitoring data compiled between 2012 and 2020 has been lost due to monitoring data corruption. Groundwater monitoring data across the monitoring bore network, augmented and revised overtime, has been compiled regularly since 2020. The locations of the current monitoring bore network are shown on Figure 8.

It is noted that the RHM groundwater model was constructed and calibrated based on available geological and groundwater data available up to 2013. The resultant model report is included in **Appendix A** to provide additional details of the available data used for the RHM groundwater model. The model report includes the location of bores used for geological and hydrogeological data.

The PRC Plan refinement of the model, using transient data from 2020 to 2024, allowed for the conceptualisation of groundwater conditions, influence of approved mining, and the transient calibration of the model. The model was then, with the use of uncertainty analysis, used to predict post-closure groundwater conditions.

Figure 8 GRB groundwater monitoring bore network

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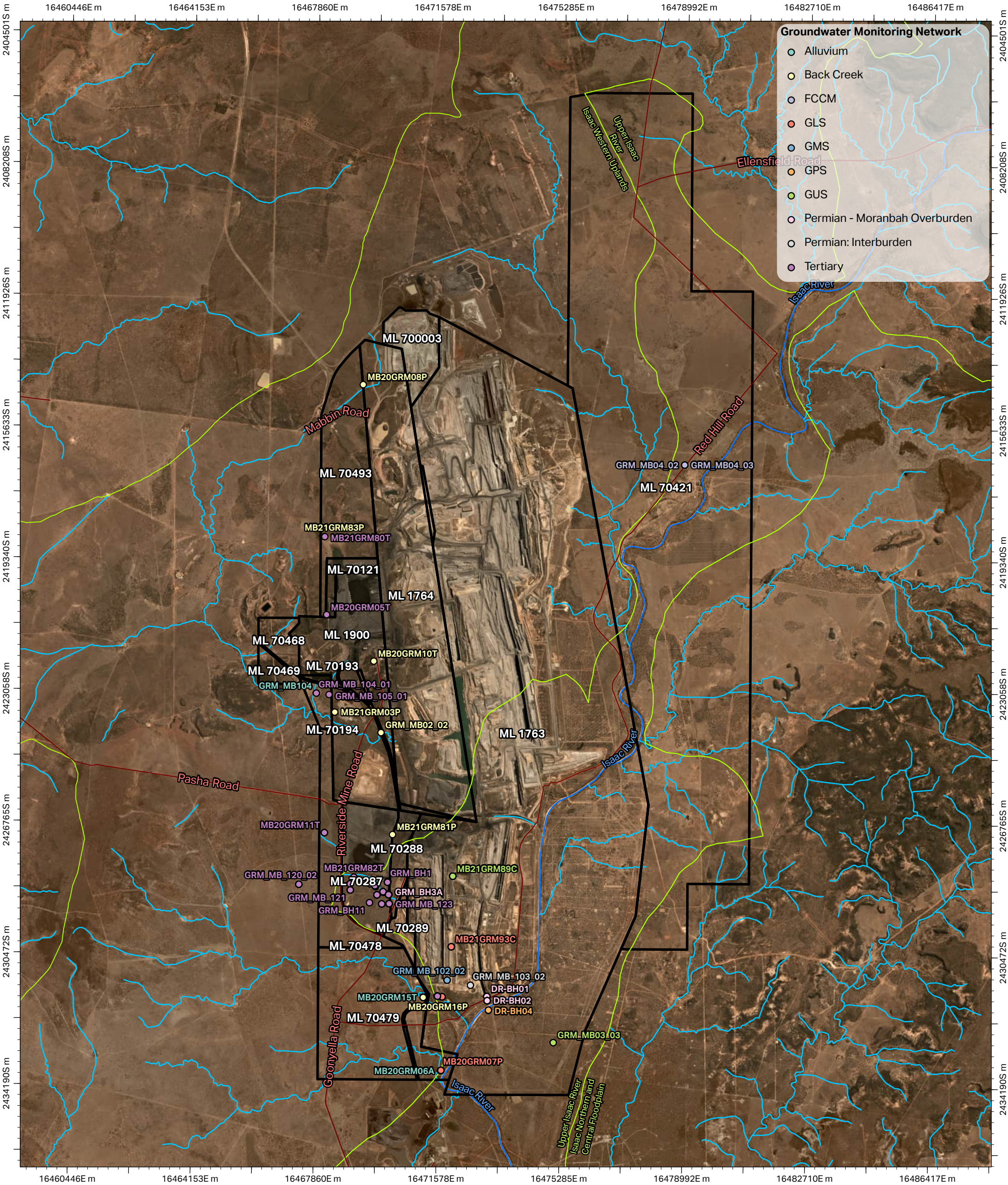

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Groundwater Monitoring Network

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)

GDA 1994 MGA Zone 55

0 1 2 3 km

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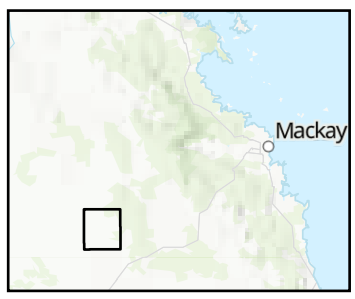

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7.2 Hydraulic conductivity

GRB groundwater hydraulic testing included slug (rising and falling head) tests, packer tests and stress and permeability tests performed on monitoring network bores across the Project area. This section presents a summary of the available site-specific hydraulic data.

7.2.1.1 Quaternary alluvium

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 provided a hydraulic conductivity value of 0.001 metres per day, typical for silty clay (URS, 2013).

The most recent tests across the Project area were undertaken between 2022 and 2024, and involved rising and falling head slug tests. Testing revealed a hydraulic conductivity range between 5×10^{-8} to 0.12 m/day.

7.2.1.2 Tertiary 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 (m/day) obtained from the variable (falling) head test at the Airstrip Pit (IESA 2001a) is low, indicating predominantly clay intersected within this area (URS, 2013).

Past tests performed in the sandstone/siltstone, sands and clays of the Tertiary Formation indicated a hydraulic conductivity range of 2×10^{-7} to 24.6 m/day. The hydraulic conductivity of 24.6 m/day is atypical, as it was the sole one that was exceedingly high.

7.2.1.3 Permian coal measures

Interpreted hydraulic conductivity values estimated from the MCM 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 MCM and FCCM. This study found a relationship for permeability variation with depth, ash, and gas content as part of this study that resulted in the ranges of hydraulic conductivity to be (URS 2013):

- GMS 0.009 to 0.1 m/day
- GLS 0.06 to 0.82 m/day
- Interburden 9×10^{-7} to 9×10^{-5} m/day.

Note: No GUS testing was conducted by WDS in 2011.

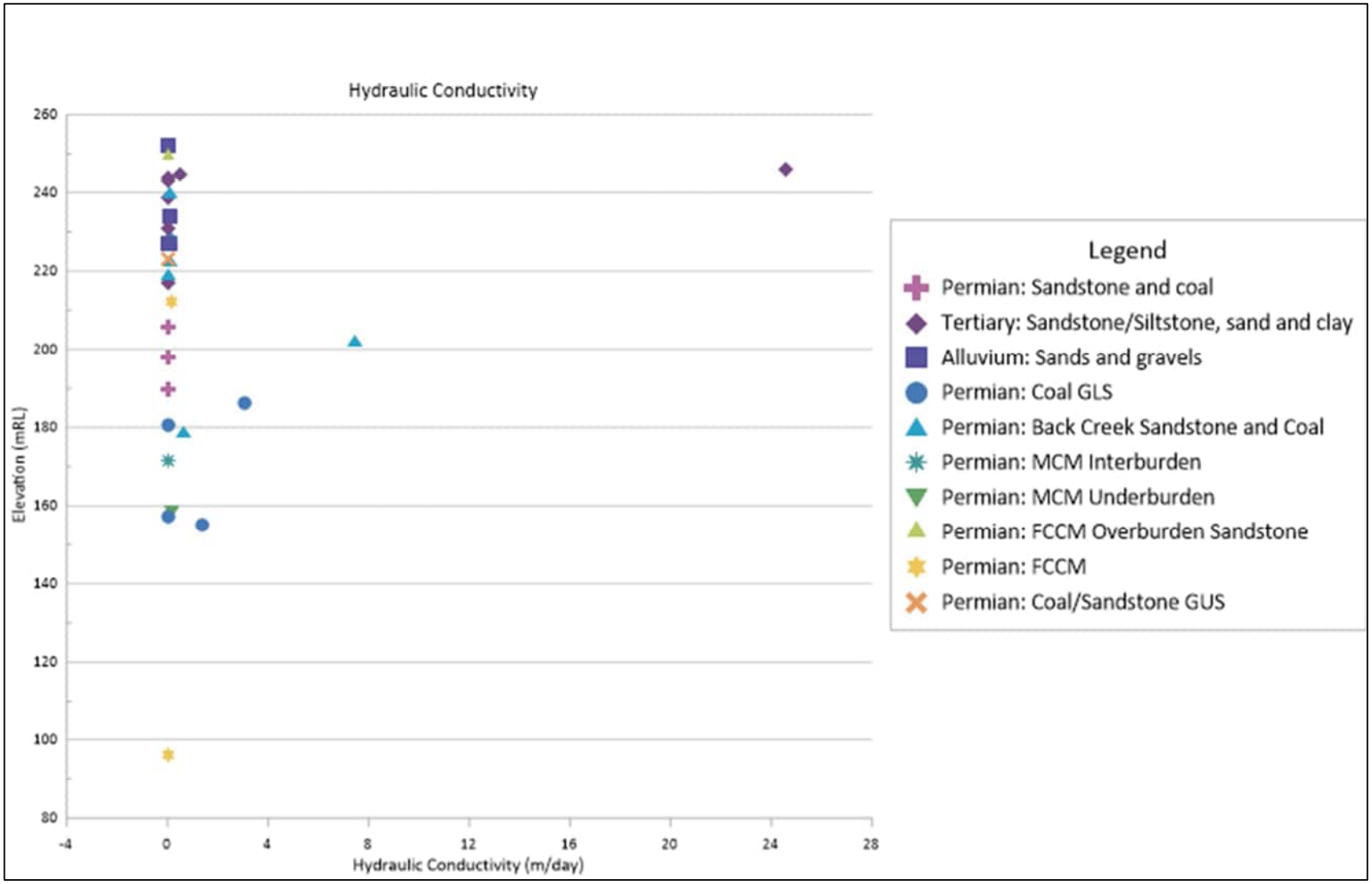
The hydraulic conductivity of the MCM that were tested between 2020 and 2024 across the Project area was variable and indicating a decrease with increasing depth, corroborating previous studies conducted in the MCM coal seams.

The MCM testing revealed hydraulic conductivity estimates:

- Overburden between 6 x 10^{-4} and 5 x 10^{-2} m/day
- GUS and GMS were estimated at 0.02 m/day
- GLS ranged from 7x10^{-7} and 3 m/day.
- Interburden and underburden at 1 x 10^{-5} and 2 x 10^{-2} m/day, respectively.

Testing data from 2020 to 2024 is summarised in Figure 9.

Figure 9 Summary of hydraulic data



7.3 Groundwater distribution, flow, recharge, discharge

7.3.1 Quaternary alluvium

7.3.1.1 Distribution and flow

Quaternary alluvial deposits in the survey area occur predominantly within the Isaac River floodplains as shown in Figure 7 (labelled Qa-QLD). Along the Isaac River these deposits consist of clay, silt, sand and gravel, to a depth of up to 37 metres, as historically recorded in monitoring bore GW1 and exploration bore 43840 (Plate 5).

Investigations into the Isaac River alluvium at the Moranbah North Mine (located immediately to the south of GRB) 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 GW8, with no alluvium present at GW7. The historic monitoring and exploration bores are included in Plate 5.

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 and monitoring on site indicates that, where groundwater does occur, depth to groundwater in the Quaternary alluvium is approximately 3 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 piezometric (confined) water level in the coal at the same location. These groundwater levels indicate a marked separation between the alluvium water table and the piezometric levels associated with the deeper coal seam aquifer groundwater (i.e., there is no hydraulic connection between the alluvium groundwater and the confined aquifers). It is, thus, unlikely that changes in piezometric levels in the coal would markedly impact on the water table associated with the alluvium.

Owing to the paucity of data for the Quaternary alluvium (Figure 10 and Figure 11), limited information exists regarding groundwater flow. However, regionally groundwater flow within the alluvium follows topography and drainage patterns.

Plate 5 Historic monitoring and exploration bores

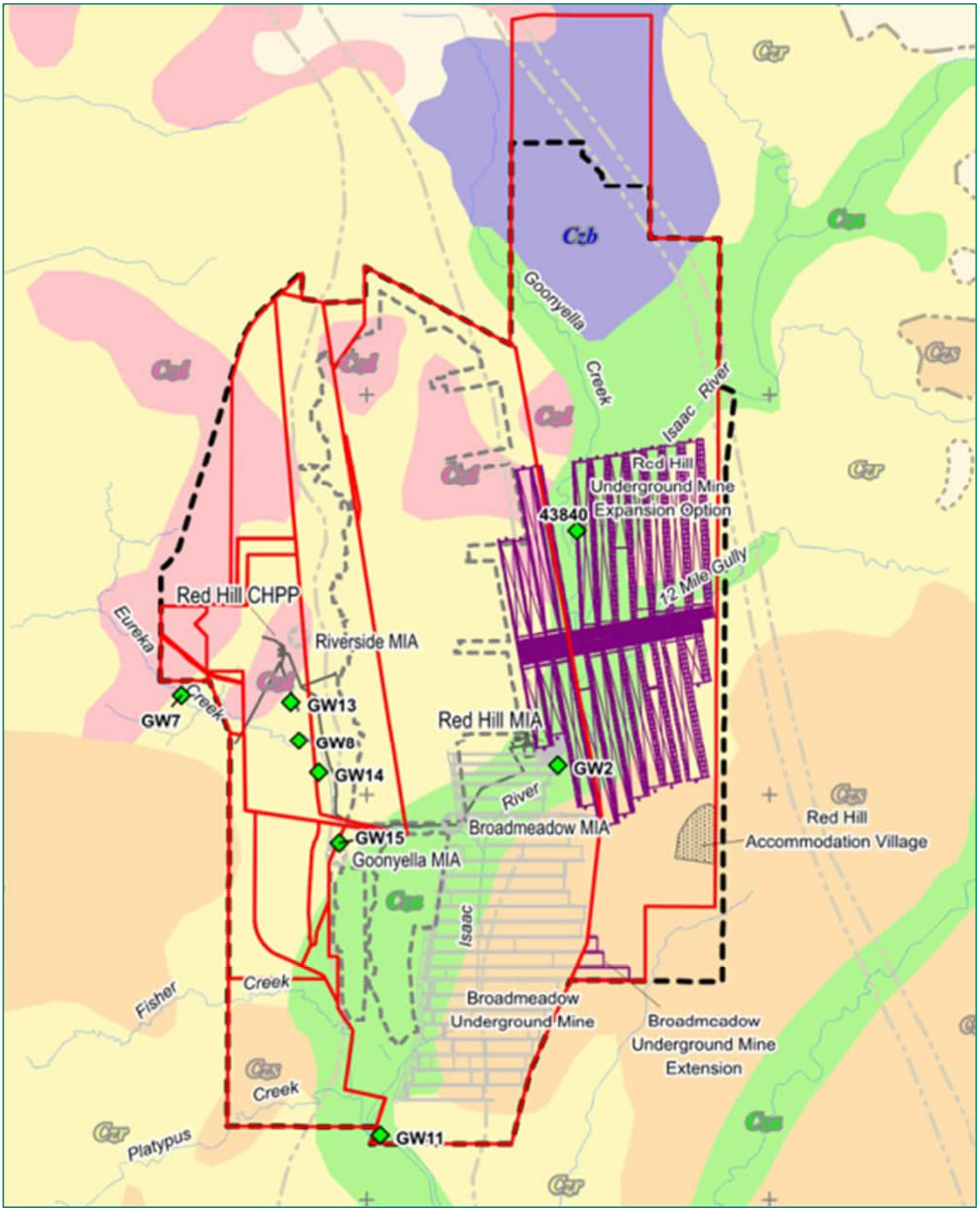
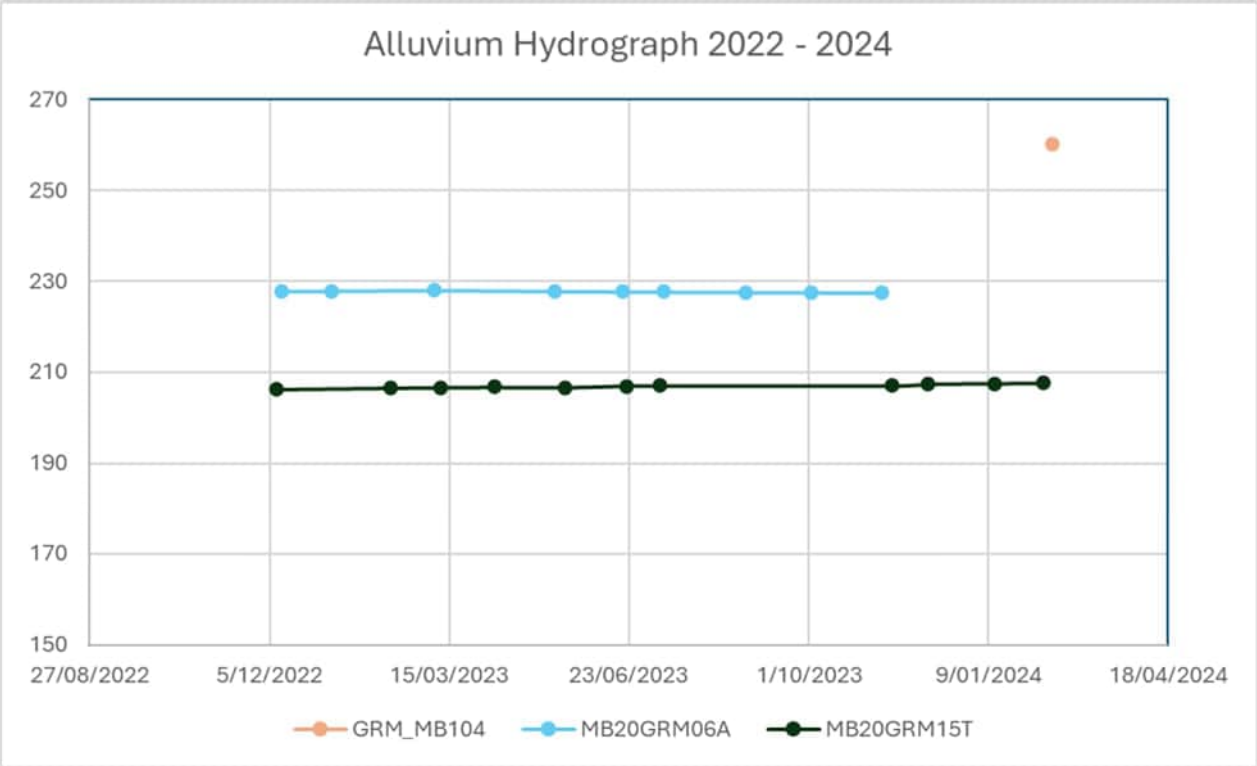


Figure 10 Hydrograph of alluvial groundwater trends



Notes:
GRM_MB104 water level is 8.86 mbgl
MB20GRM06A water level is around 9.5 mbgl, bore is 13.35 m deep
MB20GRM15T water level is on average 4.5 mbgl, bore is 7 m deep

Figure 11 Alluvium groundwater elevations

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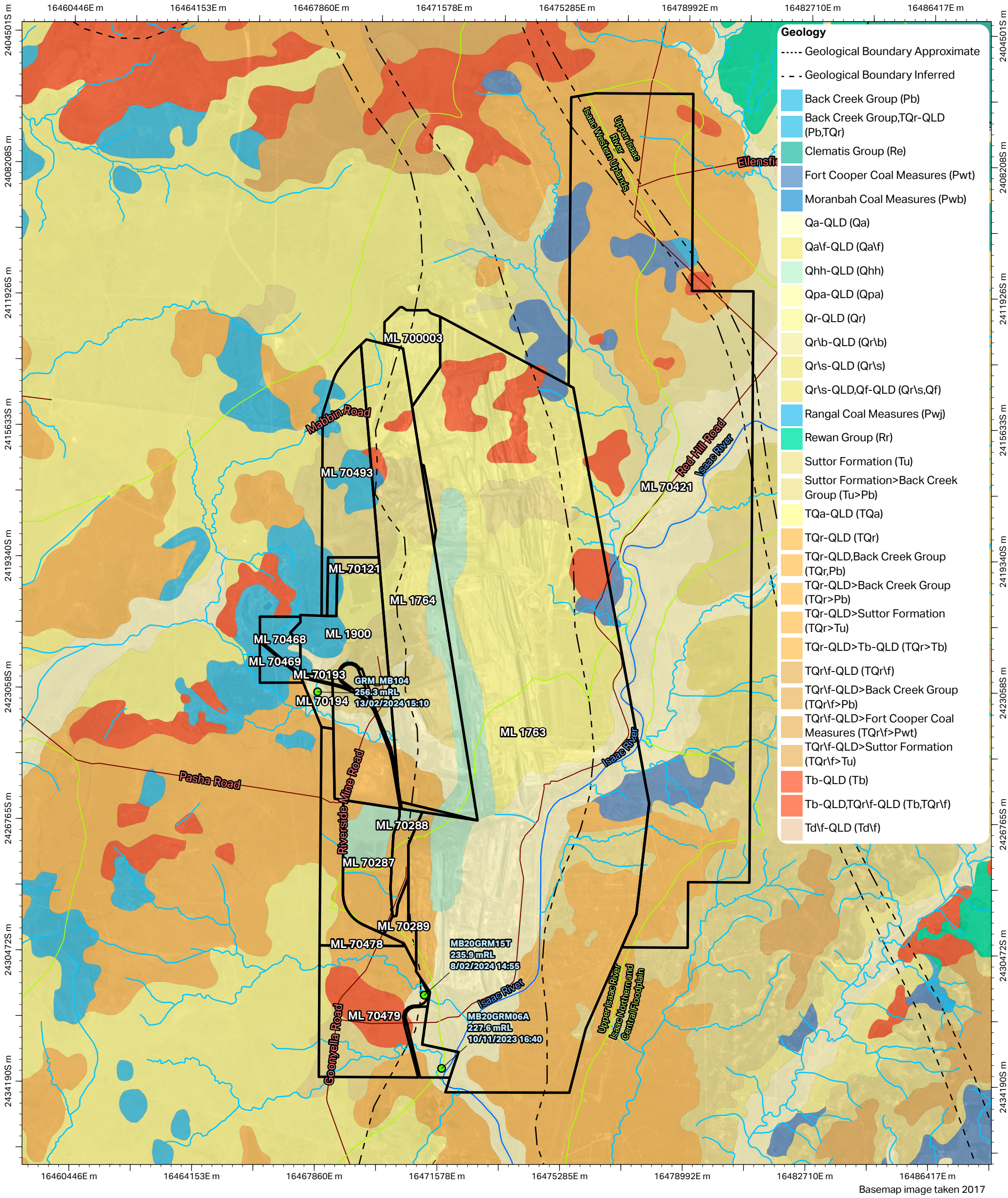

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Alluvium Groundwater Elevations

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)
- Monitoring Bore - Alluvium

GDA 1994 MGA Zone 55

0 1 2 3 km

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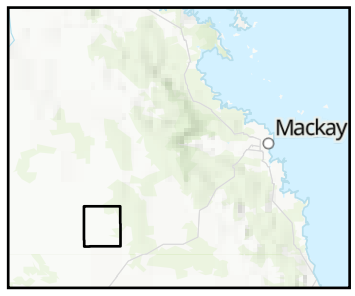

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7.3.1.2 Recharge and discharge

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, 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 at the Project are ephemeral and recharge of the alluvium is by:

- Losses from surface water flow or flooding (losing system)
- Direct rainfall and overland flow recharge, 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. The available transient groundwater level data, Figure 11, indicates saturation is sporadic and can produce semi-permanent, localised, thin, aquifers. The groundwater level data does not indicate marked variation in dry/wet seasons (noting limited manual data measurements), which could indicate isolated pockets of water not readily recharged or discharged.

Groundwater discharge from the alluvium occurs through:

- Evapotranspiration from vegetation where depth-to-groundwater is shallow, such as in the creek beds and along the banks
- Short duration baseflow from the permeable sands and gravels within the alluvium material.

Infiltration and recharge to the underlying older formations underlying the creeks is not evident based on the marked hydraulic disconnect between the depth to water in the alluvium and the confined piezometric levels associated with the confined coal seam aquifers (Section 7.3.1.1).

Surface water loss, via the alluvium, to the longwall mining panels (goaf and subsidence related) is discussed in Section 13.3.6.1.

During a ground penetrating radar 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.

7.3.2 Tertiary Formation

7.3.2.1 Distribution and flow

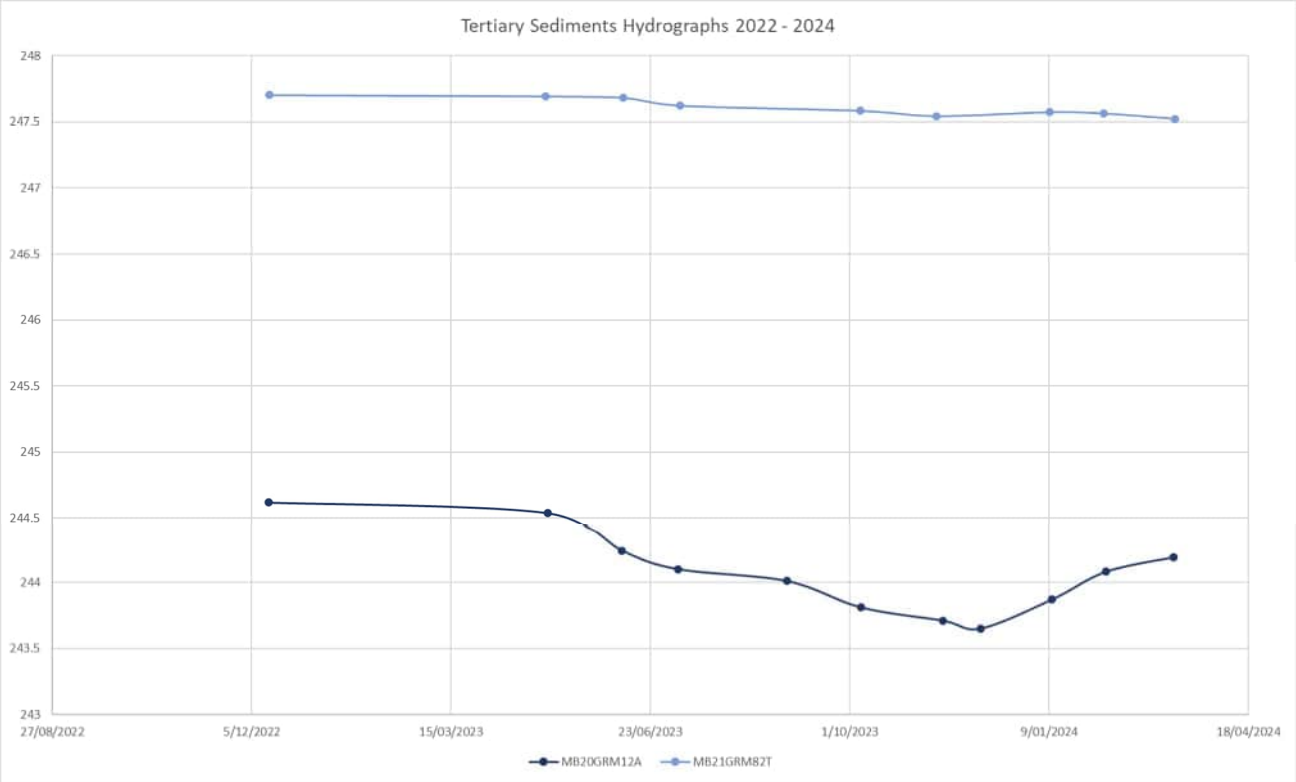
The undifferentiated Tertiary sediments and Suttor Formation is mapped across the Project area, noting that the mapped outcrop is not continuous. In areas where the Tertiary units are eroded inliers of older Permian rocks are mapped. In other locations the Tertiary units are concealed by younger alluvium.

The undifferentiated Tertiary sediments can occur as lenses of paleochannel gravels and sands separated by sandy silts, sandy clays and clays. A review of the borehole logs showed the undifferentiated Tertiary sediments vary in thickness up to approximately 80 metres with a typical thickness of up to 15 m.

Groundwater level in the Tertiary deposits was measured to be around 10 mbgl, deeper and hydraulically disconnected from the alluvium (as detailed in Section 7.3.1). There is also a distinction between the semi-confined to confined Tertiary and the coal measures potentiometric levels indicating a separation (hydraulic disconnect) between these hydrostratigraphic units.

In the Tertiary units, groundwater flow mimics topography and drainage systems.

Figure 12 Hydrographs of Tertiary Formation groundwater elevation



MB20GRM12A has an average depth-to-water of 9.4 mbgl, bore depth 18 m
MB21GRM82T has an average depth-to-water of 10.9 mbgl, bore depth 29.3 m

Additional groundwater level data for the Tertiary sediments was obtained from monitoring bores constructed across the Project area. These bores have limited geological data but bore depths and locations, plus the use of geological contact data, allowed for the identification of monitoring bores constructed within the Tertiary sediments. These monitoring bores plus groundwater elevation data is included in Figure 13.

Figure 13 Tertiary groundwater elevations

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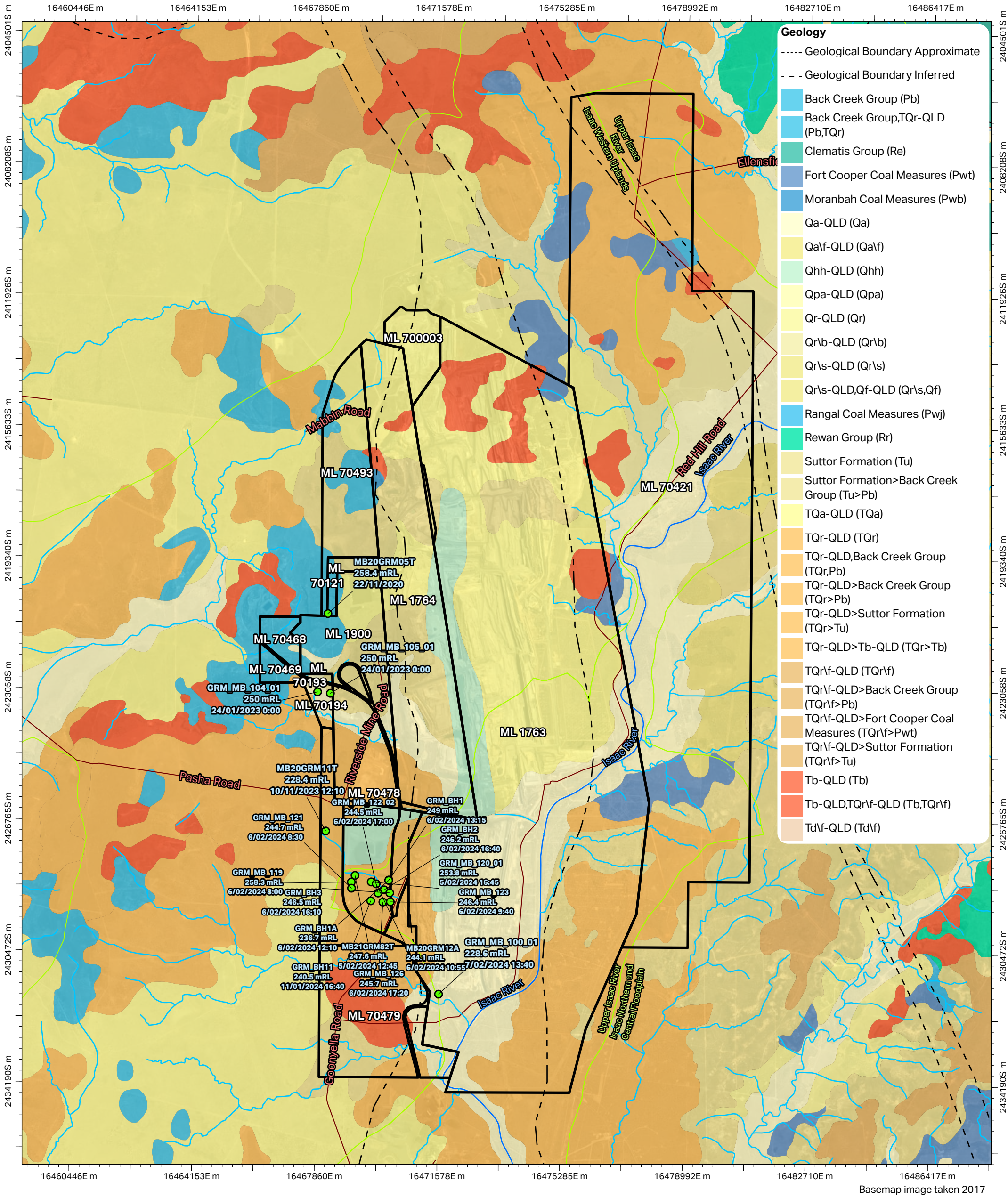

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Tertiary Groundwater Elevations

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)
- Monitoring Bore - Tertiary

GDA 1994 MGA Zone 55

0 1 2 3 km

1:100,000

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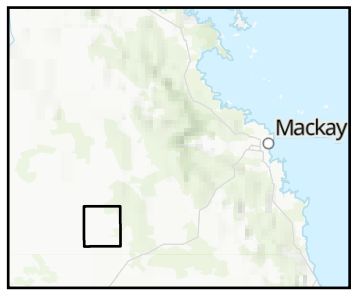

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7.3.2.2 Recharge and discharge

Potential for groundwater exists within the more permeable sand and gravel sections of the Tertiary sediments, and represents a semi-confined to confined aquifer depending on location, degree of weathering, the nature of the overlying alluvium, and clay content, as recognised in the transient groundwater level data included in Figure 12.

Recharge mechanisms include:

- Direct infiltration of rainfall
- Overland flow / ponding where Tertiary sediments outcrop and no substantial clay barriers exist in the subsurface

Little or no recharge from overlying Quaternary alluvial aquifers is identified. Groundwater elevation data for MB20GRM15T at 235.9 mAHD (Figure 11) and GRM_MB_100_01 at 228.6 mAHD (Figure 13), located in proximity to each other, indicates a marked separation (7.3 m) between the two hydrostratigraphic units (i.e., no hydraulic connection between the alluvium water table and the semi-confined Tertiary sediments).

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

- Through flow
- Evapotranspiration
- Groundwater extraction.

7.3.3 Permian – Triassic strata

The Permian-Triassic formations within the Project area comprise the two Permian formations, which are the Blackwater Group (which contains the MCM, FCCM, and RCM) and the Back Creek Group. These units are included on Figure 6. 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). The MCM coal seams, GLS, GMS and GUS, constitute the most extensive aquifers at the Project.

The coal seam aquifers are confined above and below by low permeability geological formations (Section 7.2.1.3) 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 low vertical hydraulic conductivity (leakance), such that water flows into the aquifer (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 primary water bearing strata within the Permian sequence.
- Localised fracture or fault systems which are open and have not been infilled by clay/carbonate deposition.

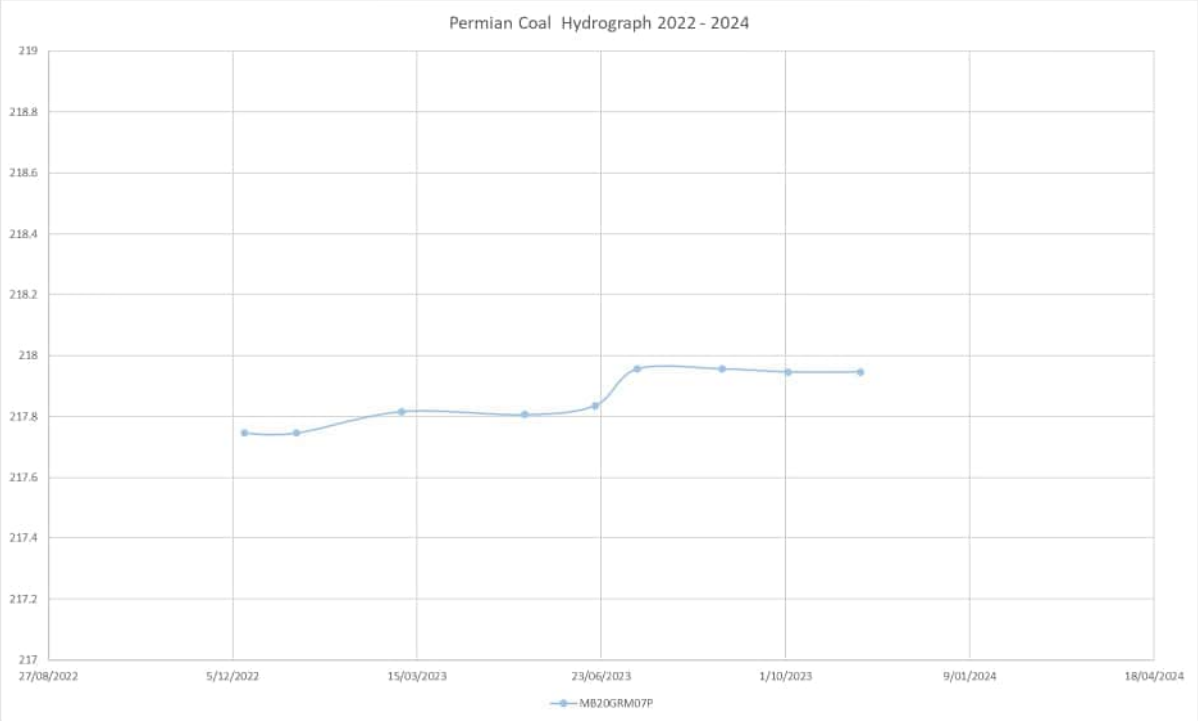
Groundwater levels in the Permian formations have historically been measured during hydrogeological investigations at the Project and used for assessing potential inflows to pits and underground workings. Other studies included the establishment of boxcut or pit dewatering bores for mine design and production purposes (AECOM, 2013). Evidence from piezometric observations for the coal seam aquifers during these previous investigations suggests the groundwater levels were 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 (i.e., no hydraulic connection between the coal seams due to interbedded aquitards). This variation in hydraulic heads between coal

seams indicates limited potential for induced flow. The piezometric levels in the coal seams varied from 15 to 69 mbgl.

Prior to development of the GRB mine complex operations, groundwater flow direction in the coal seam aquifers in inferred to have been from the north and west to the south and east across the site. This flow direction is based on recharge to the coal seams occurring at the subcrops in the west and north of the site and discharge occurring downgradient in the Isaac River sub-basin. The current (2020 to 2024) groundwater flow patterns have been altered locally with groundwater flow towards the existing mine pits and underground workings due to mine dewatering and depressurisation.

Recent transient groundwater level data for Permian coal within the Project area is available for MB20GRM07P, included in Figure 14. The average groundwater depth was 18.1 mbgl (±0.2 m) and the bore depth is 85 m.

Figure 14 Transient groundwater level data for Permian coal



The most recent available groundwater level elevation data for the Permian GMS and GLS, across the Project area, are included in Figure 15 and Figure 16, respectively.

Groundwater elevation data in the area containing the Quaternary alluvial monitoring bore MB20GRM15T indicates the following:

- Alluvium water table at 235.9 mAHD (Figure 11)
- Tertiary sub-artesian potentiometric level of 228.6 mAHD at GRM_MB_100_01 (Figure 13)
- Permian GMS groundwater elevation of 187.5 mAHD in GRM_MB_102.02 (Figure 15)
- Permian GLS groundwater elevation of 215.7 mAHD in MB20GRM18P (Figure 16).

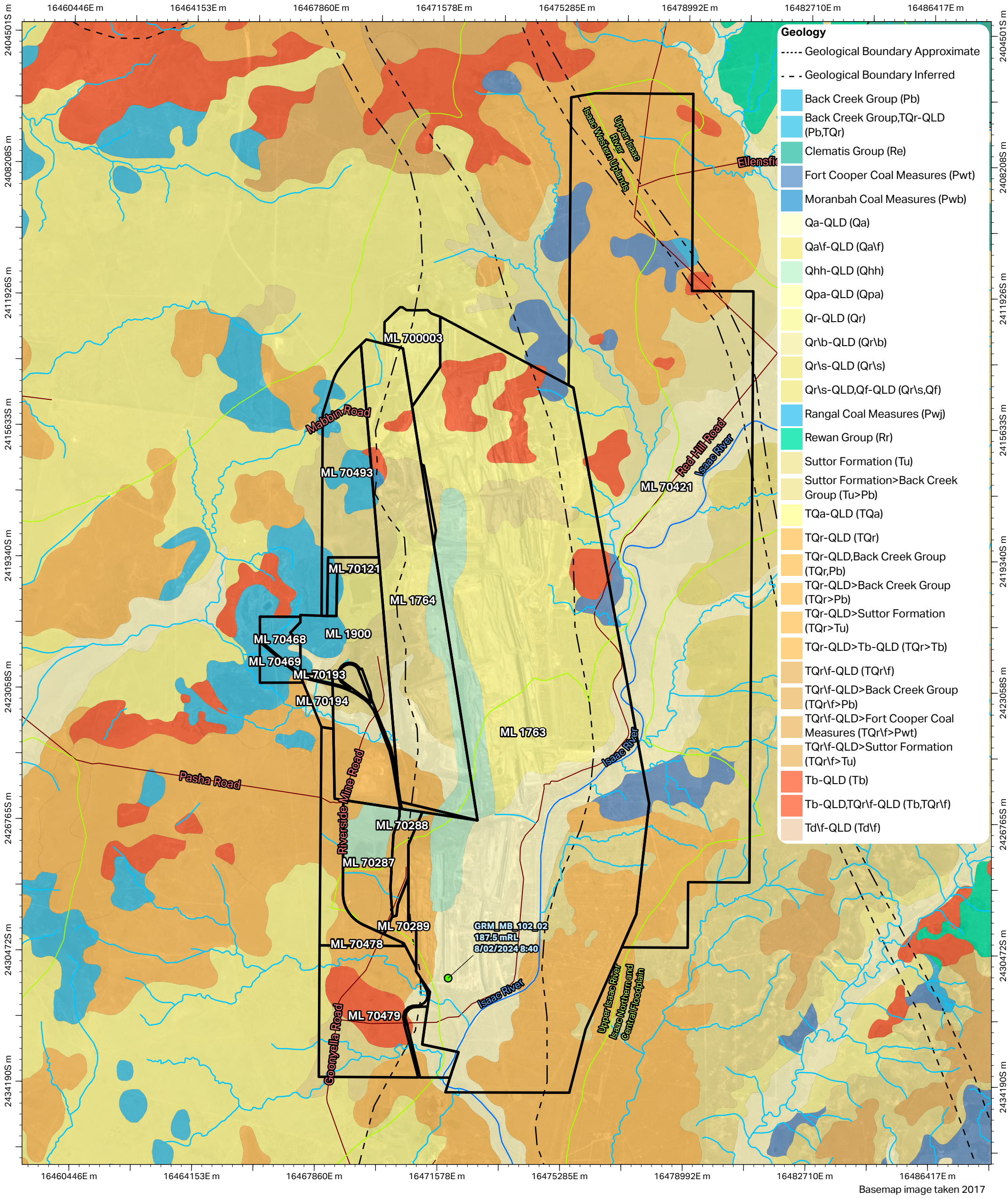
These data indicate:

- No hydraulic connection between the different hydrostratigraphic units
- Confining aquitards above and below the coal resulting in different potentiometric levels associated with the coal seams
- Upward vertical groundwater gradients from GLS to GMS
- Vertical downward groundwater gradients from alluvium, to Tertiary, to Permian coal

- Marked separation between the Tertiary and the Permian units, even with an upward vertical groundwater gradient within the coal seams.

Figure 15 GMS groundwater elevations

See overleaf for Figure 15



Goonyella, Riverside and Broadmeadow Mines

GMS Groundwater Elevations

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)
- Monitoring Bore - GMS

GDA 1994 MGA Zone 55

0 1 2 3 km

1:100,000

AECOM

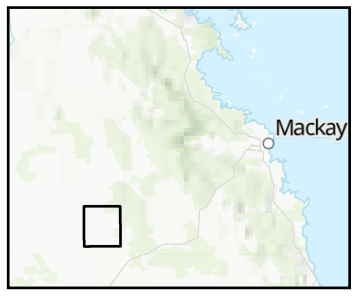


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Figure 16 GLS groundwater elevations

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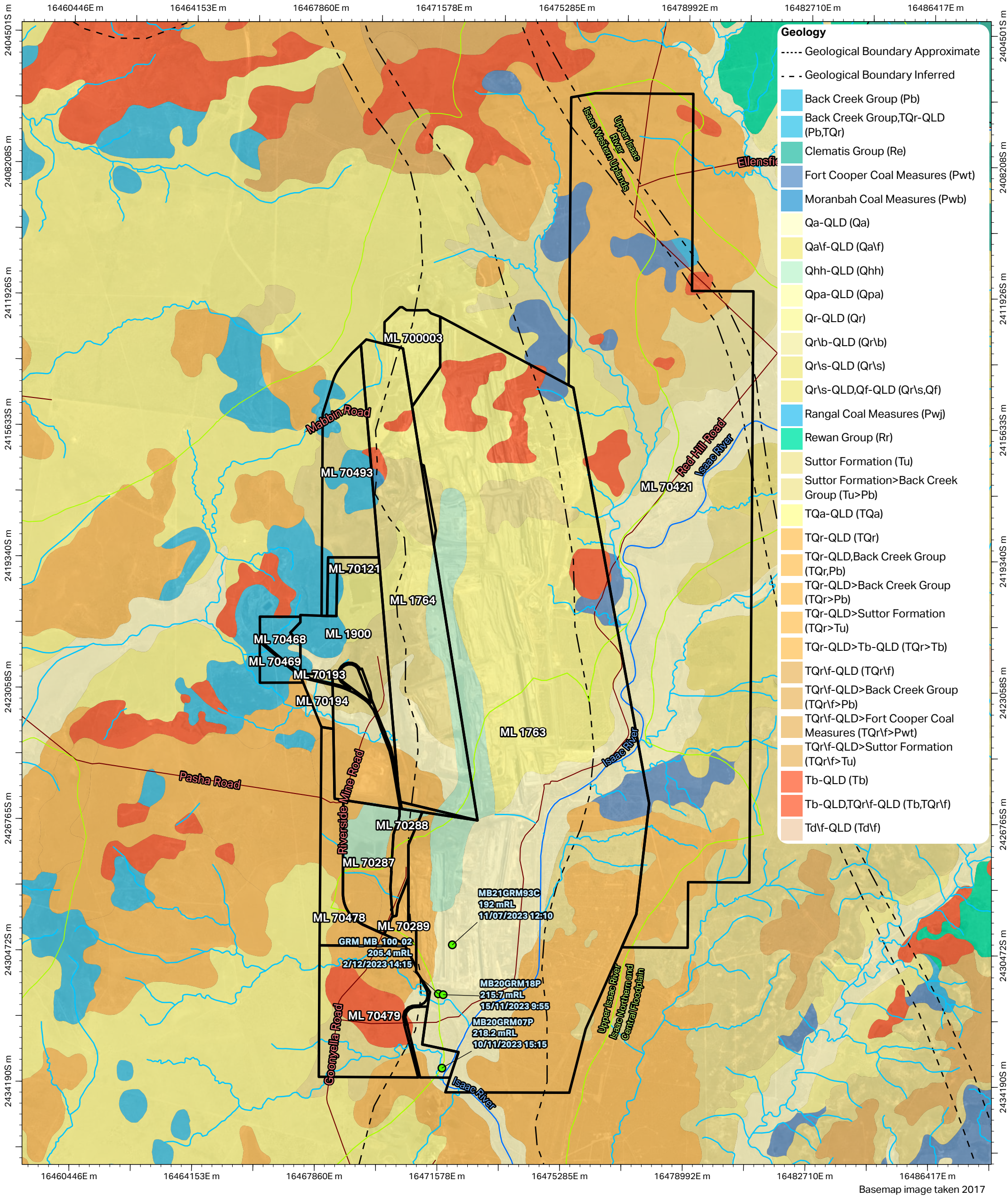

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

GLS Groundwater Elevations

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)
- Monitoring Bore - GLS

GDA 1994 MGA Zone 55

0 1 2 3 km

1:100,000

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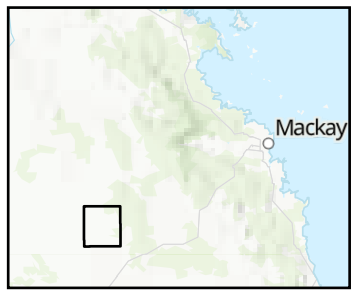

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7.3.3.1 Distribution and flow

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 north and west and discharge occurring downgradient in the Isaac River sub catchment 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.

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.

7.3.3.2 Recharge and discharge

Groundwater recharge in the coal seam aquifer occurs from:

- Infiltration of rainfall and overland flow in outcrop and sub-crop areas
- Leakage between aquifers by faulting and other structural discontinuities in overburden and interburden sediments.

Downward seepage or vertical flow from overlying alluvial or tertiary aquifers is not recognised, based on vertical groundwater elevation data, to occur.

Primary discharge mechanisms in the Permian-Triassic strata include:

- Dewatering for mine progression
- Downgradient flow within the Permian-Triassic strata away from the outcrop areas
- Possible movement to other hydrostratigraphic units / coal seams via structural discontinuities.

7.3.4 Underground mining influencing groundwater flow

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, resulting in aquifer alteration due to the goaf. 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 zones 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.

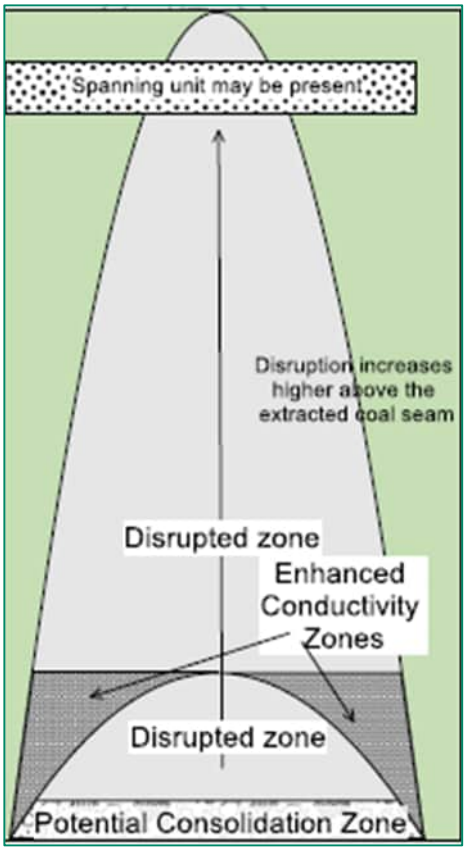
Unfortunately, the location of existing bores with groundwater level data, included in Figure 8, are not within or immediately adjacent to the Broadmeadow underground mine panels. The lack of alluvium, Tertiary and Permian groundwater level data at the Broadmeadow underground mine does not allow for the evaluation of possible vertical hydraulic connection due to longwall mining. The influence of the longwall mining was, however, assessed using geotechnical modelling.

7.3.4.1 Longwall modelling

BMA appointed Byrnes Geotechnical to undertake a geotechnical study is required to provide assessment of possible hydraulic conductivity and porosity changes due to BMA longwall and pillar extraction mining (Byrnes Geotechnical, 2024). This draft study reviewed historic approaches to estimating alteration to aquifer hydraulic properties based on geotechnical modelling, a review of previous studies and finds, allowing for a revised conceptualisation of alteration. The report is included in **Appendix B**.

The resultant geotechnical model derived from the Byrnes Geotechnical study, depicted in Plate 6, indicates differing zones of alteration above the panels. The shape and extent of these zones is markedly different to previous simulations of alteration adopted in groundwater modelling.

Plate 6 BMA longwall and pillar extraction mining geotechnical model



The BMA longwall and pillar extraction mining geotechnical model considers:

The simple triangular shape(Plate 7) of the disrupted zone is replaced by a parabolic shape following some numerical analysis of failure in bedding rock masses.

It is noted that:

- The height of the disrupted zone is a function of the average thickness of the bedded units in the overburden. The default height is two times the extraction width which is equivalent to the panel geometry that represents the step from subcritical to supercritical.
- The enhanced conductivity zone (ECZ) geometry is based on the D zone angles (Figure 17), with overall shape defined by two parabolas. The ECZ is the locus for high inflows.
- If the surface subsidence developed between adjacent chain pillars was more than 400 mm, then there would be a fracture connection, albeit possibly tortuous, between the surface and the underground workings.

Plate 7 Triangular conceptual inflow model (Younger, 2011)

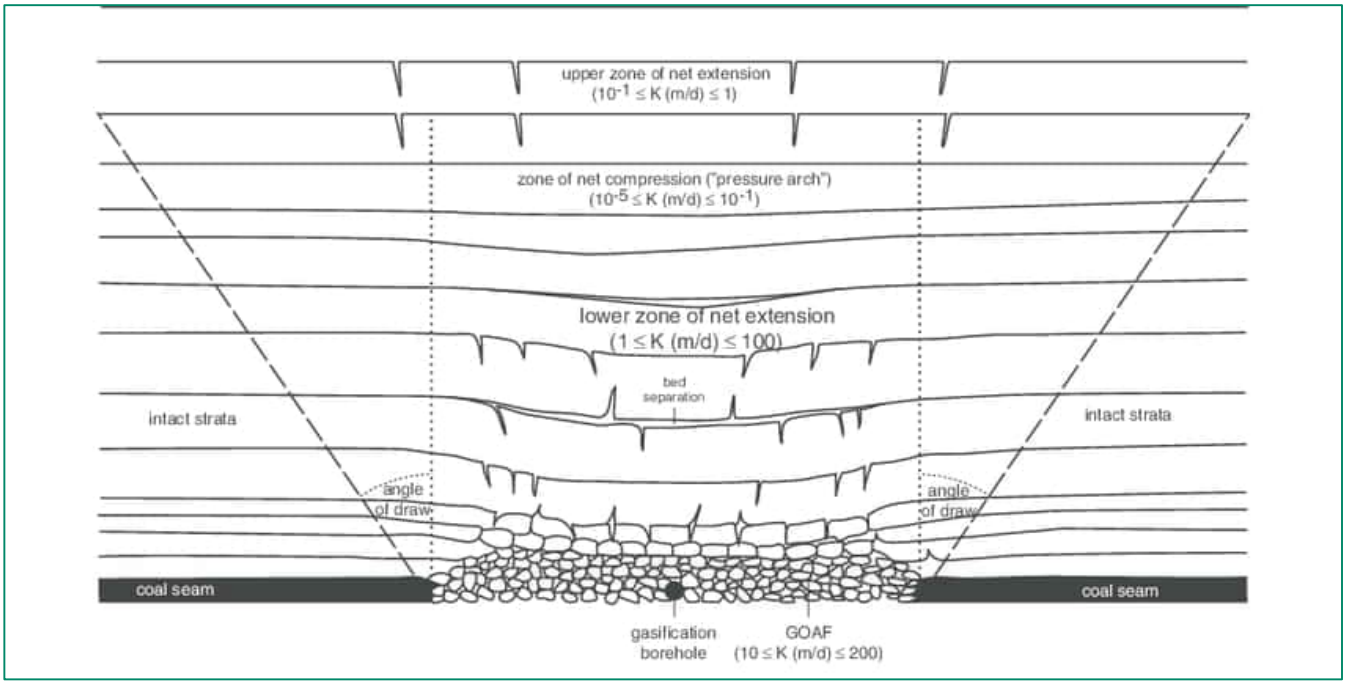
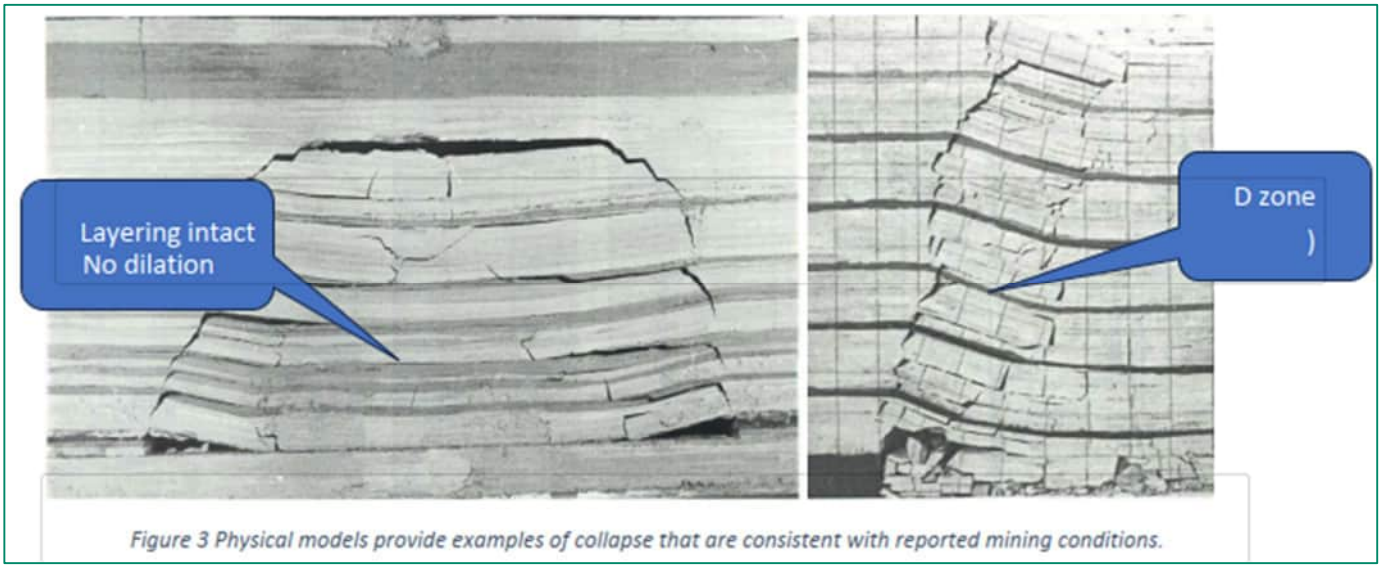


Figure 17 Physical model showing alteration shape and collapse



7.3.4.2 Alteration due to longwall mining

The Geotechnical model provides a basis for the prediction of hydraulic conductivity associated with the supercritical longwall geometry of the BMA longwall operations. It's important to note that there is no validation of the method available and Brynes geotechnical notes that is would be difficult to undertake given the large volume of longwall mining.

Mine inflows are not useful in this context as they are most likely related to the ECZ and not the larger disrupted zone and there is the problem of the low conductivity in the potential consolidated zone (PCZ).

The Geotechnical model is applicable to the Permian and Tertiary sequences but does not include the possible role of Quaternary alluvium and surficial cover.

Output from the Geotechnical Model includes the conductivity changes up to twice the excavation width, such that it can be sliced at any actual mining depth.

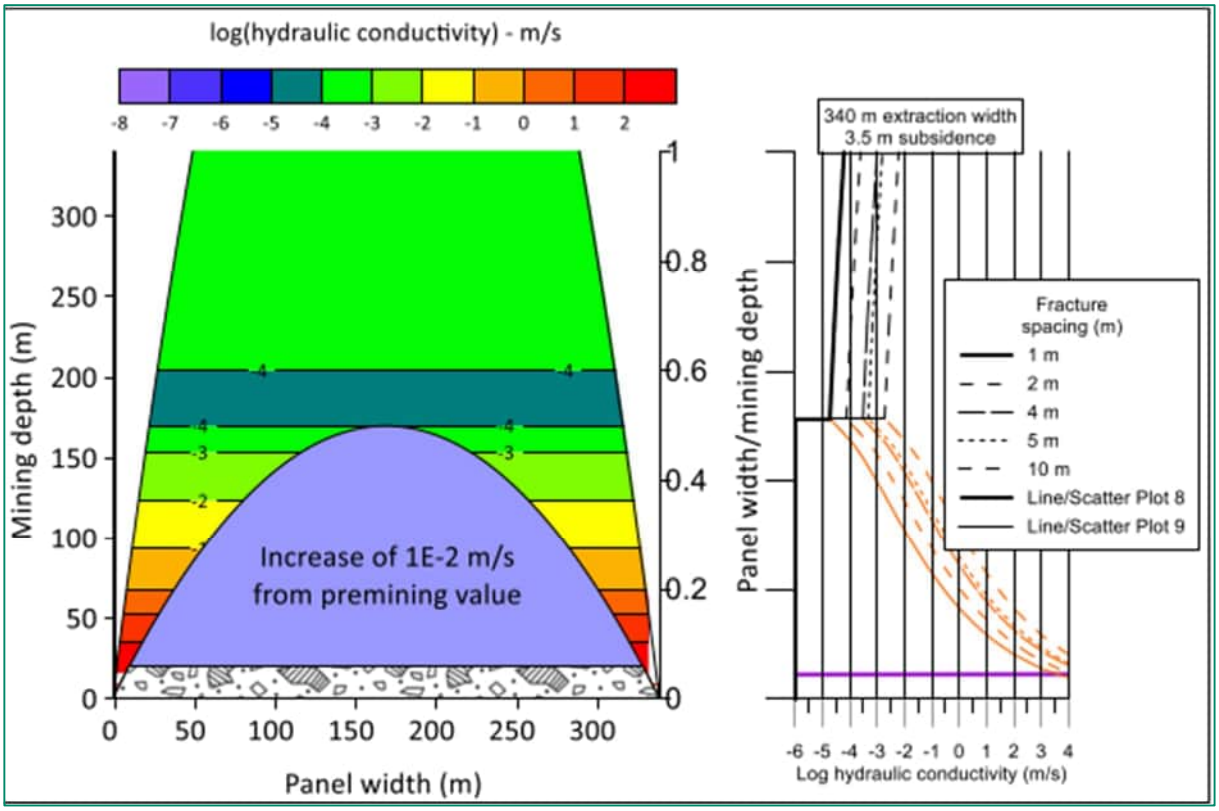
The input variables to the Geotechnical model are:

- Maximum vertical subsidence, or more precisely the difference in the maximum subsidence at /near the panel centreline relative to the subsidence above the chain pillars.
- The extraction width.
- The spacing of the cracks, where these may be mining-induced or the natural geological joints. This is a highly uncertain parameter, and its selection will require substantial judgement.

An example is presented in Figure 18, which also includes a sensitivity study on the choice of fracture spacing.

Note: The Byrnes Geotechnical report (**Appendix B**) is still in draft and was not finalised at the time of writing.

Figure 18 Example of hydraulic conductivity prediction for Broadmeadow underground mine with sensitivity to fracture spacing



7.3.4.3 Groundwater modelling approach

The alteration due to longwall mining, as conceptualised and modelled by Byrnes Geotechnical, predicts a complex heterogeneous hydrostratigraphic unit/s within, adjacent, and above the longwall panel post mining. It is also noted that Mine inflows are most likely related to the smaller more permeable ECZ at the edge of the panels rather than the larger disrupted zone.

The approach adopted to include for the alteration of the longwall mining was to assess the historic groundwater ingress into Broadmeadow GMS underground and simulate the altered target coal seam and overlying aquitards as an equivalent porous medium (EPM).

The EPM is a porous medium of a continuous solid matrix and pore-inclusions with an equivalent porosity that is higher than the porosity of the initial medium was used. Thus, an equivalent permeability across the entire mine panel was used in lieu of complex parametrisation within each panel to simulate high permeable areas (ECZ) and low permeable zones (PCZ).

Model calibration to match the actual groundwater extraction from the Broadmeadow GMS underground mining (Plate 8), allowed for the refinement of alteration to be adopted at all longwall mining panels across the Project.

The model calibration is detailed in Section 13.0. The model calibration using the groundwater extraction results plus the EPM approach indicated alteration resulting in hydraulic properties as follows:

- GMS goaf Horizontal hydraulic conductivity (Kh) = 1.1 m/day
- GMS goaf Vertical hydraulic conductivity (Kv) = 5E-05 m/day
- GMS goaf Specific capacity (Sc) confined storage = 1.5E-03
- GMS goaf Specific yield (Sy) unconfined storage = 0.15

The Kv in the overlying model layer (interburden aquitard) was 0.0005 m/day after longwall mining. The goaf K and S parameters were adjusted by comparing computed extracted groundwater volumes from the goaf areas to the measured and recorded groundwater ingress pumped from the underground between 2018 and 2023.

The yellow highlighted areas in Plate 8 are the GMS underground longwall panels included in the original (RHM Model) mine plan (2010 to 2023).

Plate 9 includes the goaf aquifer hydraulic parameters included after longwall mining was complete.

Goaf Kv in model layer 10 (GMS) is similar to the pilot point estimates (Section 14.3) and the Kv in model layer 9 (MCM interburden) was increased to 5 E-5 m/day.

Specific yield, as a result of longwall mining, increased from 0.001 to 0.15, and the storage coefficient increased from 1E-5 to 0.0015.

Plate 8 Historic GMS mine panels (2010 to 2023) in yellow - overleaf

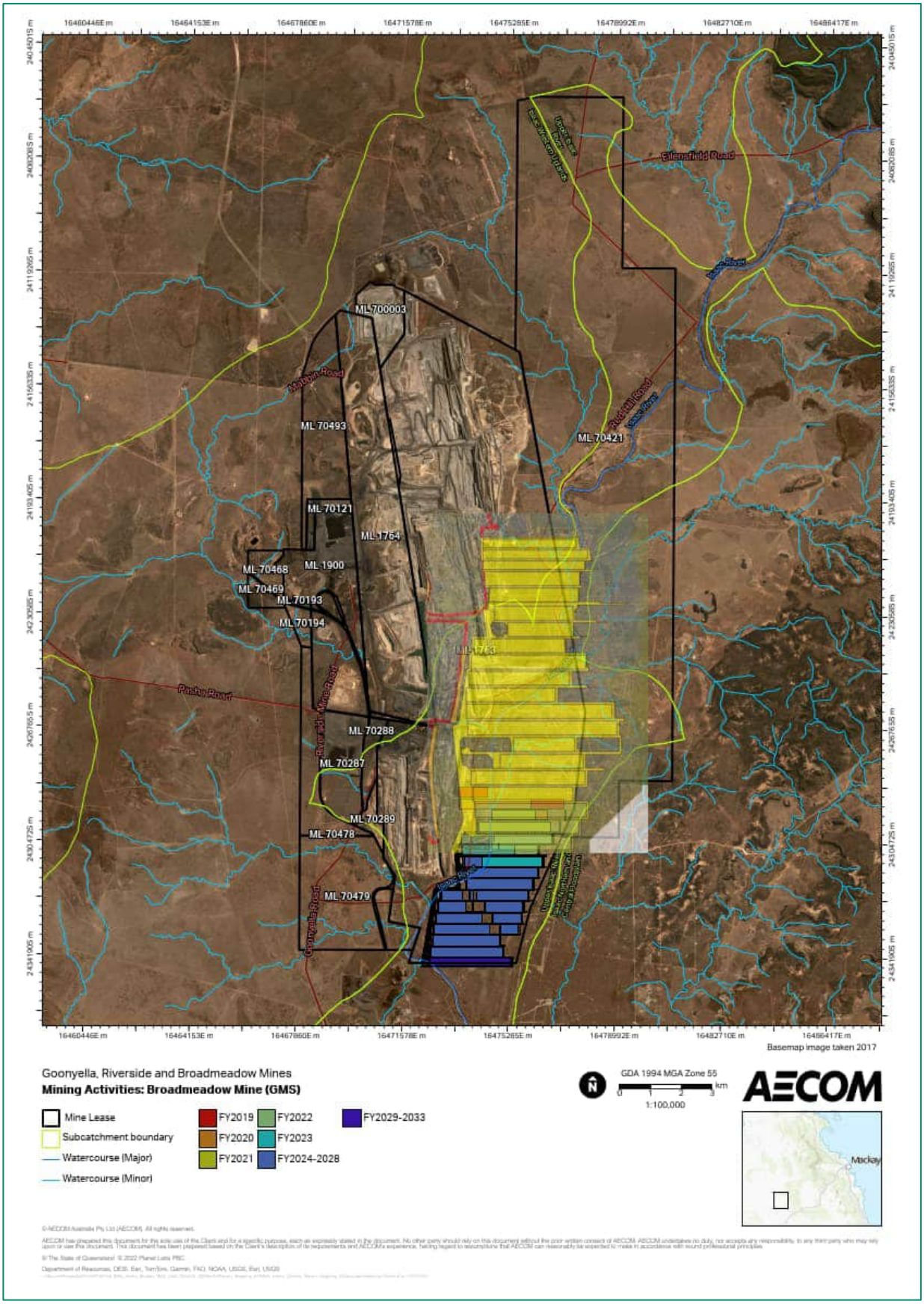

ML 700003
ML 70493
ML 70421
ML 70121
ML 1764
ML 1900
ML 70468
ML 70469
ML 70193
ML 70194
ML 1763
ML 70288
ML 70287
ML 70289
ML 70478
ML 70479
Basemap image taken 2017
Goonyella, Riverside and Broadmeadow Mines
Mining Activities: Broadmeadow Mine (GMS)
Mine Lease
Subcatchment boundary
Watercourse (Major)
Watercourse (Minor)
FY2019
FY2020
FY2021
FY2022
FY2023
FY2024-2028
FY2029-2033
GDA 1994 MGA Zone 55
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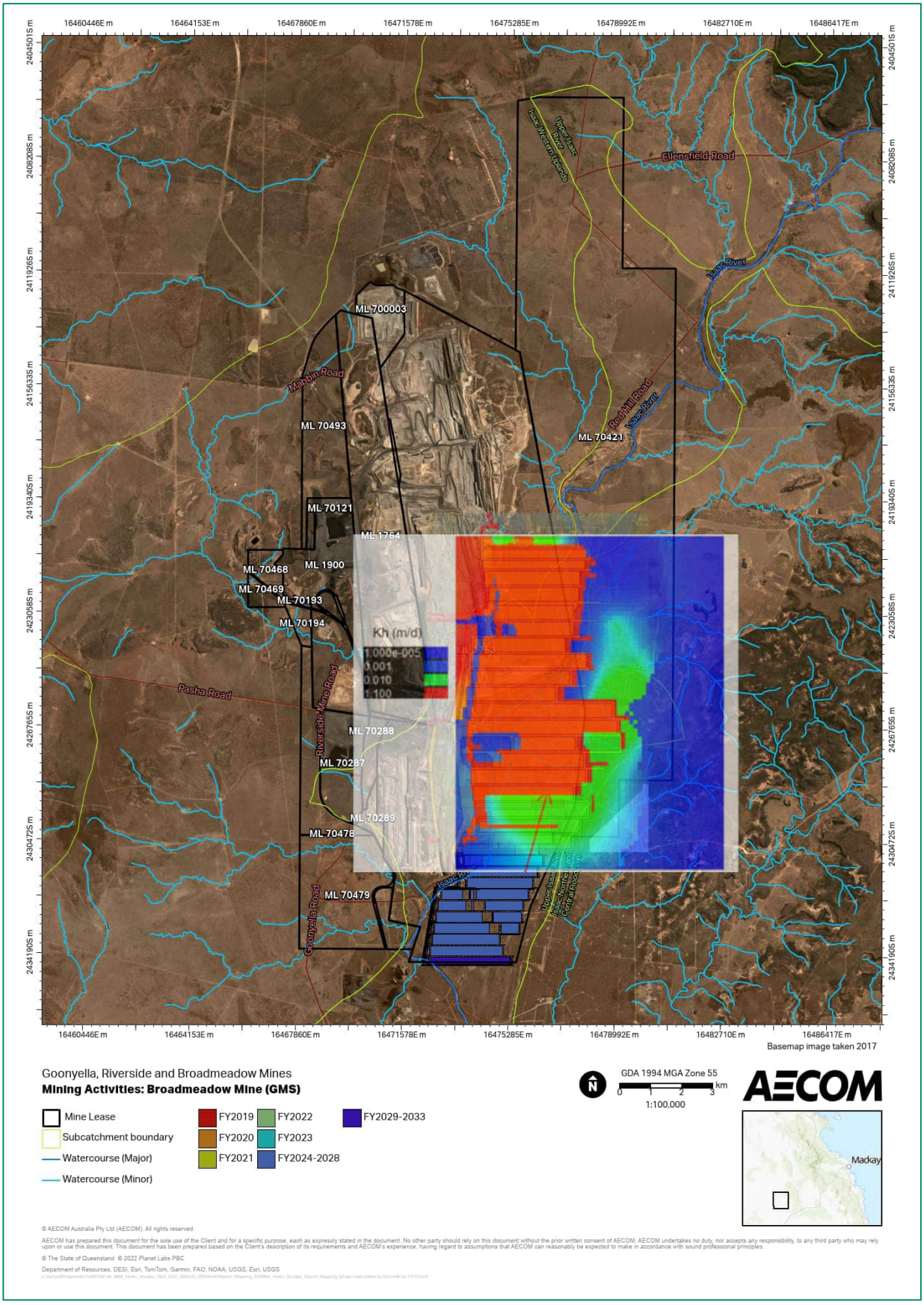
Plate 9 Representation of hydraulic conductivity distribution at the GMS mine panels after mining alteration - overleaf


16460446E m
16464153E m
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16471578E m
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2408208S m
2411926S m
2415633S m
2419340S m
2423058S m
2426765S m
2430472S m
2434190S m
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ML 1900
ML 70468
ML 70469
ML 70193
ML 70194
ML 70421
ML 1763
ML 70288
ML 70287
ML 70289
ML 70478
ML 70479
Mainbin Road
Pasha Road
Riverside Mine Road
Goonyella Road
Ellensfield Road
Red Hill Road
Isaac River
Upper Isaac
Isaac Western Tributary
Kh (m/d)
1.000e-005
0.001
0.010
1.100
Basemap image taken 2017
Goonyella, Riverside and Broadmeadow Mines
Mining Activities: Broadmeadow Mine (GMS)
Mine Lease
Subcatchment boundary
Watercourse (Major)
Watercourse (Minor)
FY2019
FY2020
FY2021
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FY2023
FY2024-2028
FY2029-2033
GDA 1994 MGA Zone 55
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8.0 Water Quality

8.1 Baseline groundwater quality

Available hydrochemistry data for the key hydrostratigraphic units across the Project area included data from 2001 to 2020, which was used to describe the historic conditions. More recent data, from 2020 to 2024, allowed for the evaluate of current groundwater quality and a comparison to historic data. This allowed for the evaluation of possible alteration due to approved mining activities at the Project.

8.1.1 Historic data

Groundwater quality data from previous investigations at GRB and RHM, from 2001 to 2010 (Table 7) have informed this section and from RHM from 1998 to 2011.

Groundwater chemistry is typically neutral to weakly alkaline (pH) for all formations.

The groundwater from the Quaternary alluvium is dominated by sodium and bicarbonate ions. The alluvial aquifer has variable salinity as the depth of the aquifer and its distance from the area of recharge are likely to influence the result at a given sample point and appears to increase with depth and the distance from the area of recharge (i.e., residence time increases the salinity of the groundwater). Generally, the alluvial groundwater has lower salinity than the Permian age confined formations.

The Tertiary and Permian age formations have variable salinity (measured as electrical conductivity), ranging from brackish to saline.

The Permian MCM 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 MCM (URS 2013).

Table 7 Groundwater quality results (2001 – 2010)

Lithology	Number of Samples	Electrical Conductivity (µS/cm)		pH	
		Range	Median	Range	Median
Alluvium	2	521 – 561		6.88 - 7.55	
Tertiary Basalt	3	2,670-15,384	13,100	8.19 – 8.67	8.38
Tertiary Sediments	1	5,060		9.3	
Permian Interburden	6	7,030 – 18,800	12,805	7.38 - 8.38	8.06
GMS coal seam	5	2,450 – 16,127	9,110	6.65 – 7.9	7.12
GLS coal seam	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 samples from airlift during exploration	75	100 – 30,000	12,593	6.89 – 9.18	7.68
EPP (Water) - 50th Percentile					
Shallow groundwater (<30 m)		2,150		7.75	
Deep groundwater (>30 m)		6,100		7.8	

Notes:

- Electrical Conductivity value based on TDS value for livestock (EC [µS/cm] = 1.67 × TDS [mg/L])
- EPP (Water) Isaac River Sub-basin Environmental Values and Water Quality Objectives for Zone 34.

8.1.2 Recent data

Groundwater quality monitoring results, compiled between 2020 and 2024, show that the alluvium indicated high variability, with salinity varying from fresh to highly saline.

Tertiary sediments have salinity that ranges from moderate to highly saline. The GMS coal seam salinity ranges from brackish to highly saline. The GLS coal seam and Back Creek Group samples indicate high salinity.

Table 8 Groundwater quality results (2020 – 2024)

Geology	Number of Samples	Electrical Conductivity (µS/cm)		pH	
		Range	Median	Range	Median
Alluvium	27	492 – 41,000	696	5.25 – 8.1	7.42
Tertiary Sediments	57	11,400– 42,200	21,700	5.52 - 8.33	6.59
FCCM	6	167 – 36,500	22,300	7.24 – 8.99	7.65
Permian Interburden	28	2,120 – 17,800	3,305	6.22 - 8.47	7.62
GMS coal seam	13	6,720 – 26,100	9,610	7.15 - 8.32	7.68
GLS coal seam	4	14,900 – 42,200	24,400	6.34 - 8.54	7.50
Back Creek Group	2	17,200 – 24,452	24,700	6.37 – 8.08	7.62
EPP (Water) - 50th Percentile					
Shallow groundwater (<30 m)		2,150		7.75	
Deep groundwater (>30 m)		6,100		7.8	

8.1.3 Water quality data review

Historic data

Alluvium major ions and nutrients minimum values from the 1998 to 2011 monitoring data:

- Did not exceed the EPP (Water) 50th percentile water quality objectives for the shallow (<30 m depth) groundwater
- All the maximum concentrations and several median values exceeded the 50th percentile water quality objectives.

The maximum analysis concentrations for the MCM major ions were above the 50th percentile water quality objectives for both the shallow and deep groundwater. The MCM sodium and chloride median values exceeded the 50th percentile water quality objectives for shallow groundwater.

The median and maximum values for the Back Creek Group major ions were greater than the shallow and deep groundwater 50th percentile water quality objectives, except for bicarbonate. Sodium, chloride, and sulphate of the Back Creek exceeded water quality objectives for shallow groundwater (Table 9).

Recent data

During the 2020 to 2024 monitoring, the minimum and median values for groundwater samples from the alluvium major ions remained below the shallow groundwater 50th percentile water quality objectives. However, the maximum values were found to be above the 50th percentile water quality objectives except for chloride, which was slightly below the objective.

MCM analyses indicated exceedance of the 50th percentile water quality objectives for the median and maximum values of the major ions, with the exception of the bicarbonate. Minimum values were all below the objectives.

All Back Creek Group major ions exceeded the water quality objectives for both the shallow and deep groundwater water quality objectives, with the expectation of the bicarbonate which was below the objectives for all geological units (Table 10).

	Water Quality Objectives		Alluvium				MCM				Back Creek Group			
	EPP(Water) – 50th Percentile, Shallow (<30 m depth)[1]	EPP(Water) – 50th Percentile, Deep (>30 m depth)[1]	Count	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count	Min (mg/L)	Med (mg/L)	Max (mg/L)
Parameter														
Major Ions														
Sodium	747	1,100	13	40	1,096	3,560	3	824	3,470	4,400	2	40	-	94
Calcium	84	145	13	<0.01	49	469	3	34	214	422	2	13	-	39
Magnesium	108	115	13	<0.01	25	570	3	86	542	805	2	7	-	20
Potassium			13	1.4	6	28	3	29	35	38	2	3	-	3
Chloride	1,309	1,900	13	64	2,024	7,510	3	1,390	7,000	9,750	2	10	-	71
Bicarbonate	536	330	13	85	497	5,656	3	10	417	774	2	180	-	293
Sulphate	140	138	13	0.2	4	626	3	223	692	763	2	6	-	26
Fluoride	0.28	0.155	11	<0.1	0.2	1.2	3				2	0.2	-	0.4
Nutrients														
Nitrite + Nitrate as N	0.95	2.15	13	0.02	0.2	0.9	3	0.05	0.09	0.33	2	0.125	-	0.315
Total Phosphorous as P			13	0.03	0.5	5.08	3	0.78	1.49	1.56	2	0.47	-	0.75

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

Table 9 Groundwater quality results (1998 – 2011)

	Water Quality Objectives		Alluvium				MCM				Back Creek Group			
	EPP(Water) – 50th Percentile, Shallow (<30 m depth)[1]	EPP(Water) – 50th Percentile, Deep (>30 m depth)[1]	Count	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count	Min (mg/L)	Med (mg/L)	Max (mg/L)	Count	Min (mg/L)	Med (mg/L)	Max (mg/L)
Parameter														
Major Ions														
Sodium	747	1,100	27	49	116	8,140	89	293	2,450	8,770	24	3,160	4,115	4,540
Calcium	84	145	27	11	23	290	89	40	211	662	24	160	276	358
Magnesium	108	115	27	8	18	915	89	41	425.5	1,230	24	403	458.5	558
Potassium			27	1	3	64	89	3	14	34	24	13	15	37
Chloride	1,309	1,900	27	24	75	13,000	89	414	7,460	16,900	24	6,420	7,710	8,320
Bicarbonate	536	330	27	1	256	492	89	166	469	1,360	24	313	478	520
Sulphate	140	138	27	13	30	3,400	89	36	555	2,160	24	438	552	655
Fluoride	0.28	0.155	27	0.1	0.1	0.7	89	0.1	0.2	400	24	0.1	0.4	400
Nutrients														
Nitrite + Nitrate as N	0.95	2.15	27	0.01	0.125	2.42	89	0.01	0.035	0.44	24	0.01	0.04	0.67
Total Phosphorous as P			27	0.01	0.06	0.34	89	0.01	0.055	19,000	24	0.09	0.16	0.44

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

Table 10 Groundwater quality results (2020 – 2024)

The comparison of water quality data, to the relevant water quality objectives, does not readily indicate a marked difference in water quality over time. The variation in data is considered related to differing groundwater monitoring locations (reflecting the heterogeneous nature of the sediments across the Project), the number of samples, and the difference in residence time (different recharge / climate conditions).

8.2 Groundwater Environmental Values

Water plans have been developed by the State regulators, under the Water Act to sustainably manage and allocate water resources in Queensland. The Project is located within the Isaac Connors Groundwater Management Area (GMA) as defined in Schedule 3 of the Water Plan (Fitzroy Basin) 2011 (current as of 2 September 2022). Plate 10 indicates the Isaac Connors GMA and the approximate Project location.

Plate 10 Water Plan (Fitzroy Basin) 2011 Schedule 3 Groundwater Management Areas (Project is red dot)

GRB lies within or in proximity to the Isaac Connors Groundwater Management Area (GMA – Zone 34) of the Fitzroy Basin under the Water Plan (Fitzroy Basin) 2011 (Plate 11). Within the GMA, alluvial groundwater is managed as Groundwater Unit 1 and water within the hard rock aquifers as Groundwater Unit 2 (sub-artesian aquifers). Volumetric limits apply to extraction of groundwater within the GMA for non-stock and domestic purposes.

Groundwater resources in the GRB are also scheduled under the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 as Isaac Groundwaters of the Isaac River Sub-basin of the Fitzroy Basin water plan (WQ1310). The legislated environmental values (EVs) for these groundwaters are:

- Biological integrity of aquatic ecosystems.
- Human use EVs:
  - Suitability of water supply for irrigation
  - Farm water supply/use
  - Stock watering
  - Primary recreation
  - Drinking water supply
  - Cultural and spiritual values.

The WQ1310 WQOs for groundwater at GRB are shown in Table 11.

The EPP Water and Wetland Biodiversity provides water quality objectives (WQOs) for the scheduled EVs in WQ1310. WQOs are long-term goals for water quality management and the purpose of the WQOs is to support and protect EVs. They are numerical concentration levels or narrative statements of indicators established for receiving waters to support and protect the designated EVs for those waters. They are based on scientific criteria or water quality guidelines but may be modified by other inputs (e.g. social, cultural, economic). Where groundwater quality analysis results exceed a particular WQO for a particular EV, it is considered indicative that the groundwater may be unsuitable for supporting that particular EV.

The EPP Water and Wetland Biodiversity also provides limited WQOs specifically for underground aquatic ecosystem protection in Fitzroy Basin groundwaters. These WQOs vary across the Fitzroy Basin and are defined on the basis of groundwater Chemistry Zones. The applicable Chemistry Zone for the GRB is Isaac Groundwater (Zone 34; Sodic Sequence - Saline: Na, Cl). These WQOs are classified by groundwater depth (‘shallow’ being <30 m depth, and ‘deep’ being >30 m depth) and are summarised in Table 12. The management intent of Zone 34 WQOs is to “maintain each of 20th, 50th and 80th percentile values”, i.e. that there should be no change to existing water quality (no statistical change in the natural range of values) (DES, 2022).

Plate 11 Fitzroy Basin Groundwater Zones (Project red dot)

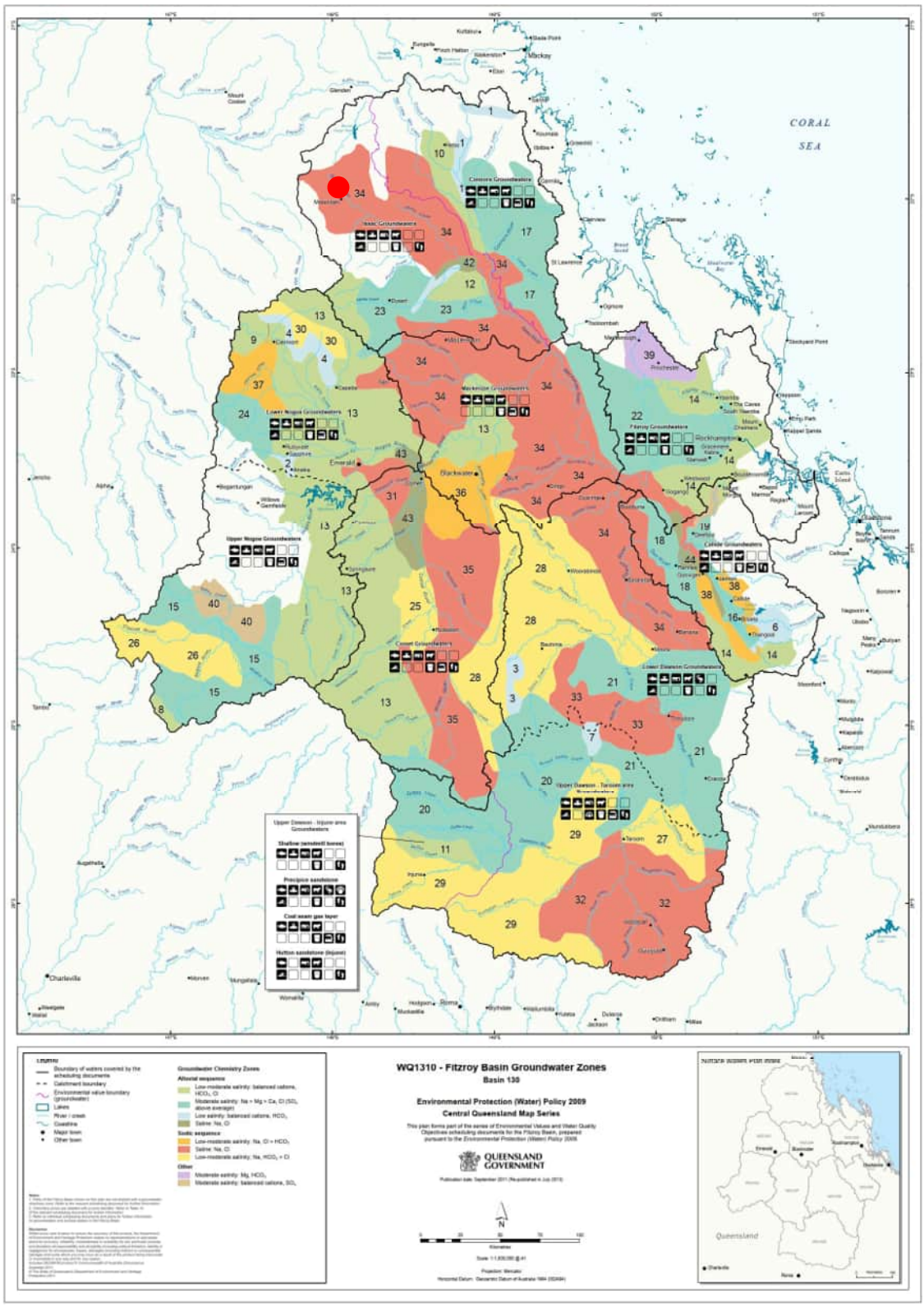

Table 11 WQOs for Isaac River sub-basin EVs

Water quality indicator	Unit	ADWG Guidelines[1]		Isaac River Sub-basin EVs[2]		
		Health	Aesthetic	Irrigation	Stock	Aquatic 95% spp[3]
pH	pH units	6.5 – 8.5				6.5 – 8.5
Al	mg/L		0.2		5	0.055
Ca	mg/L				1,000	
Cl	mg/L		250			
Mg	mg/L				2,000	
Mn	mg/L	0.5	0.1	10		1.9
Na	mg/L		180			
SO_4	mg/L				1,000	
Zn	mg/L		3			0.008
As	mg/L	0.01		2	0.5	0.024
Cd	mg/L	0.002			0.01	0.0002
Cr	mg/L	0.5			1	0.001
Co	mg/L			0.1	1	
Cu	mg/L	2	1		1	0.0014
Pb	mg/L	0.01			0.1	0.0034
Hg	mg/L	0.001			0.002	0.0006
Ni	mg/L	0.02			1	0.011
Se	mg/L	0.01			0.02	0.005
Ag	mg/L	0.1				0.05

Table notes:
1. Table 4 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Drinking water EV.
2. Table 2, Table 9, Table 10 and Table 11 of Isaac River Sub-basin Environmental Values and Water Quality Objectives: Aquatic ecosystem – moderately disturbed.
3. Table 3.4.1 of Australian and New Zealand Guidelines for Fresh and Marine Water Quality: trigger values for slightly - moderately disturbed systems (95% level of protection).

Table 12 Isaac River Sub-basin Zone 34 WQOs for groundwater resources (aquatic ecosystem protection)

Water quality indicator	Unit	Shallow groundwater (<30m) percentile			Shallow groundwater (>30m) percentile		
		20th	50th	80th	20th	50th	80th
EC	µS/cm	498	2,150	8,910	3,419	6,100	16,000
Hardness	mg/L as $CaCO_3$	163	674	2,228	359	919	3,208
pH	pH units	7.1	7.75	8.1	7.4	7.8	8.03
Alkalinity	mg/L	154	435	752	156	275	536
Ca	mg/L	18	84	215	46	145	442
Mg	mg/L	27	108	389	35	115	491
Na	mg/L	135	747	1,500	480	1,100	2,565
Cl	mg/L	171	1,309	3,185	753	1,900	5,905
SO_4	mg/L	12	140	318	25	138	398
HCO_3	mg/L	187	536	878	188	330	650
NO_3	mg/L	0	0.95	5.3	0.01	2.15	14.92
SiO_2	mg/L	21	36	52	16	25	36
F	mg/L	0.1	0.28	0.5	0.02	0.155	0.4
Fe	mg/L	0	0.03	0.14	0	0.05	0.246
Mn	mg/L	0	0.01	0.16	0	0.05	0.291
Zn	mg/L	0	0.015	0.06	0.01	0.025	0.317
Cu	mg/L	0	0.01	0.03	0.017	0.03	0.03
SAR	-	4.37	10.85	18.21	10.5	15.6	24.65
RAH	meq/L	0	0	2.3	0	0.24	6.25

In order to understand the groundwater resources within the GRB area, available water quality data Isaac River Sub-basin Environmental Values and Water Quality Objectives for Zone 34 groundwater have been compared to the:

- Australian Drinking Water Guidelines (ADWG) (NHMRC, 2011)
- ANZG (2018) guidelines for irrigation (long-term and short-term), stock water supply, and 95% level of protection for aquatic ecosystems in slightly - moderately disturbed systems
- Isaac River Sub-basin Zone 34 WQOs for groundwater resources (aquatic ecosystem protection) for deep and shallow groundwater.

8.2.1 Groundwater quality comments

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

Alluvium

- Major ion concentrations for alluvial groundwater are less than the EPP (Water) 50th percentile water quality objectives for shallow (<30 metre depth) groundwater.
- The maximum concentration of zinc recorded is above the ANZG (2018) water quality guideline for aquatic ecosystems.

MCM

- The median concentration of sodium for groundwater from the MCM is less than the EPP (Water) 50th percentile water quality objective for deep (>30 m depth) groundwater.
- The median concentrations of chloride and bicarbonate were above their respective water quality objectives.
- The median concentration of manganese was 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 all above the ANZG water quality guidelines for aquatic ecosystems.
- The median concentrations of manganese and iron are above the relevant water quality objectives, 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.

Based on the historic and more recent groundwater quality data for the Project area, the groundwater quality does not readily comply with the guideline WQOs. The limited variation over time, considering the historic and recent water quality sample results, indicate the natural groundwater quality reduces the suitability for use (Isaac Connors Groundwater Management Area EVs) and aquatic ecosystems.

9.0 Groundwater Receptors

9.1 Groundwater Bores

A search of the Department of Regional Development, Manufacturing and Water (DRDMW) Groundwater Bore Database (GWBD) was carried out for registered bores within and adjacent to the Project. The search, across the mine lease areas and a 5 km buffer around the mine leases, indicated that there are 238 registered bores (Figure 19). These registered bores, summarised in Table 13, include:

- Sixteen (16) bores are abandoned and destroyed, with the rest are reported as existing on the GWDB bore cards.
- 190 of the registered bores are reported as used for groundwater monitoring.
- Six (6) are used for water supply, with three reported as no longer being used.
- 20 are recorded as exploration bores.
- Six (6) are reported as use unknown.

Table 13 Registered groundwater bores in proximity to GRB

Use	Number of bores	Percent total
Groundwater monitoring (mine monitoring, water resource investigation,etc.)	190	85
Water supply	6	3
Exploration	20	9
Unknown	6	3
Total		100

A search of the Queensland Water Entitlement Database showed that none of the 224 existing registered groundwater bores located within 10 km of GRB had water licences (i.e., there are no licensed water users identified within the GRB mine area) This indicates that the bores reported as water supply bores (on the bore cards) are entitled to be used for stock and domestic purposes, which do not require a water licence and allocation.

Table 14 Registered water supply bores in proximity to GRB

RN	Easting	Northing	Name	Depth	Comment
182313	604240	7594890	Cleanskin Gully	25.34 mbgl	No longer used Water level 14.02 mbgl
81696	608182	7586081	Skeleton Bore	63.7 mbgl	No details Water level 28.41 mbgl Yield 1.3 L/s
81700	591815	7587788	Harvey's Bore	No data	No data
182311	599005	7610760	Old Mill Bore	117.1 mbgl	No details Water level 90.66 mbgl Yield 1.9 L/s
182312	596795	7610020	Tex's bore	118.9 mbgl	No longer used Water level 34.13 mbgl Yield 4.5 L/s
132496	586258	7611031	?	79.6 mbgl	Back Creek Group Water level 50 mbgl Yield 1.1 L/s

The water supply bores, included in Figure 65, are discussed in detail in Section 15.8.1, which includes an assessment of potential long term (closure) impacts to the water supply bores.

Figure 19 Registered groundwater bores

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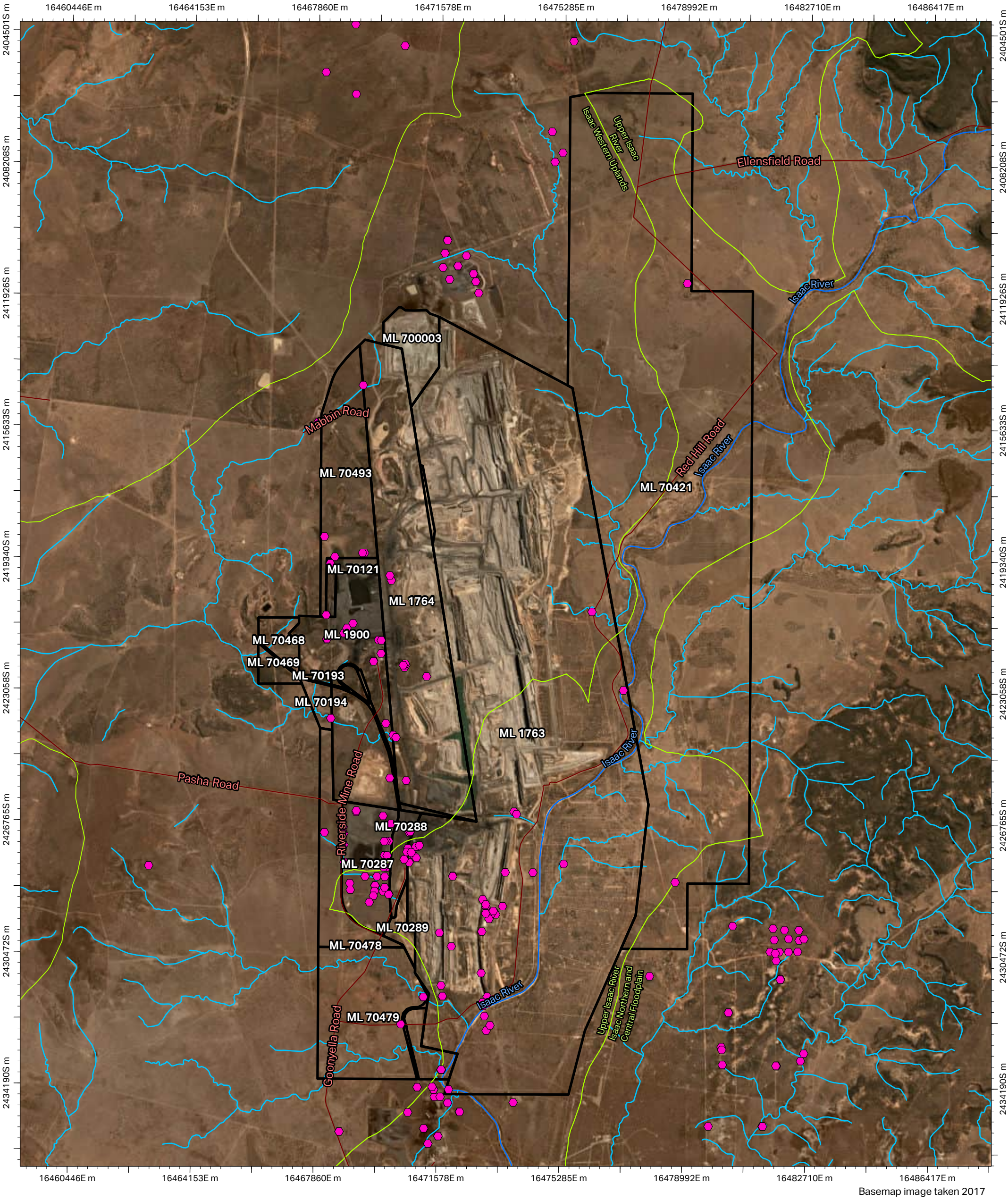

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Registered Bores

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)
- GWDB registered bores

GDA 1994 MGA Zone 55

0 1 2 3 km

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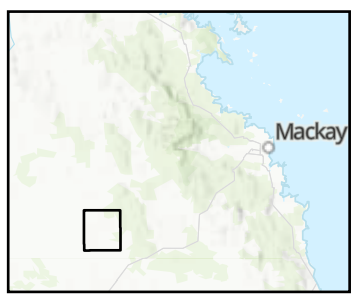

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9.2 Groundwater Dependent Ecosystems

A groundwater dependant ecosystem (GDE) is a natural ecosystem that requires “access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis, so as to maintain their communities of plants and animals, ecosystem processes and ecosystem services” (Richardson, S., et al., 2011). GDEs can require access to groundwater on a permanent (obligate) or intermittent (facultative) basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Doody et al., 2019).

GDEs can be classified as either:

- Aquatic GDEs (i.e. ecosystems dependent on the surface-expression of groundwater, such as aquatic species that inhabit groundwater-fed surface pools).
- Terrestrial GDEs (i.e. ecosystems dependent on the sub-surface presence of groundwater, including some riparian vegetation communities with rooting depths that intersect the groundwater table).
- Subterranean GDEs (aquifer and cave ecosystems, such as stygofauna that can live within aquifer systems).

Broad-brush national scale desktop mapping of potential GDEs is available in the Bureau of Meteorology (BoM) National Atlas of GDEs (GDE Atlas). The GDE Atlas classifies ecosystems based on the potential for dependence on groundwater through desktop collation of multiple lines of scientific evidence. Ecosystems have been mapped as either:

- High potential for groundwater dependence (indicating a strong possibility the ecosystem is interacting with groundwater).
- Moderate potential for groundwater dependence.
- Low potential for groundwater dependence (indicating it is relatively unlikely the ecosystem will be interacting with groundwater and will include ecosystems that are not interacting with groundwater).

The broadbrush GDE Atlas mapping of potential aquatic and terrestrial GDEs indicates that areas with possible high, moderate, and low potential for groundwater interaction occur in the vicinity of the Project area (Figure 20).

Figure 20 indicates moderate and high potential Aquatic GDEs and moderate and low potential Terrestrial GDEs are mapped within the GRB mine lease. There are isolated areas of high potential Aquatic and Terrestrial GDEs, where aquatic GDEs are associated with rivers and tributaries. The only high potential Terrestrial GDEs are identified approximately 10 km north of the northern boundary of the mine.

It is noted that the potential aquatic GDEs, mapped at GRB in Figure 20, are tailings dams, mine water storages and mining voids. Thus, the mapping is recognised to identify potential GDEs only.

The remaining potential Aquatic and Terrestrial GDEs outside of the GRB mine leases fall between moderate and low potential GDEs, with low potential GDEs identified predominantly around the GRB boundaries. The groundwater study for the PRC Plan considers post mining conditions as the risks and management of these potential GDES has been assessed as the mining activities are approved and licensed activities. These mined areas will not be present (rehabilitated) during closure.

Sampling for stygofauna was undertaken as part of the Red Hill Mining Lease EIS; no stygofauna were found in any of the accessible groundwater bores on site (URS 2013).

Figure 20 Mapped GDEs

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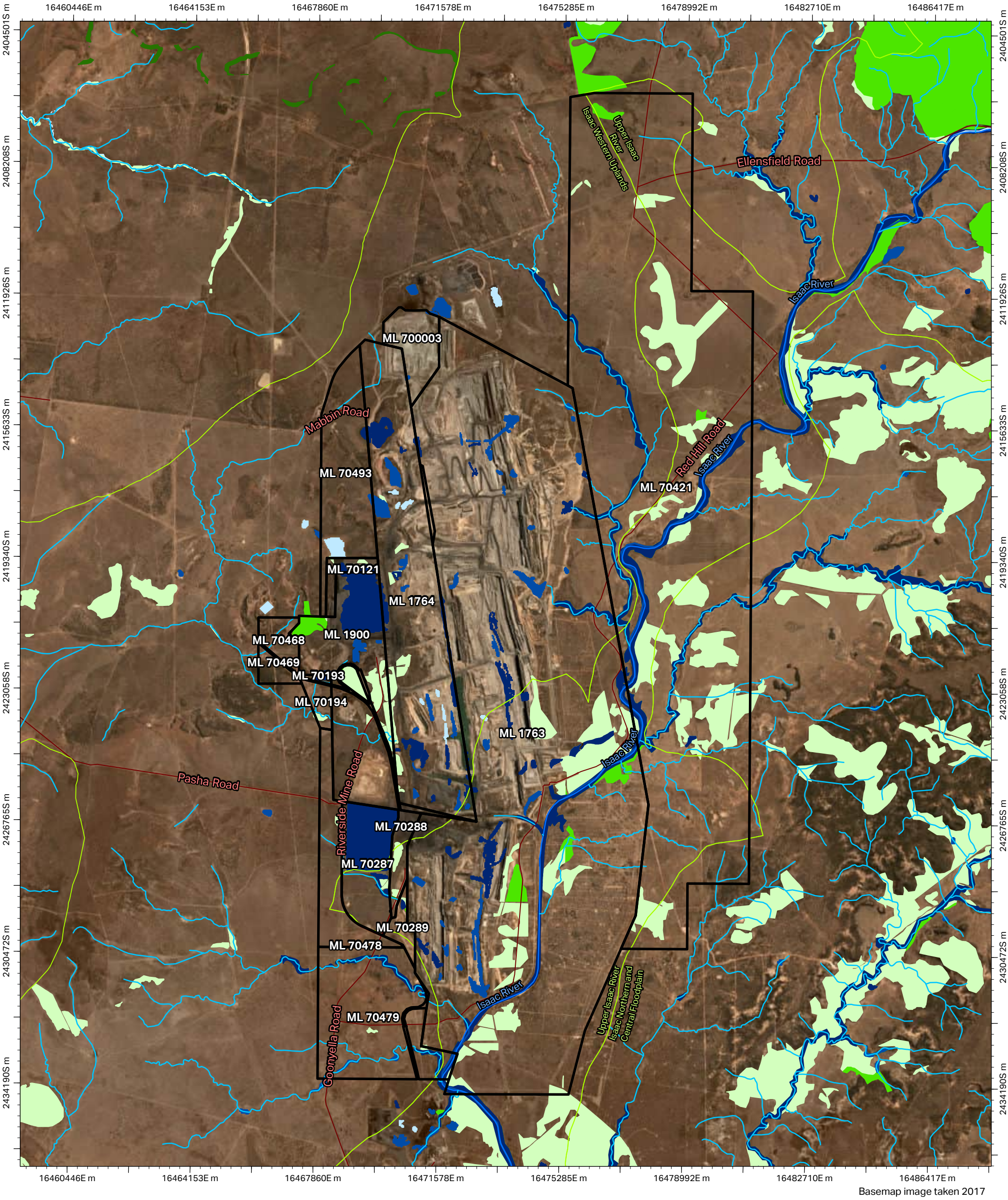

Basemap image taken 2017

Goonyella, Riverside and Broadmeadow Mines

Potential GDEs (Aquatic, Terrestrial, and Springs)

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)

Aquatic GDEs
- High potential GDE
- Moderate potential GDE
- Low potential GDE

Terrestrial GDEs
- High potential GDE
- Moderate potential GDE
- Low potential GDE

GDA 1994 MGA Zone 55

0 1 2 3 km

1:100,000

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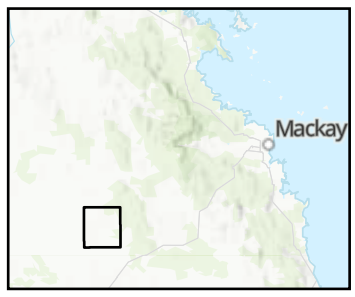

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10.0 Mining activities

10.1 Mine plans

Goonyella, Riverside, Broadmeadow, and Red Hill mining is through both open pit and underground methods. Drill and blast/truck and shovel are the employed mining process for the open pit. The open pit depth will range from approximately 60 m below ground level to greater than 300 m; depth is controlled by the target coal seams.

The underground operations are an extension of the open pits. It allows for mining of the coal further down dip. Mining is mechanised and is conducted by longwall. Once the coal has been removed from the mines, it is conveyed to the preparation plant for processing, sorting, and then distribution.

Mining at the GRM will continue until 2059 and the target seam for this mine is the GLS, with the final void used to access the underground RHM. The void will stay dewatered until end of mining at RHM.

The underground operations for the Broadmeadow GMS will continue until 2031, and will stay dewatered to allow for the mining of Broadmeadow GLS. Mining is planned to continue from 2031 until 2055 within the Broadmeadow GLS. Access to the GLS will be through the Broadmeadow GMS portal.

RHM underground mining is planned to commence in 2063 and will last until 2091. Access into the mine will be through the GRM void.

Predictive modelling to predict groundwater level, flow patterns, and potential for ingress into the residual voids adopted the mine plan schedules and decommissioning activities as detailed in Table 15.

Table 15 Mine plans and decommissioning activities until end-of-mining for PRC Plans

Mine	Planned start / Continued mining	End-of-mining	Closure	Comments
Goonyella / Riverside open cut mining	Prior to 2019	2059	2092	Target GLS Figure 21
Existing / residual pits Broadmeadow Isaac Ramp 32 East Thiess Ramp 32 South	 n/a n/a 2025 n/a 2033	 2009 1997 2026 2031 2036	 2053 2053 2032 End of mining End of mining	
Broadmeadow underground - GMS	2007	2031	2053	GMS seam continued longwall mining Figure 22
Broadmeadow underground - GLS	2031	2055	2056	Same portal as Broadmeadow GMS, mining below the GMS longwalls Figure 23
Broadmeadow underground	2057 2058, 2059, 2060			Decommissioning Injection of water to fill workings
Red Hill underground mine - GMS	2063	2091	2092	Access through Goonyella / Riverside highwall GMS (50 m above GLS) Figure 24
RHM	2093 2094, 2095, 2096			Decommissioning Injection of water to fill workings
Recovery	2097 onwards			All mining complete

Figure 21 Goonyella / Riverside open cut mining plan (plus Ramp 32)

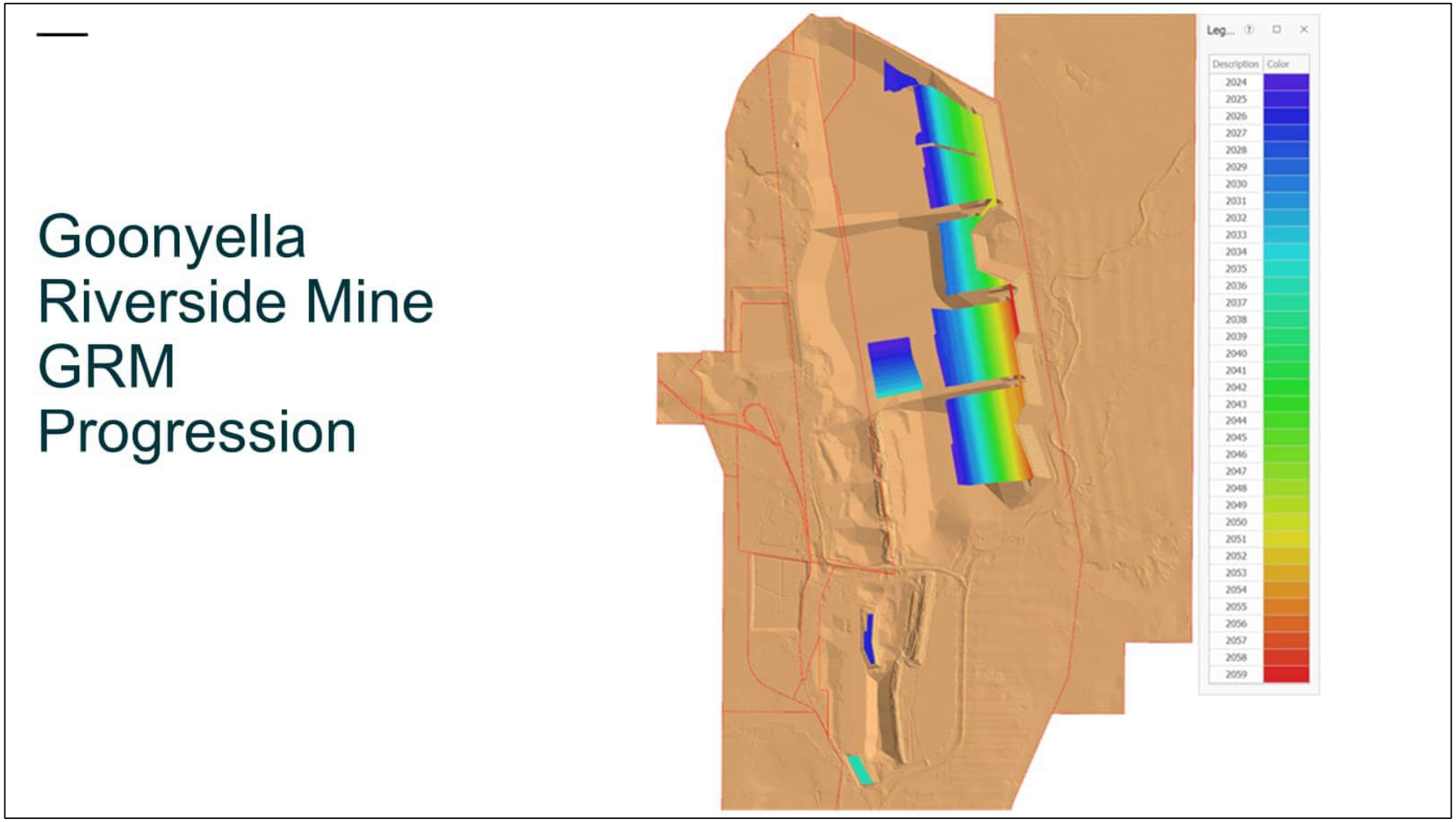


Figure 22 Broadmeadow underground mine plan – GMS

Figure 23 Broadmeadow underground mine – GLS

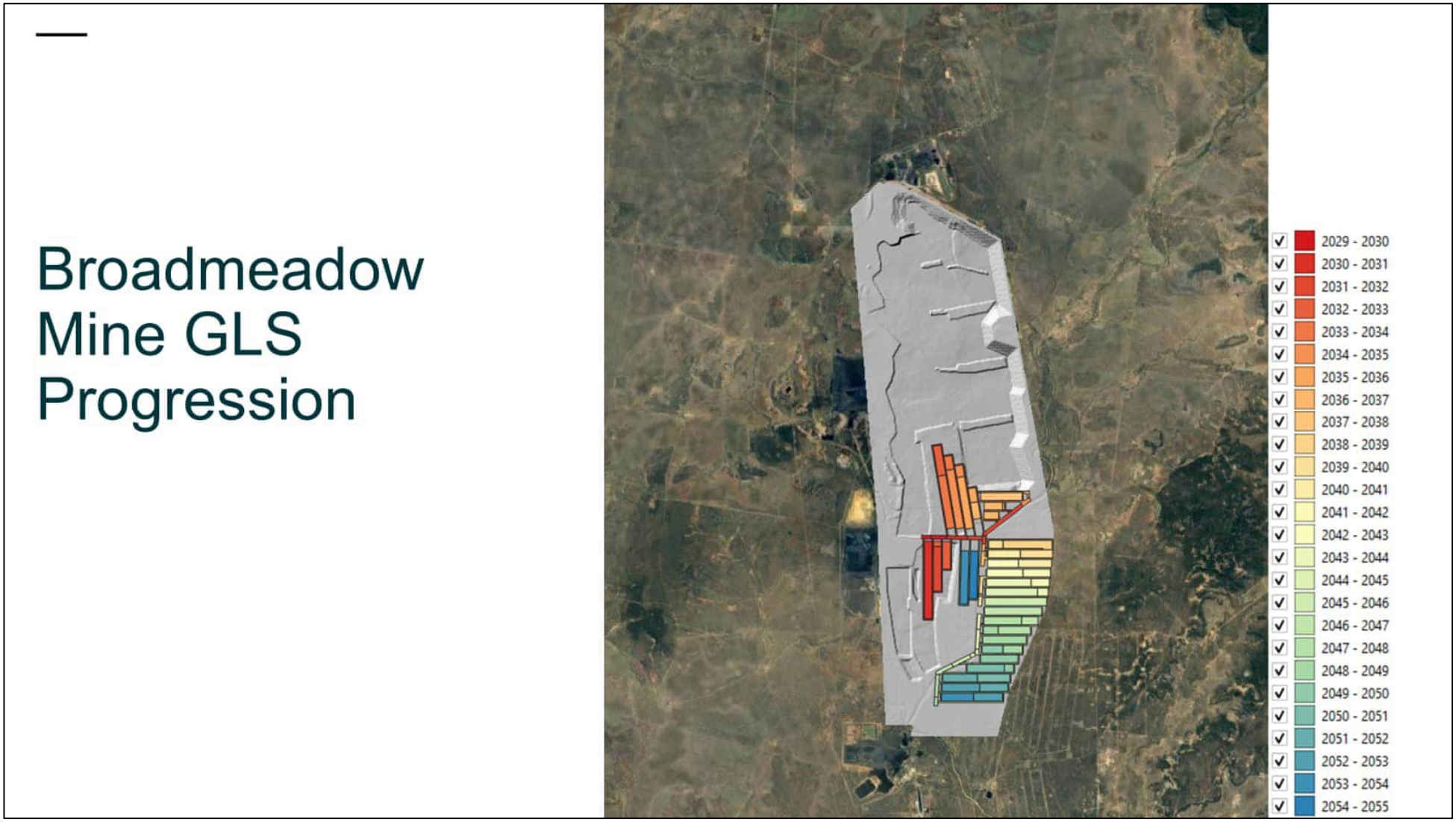
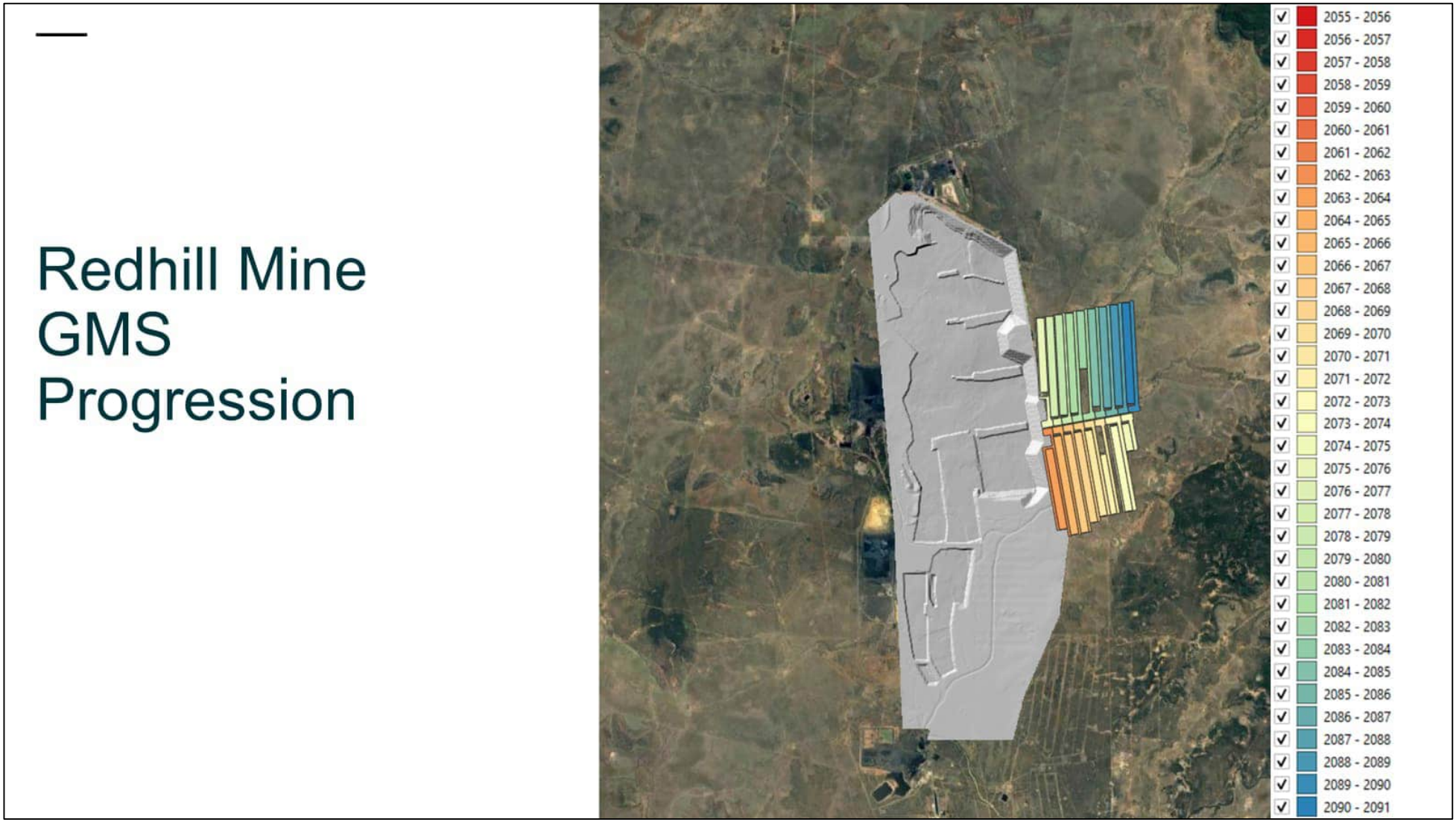


Figure 24 Red Hill underground mine plan



10.2 Mine Pit Inflows

Groundwater inflows from the Permian coal measures to GRB's active and residual pit voids are generally small in volume and do not typically need to be actively managed via advance dewatering or other groundwater management methods, with evaporation from the pit void walls and floors accounting for most of the groundwater. Small volumes of groundwater inflow, when they occur, are generally managed via the use of in-pit sumps to capture water that is then used for dust suppression purposes or circulated via the mine water management system for use in coal washing.

Groundwater inflow estimates for GRB for a typical year (2020 – 2021) are provided in Table 16 below based on BMA's annual Associated Water Take reporting to the Queensland Department of Resources (DoR). Estimates are based on BMA's site water balance calculations using site climate data, pit void storage, and pumped outflow data in accordance with the DNRME (2020) Associated Water Take Guideline, and as such inflow estimates are considered conservative. Refer to Figure 2 for pit locations.

Table 16 Estimated groundwater inflow at GRB (2020 – 2021)

Open Cut Pits	Annual estimate (ML/year)
Dampier Pit	0 (0)
Red Hill Pit	26 (±5)
Denham Pit	63 (±11)
Cleanskin Pit	67 (0)
Riverside Pit (Ramp 8)	11 (±2)
Riverside Pit (Ramp 6)	255 (±30)
Broadmeadow Pit	27 (0)
Isaac Pit	0 (±1)
Eureka Pit	79 (±4)
Airstrip Pit	0 (±45)
Lenton Pit	2 (0)
Broadmeadow underground	60 (±7)

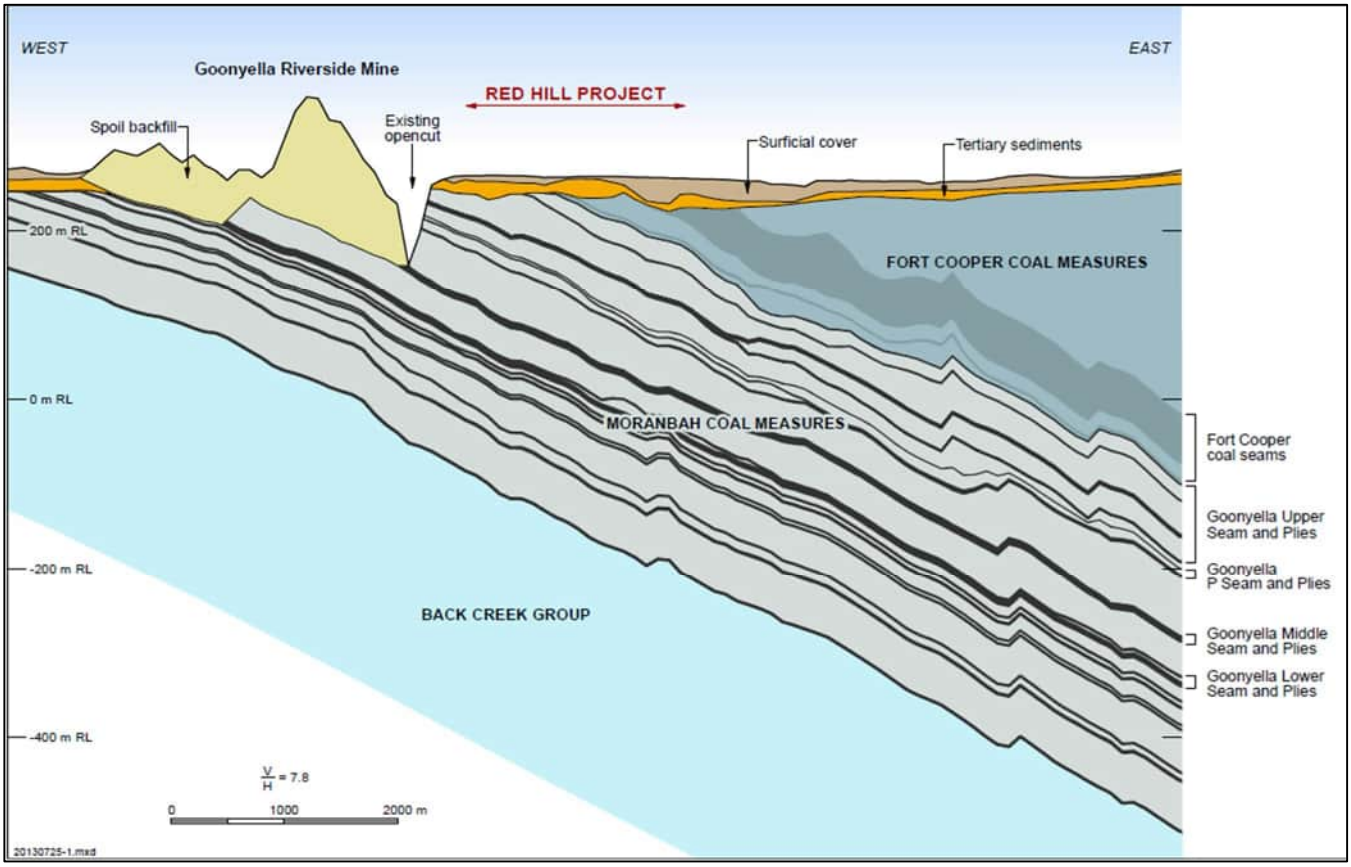
11.0 Conceptualisation – End of Mining

Conceptualisation of the groundwater regime/s has been developed based on the review of the hydrogeological information for GRB presented in the above report sections. Hydrogeological conceptual models (HCMs) are presented as conceptual cross-sections.

11.1 Overview

The geology of Project area comprises the stratified sequences of the MCM at the westernmost extent of the syncline that dip towards the east. Mining at GRB targets the coal seams of the MCM, that occur at subcrop, and increase with depth towards the east. Surficial cover at GRB includes alluvium associated the Isaac River floodplains and tributaries, primarily Eureka Creek. Surficial cover at GRB outside of these water lines consists of Quaternary to Tertiary age sediments (Plate 12).

Plate 12 Lithological cross section



The primary hydrogeological features at GRB include:

- Cainozoic sediments:
  - Quaternary alluvium – unconfined
  - Tertiary unconsolidated sediments of the Suttor Formation – unconfined / semi-confined.
- Permian – Triassic coal measures with
  - Low permeability interburden aquitards
  - Coal seams have higher groundwater potential due to secondary porosity through cleats.

Surficial cover

Groundwater within the alluvium is recorded at depths of 4.5 to 9.5 mbgl (Figure 10). Regionally, groundwater flow within the alluvium is a subdued reflection of topography, with groundwater flowing in an east-south-easterly direction.

Losing conditions from water courses to the underlying alluvium are evident during flow periods. Recharge to the alluvium is considered to be primarily from stream flow or flooding. Direct infiltration of rainfall also occurs where there are no substantial clay barriers in the shallow sub surface.

On a regional scale, discharge is via evapotranspiration from riparian vegetation growing along creek beds and minor short duration baseflow events after significant rainfall/flooding.

The Tertiary Suttor Formation and undifferentiated Tertiary sediments comprise unconsolidated sediment aquifer/s, which has a depth to groundwater in monitoring wells at RHM around 10 mbgl (Figure 12). The clean sand and gravel lenses in the Tertiary sediments are permeable but are of limited lateral and vertical extent.

Coal seams

Regionally, groundwater within the Permian-Triassic coal measures flows in a south-easterly direction, but the flow system is modified on a local scale by mining activities in the region with ongoing discharge to mine workings, including at GRB.

Review of water quality data indicates water within the Permian coal measures is generally saline at GRB but can range between brackish to highly saline. Groundwater within the coal measures at GRB exceeds guideline criteria for irrigation, drinking water, and protection of aquatic ecosystems, and only variably meets the guideline criteria for stock water supply with guideline exceedances for salinity and sulfate.

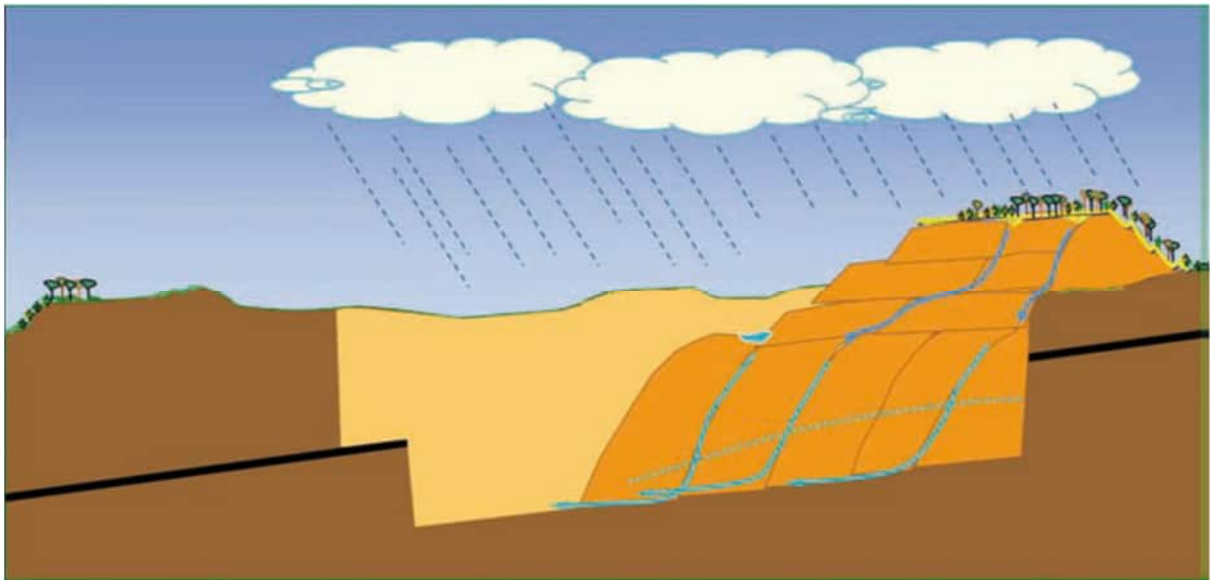
11.2 Hydrogeological conceptualisation

For the conceptualisation of groundwater response to mining, the recharge and discharge mechanisms at several (mine area) locations across the GRB were considered. These conceptual cross sections include the envisaged end-of-mining groundwater conditions. These conceptual models were considered when undertaking the predictive groundwater modelling.

Recharge mechanisms include:

- Rainfall recharge.
- Enhanced recharge through spoil (loose, unconsolidated).
    - Discrete ingress flow patterns and intermittent saturation within the spoil (as conceptualised by NSW Department of Primary Industries included in Plate 13, noting this is a fully backfilled mine void which has been rehabilitated).

Plate 13 Conceptual model of movement of water in a typical rehabilitated mine void and spoil pile



- Possible induced flow from over- and under-lying hydrostratigraphic units towards the dewatered target coal seams.
- Vertical groundwater movement (in response to vertical groundwater gradients and longwall alteration).
- Surface water losing systems.

Discharge mechanisms include:

- Mine dewatering resulting in groundwater drawdown into open cut and underground workings.
- Groundwater flow into the open cut workings where the pits intersect saturated hydrostratigraphic units (including the surficial cover).
- Evaporation from pits resulting in groundwater drawdown and local groundwater flow into open cut workings.
- Evapotranspiration.
- Groundwater extraction.

11.3 End of Mining

The potential impacts to the groundwater system at end of mining, as relevant to the hydrogeology assessment for the transitional PRC Plan/s, relate to how the groundwater system is dewatered, artificially recharged (through reinjection into the underground workings), and then recovers after all active mining ceases (Table 15). Therefore, it is important to understand the nature of the groundwater system/s at the conclusion of mining immediately prior to the closure period.

A visual representation of the end of mining HCMs for GRB is provided in a series of conceptual cross sections. These cross sections depict the different mining activities across the GRB. The location of the cross-sections is included in Figure 25.

Key features relevant to groundwater conditions at the end-of-mining include:

- Groundwater drawdown within the MCM, associated with passive dewatering into the GRB residual voids, results in inwards hydraulic flow gradients in the coal measures.
- Drawdown in the MCM at the end of mining is at, or close to, the maximum expected to occur as a result of GRB.

- Residual voids capture seepage from spoil emplacements
- Residual voids capture seepage from TSFs
  - Runoff from the spoil and TSFs is directed down ramps into the residual voids.
- Little to no impact on surficial aquifers, which is intermittently saturated, including the Isaac River Alluvium.
- Little to no impact on environmental receptors.
- No impact on anthropogenic receptors (i.e., private groundwater users).

11.4 Continual mining

The timing and extent of mining, at Goonyella / Riverside Mine, Broadmeadow Mine (both GMS and GLS), and Red Hill Mine, is envisaged (for the purposes of the PRC Plan) to continue sequentially leading to continued groundwater extraction during mining within the Project area. Section 10.1 presents the mine plans, including the end-of-mining dates.

The HCMs consider groundwater drawdown at the end-of-mining at different time periods, corresponding with different mine end dates. Based on the proximity of mines and continuous sequencing plus mine locations (such as Broadmeadow GLS underneath GMS), little or no groundwater recovery (and thus contribution to the final voids at GRB) is envisaged until all mining ceases or when underground workings are artificially filled with water.

The prediction of groundwater response to continuous mining, spatial and overtime, will be included in the predictive groundwater modelling.

Figure 25 GRB cross section locations

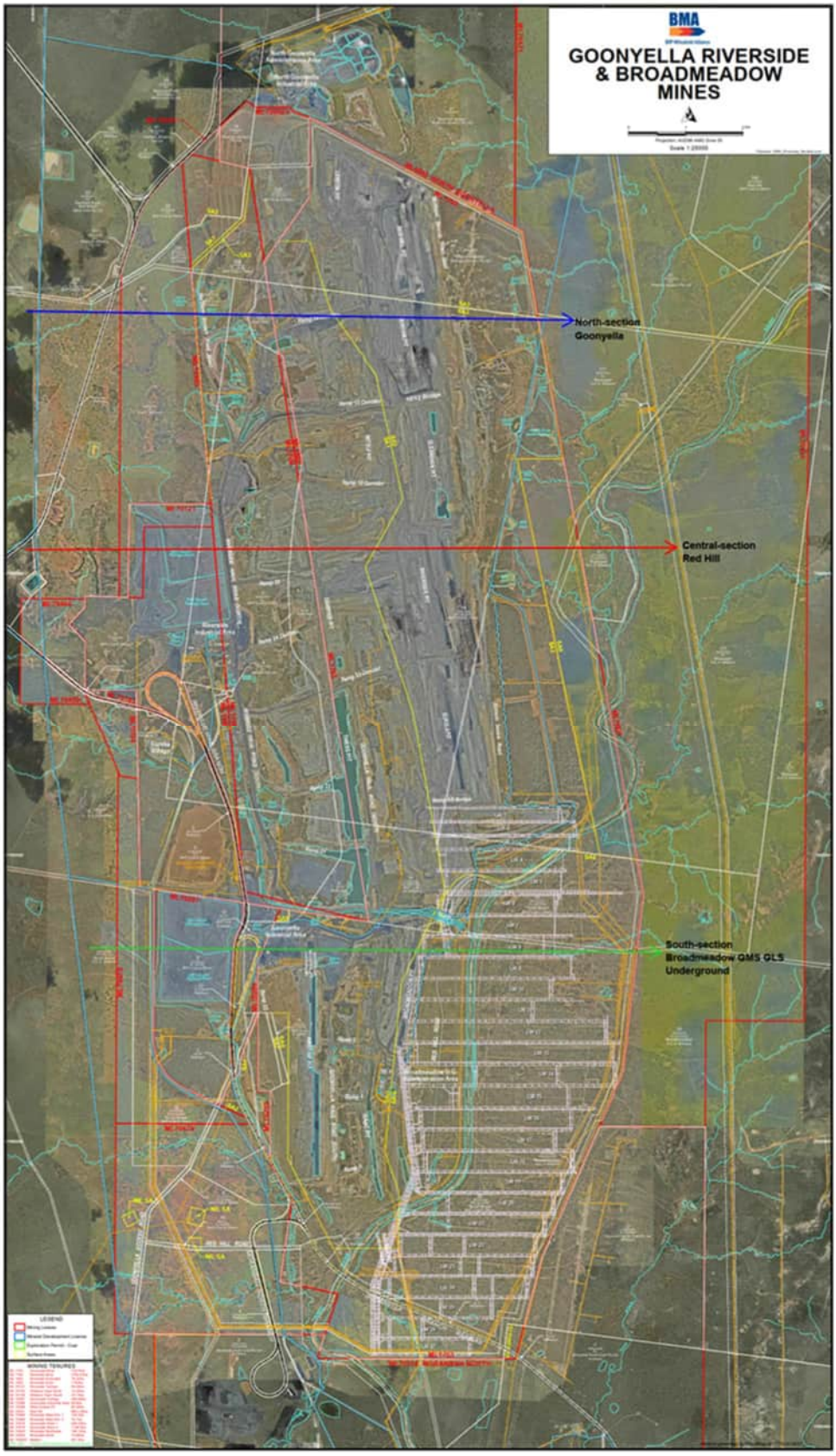


Figure 26 Goonyella open cut mining – North cross-section west to east at end of mining

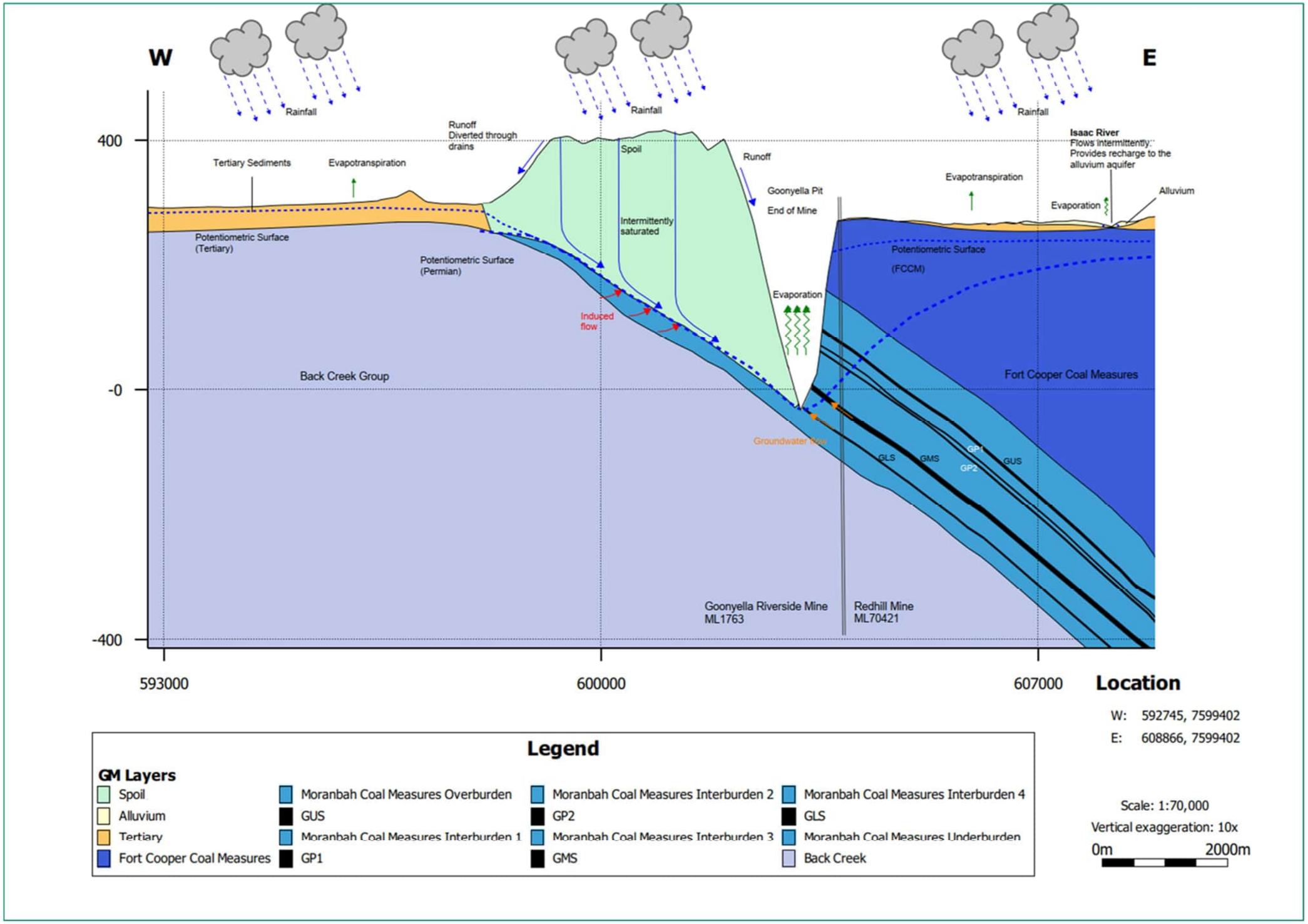


Figure 27 Goonyella open cut and Red Hill underground mines – Central cross-section west to east at end of mine

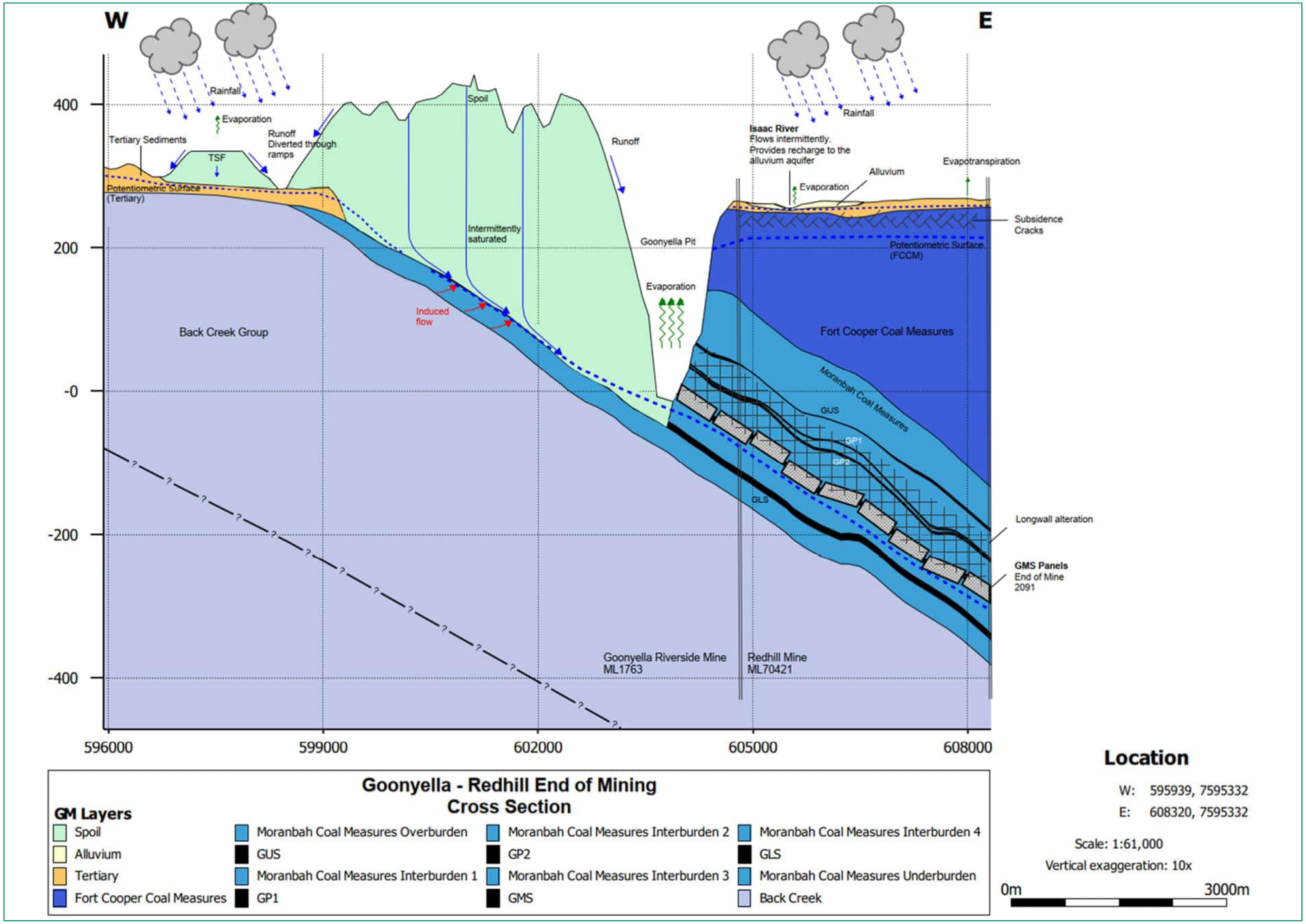
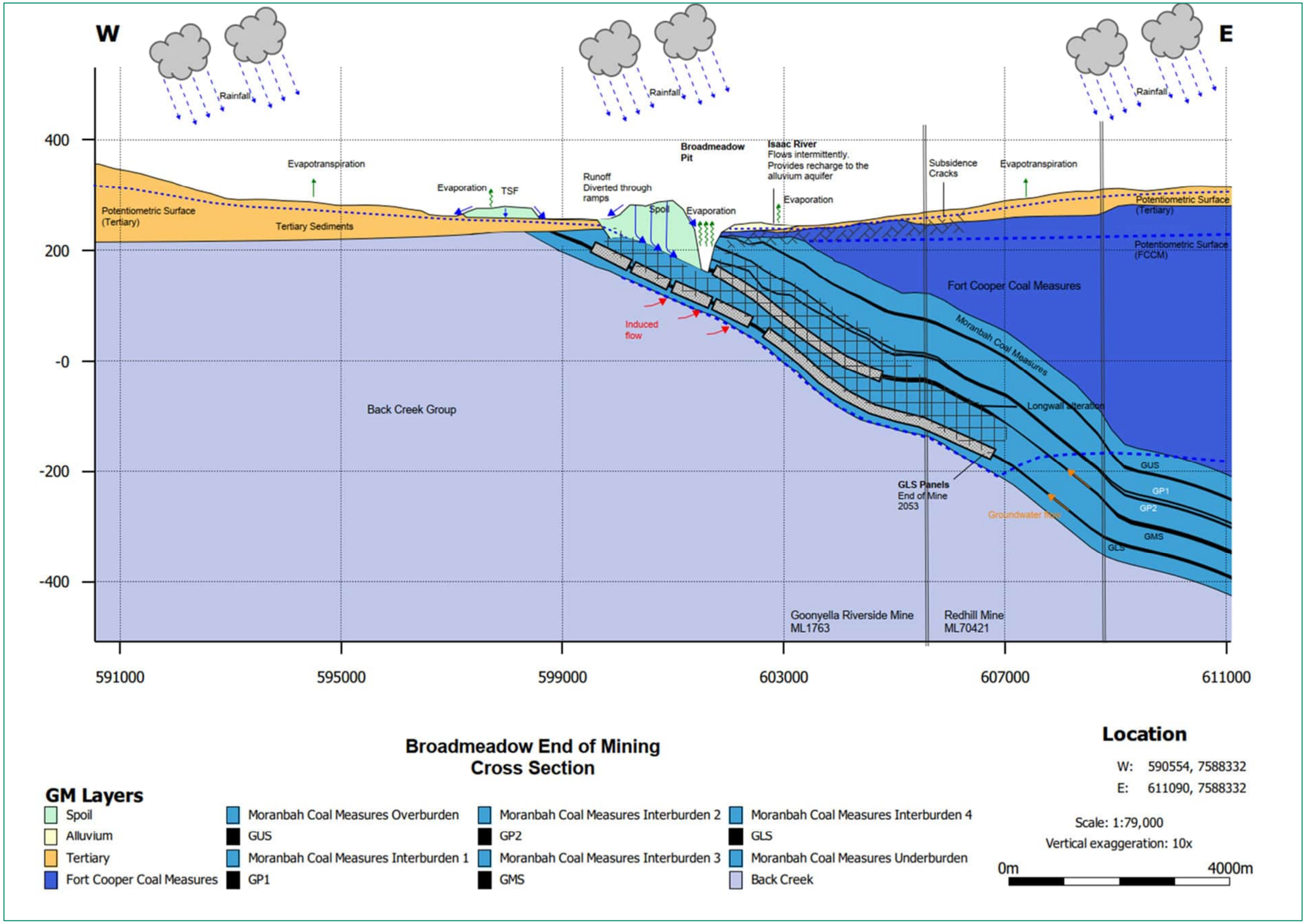


Figure 28 Broadmeadow longwall mining GMS and GLS – South cross-section west to east at end of mining



12.0 Potential Impacts

Potential impacts associated with shallow sources of potential groundwater contamination at GRB are being assessed for the PRC Plan by a separate Contaminated Land Assessment. Therefore, this hydrogeology assessment focuses on the larger scale impacts to the GRB groundwater system. However, the movement of potential contaminants in groundwater that might be associated with seepage from spoil dumps is considered within this hydrogeological assessment.

Predictive groundwater modelling is to include particle tracking simulations, where particles were included in the saturated model cells and the migration over time mapped. Particles moved in response to groundwater head differences, aquifer hydraulic properties, and evaporation from the final voids (acting as groundwater extraction).

These predictions through the generation of hydrographs for hypothetical observation points within and adjacent to the residual voids plus drawdown contours, allowed for the evaluation of the residual voids acting as source or sinks to the groundwater system. This then allowed for the evaluation of the risk of residual void water migrating from the mine leases during closure.

12.1 Groundwater System Post-Mining

The potential impacts to the groundwater system at the end-of-mining, as relevant to the hydrogeology assessment for the PRC Plan, are relative to how the groundwater system recovers from active mining including the groundwater flow regime that results from the final landform. Therefore, it is important to understand the nature of the groundwater system at the conclusion of mining immediately prior to the closure period.

The nature of the GRB groundwater system at the end of mining, and potential groundwater system impacts that may have arisen at the end of mining, can be summarised as:

- Groundwater level drawdown of the Permian coal measures, associated with passive dewatering into the active GRB mine pit voids.
  - The magnitude of this drawdown will be most significant in the immediate vicinity of the pit voids, but extend northwards, eastwards and southwards of GRB by several kilometres and interact with drawdown from nearby mining activities.
- Little to no groundwater level drawdown of the alluvium away from GRB due to limited hydraulic connection between the hydrostratigraphic units (Section 7.3.3). The conceptualisation cross sections (plus predictive modelling) indicate:
  - No groundwater-related effect on surface water flows of the Isaac River
  - Low potential for groundwater level drawdown impacts to potential GDE's
- One of the six water supply bores, located in proximity to the Goonyella residual void, will be impacted (dewatered) as a result of approved mining (Section 15.8.1).
- The comparison of historic and recent groundwater quality data does not readily indicate impacts associated with spoil dumps and TSFs.

12.2 Groundwater System Post-Closure

The potential impacts to the groundwater system at the end-of-mining, as relevant to the hydrogeology assessment for the PRC Plan, are relative to how the groundwater system recovers from active mining including the groundwater flow regime that results from the final landform. Therefore, it is important to understand the nature of the groundwater system recovery and pseudo-steady state conditions post closure.

The predictive groundwater modelling allows for the assessment of groundwater level recovery, groundwater flow patterns, and the influence of residual voids (included in the final landform) on the groundwater resources and receptors.

The post-closure conceptualised groundwater can be summarised as:

- There will be limited recovery in groundwater levels post-closure, with groundwater recovery characterised as ‘slow’ within the Bowen Basin. Limited recovery of groundwater levels naturally was considered due to:
  - Limited rainfall recharge
  - Long term mine dewatering across a large area and several mining areas, which has resulted in groundwater being removed from storage which needs to be replaced before marked changes in groundwater levels will be observed
  - High evaporation over large final void areas (particularly the Goonyella Pit)
  - Low permeability within the sediments surrounding the residual pits.
- Consideration of the climate data, limited runoff (catchment around pits) and limited groundwater ingress would result in the high probability of the residual pit water levels being below pre-mining groundwater levels (i.e., residual voids likely to act as groundwater sinks post-closure).
  - The residual void water level recovery is expected to be below the base of weathering or any shallow Cainozoic aquifers (i.e., limited potential for discharge into the surrounding surficial units, including alluvium).
- Ongoing groundwater discharge to the residual voids driven by the inwards hydraulic gradient between the void lakes and the surrounding groundwater system will be maintained by ongoing evaporative discharge from the voids.

The predicted post mining conditions, considering the residual voids, are presented after Section 13.0, the groundwater modelling. These predictions indicate the likelihood for impacts to receptors, other than one water supply bore in proximity to the Goonyella residual void, is low.

13.0 Groundwater Modelling

The existing RHM predictive groundwater model (**Appendix A**) was adopted for the PRC Plan's hydrogeological assessment (Figure 29). The refinement of the existing model, including increasing the model domain and model boundary conditions, was used to promote efficiencies in the delivery of the outputs for the PRC plan/s.

Figure 29 Extent of the existing RHM model domain

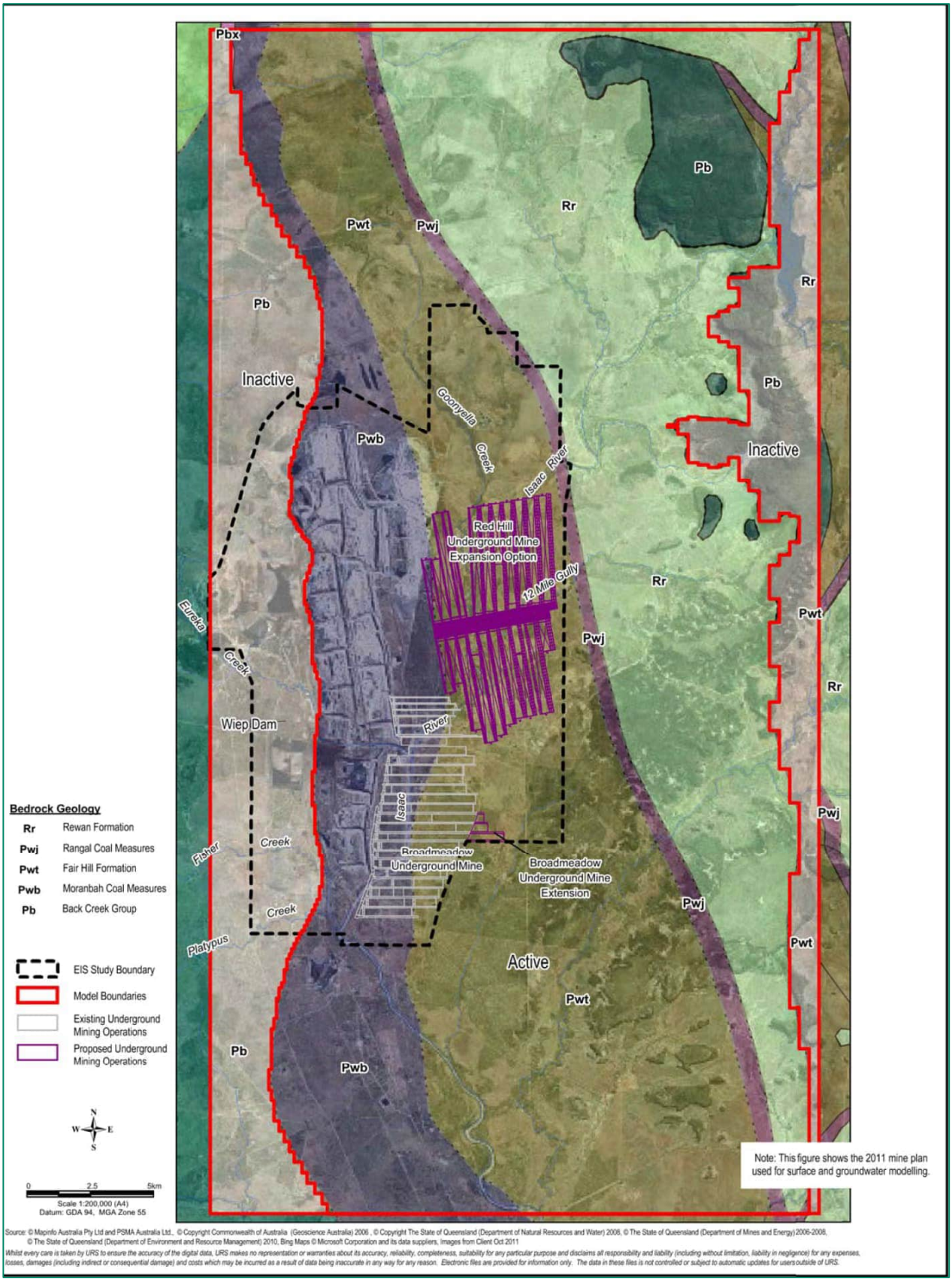
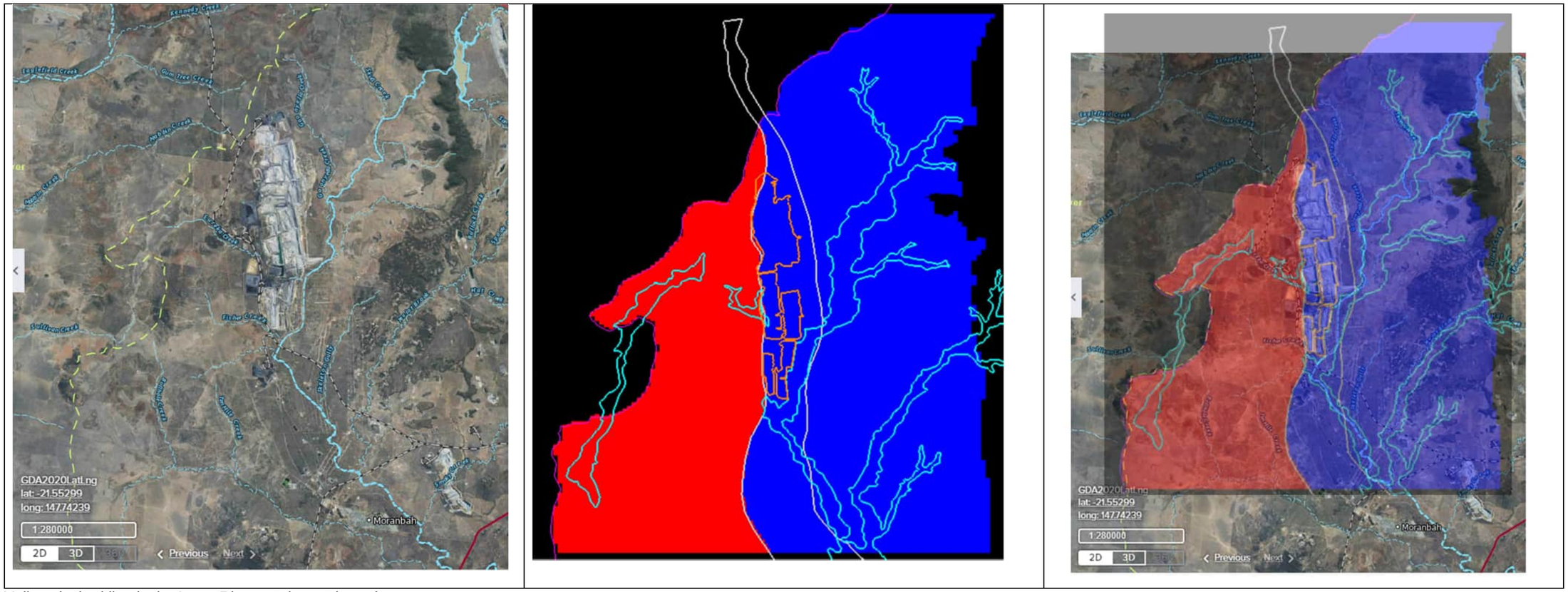


Figure 30 Extent of the refined GRB and RHM model domain



Yellow dashed line is the Isaac River catchment boundary

The red area of the model domain includes the Back Creek Group subcrop, the blue area indicates the coal bearing Permian age sediments. The contact between the two areas illustrates the GLS coal seam subcrop.

13.1 Model Details

AECOM utilised the existing RHM numerical (MODFLOW-SURFACT) groundwater – surface water interaction model with refinement from data compiled since the existing model was constructed and calibrated in 2013.

The use of the existing MODFLOW-SURFACT model, after review of the available more recent geological and hydrogeological data compiled in the report above, was considered suitable based on the following:

- Selection of the model software package
  - The MODFLOW-SURFACT model software package is suitable for dewatering and recovery model simulations in the open cut and underground mine workings. It converts from saturated flow to an unsaturated flow equation as the groundwater elevation drops below the base of the model cell. The key point of MODFLOW-SURFACT is that the cell does not go dry, is never excluded from the numerical calculations, and as heads rise again the model switches the cell back to saturated flow.
- The model allows for the refinement of model grid cell size to ensure the correct relationship between the key features (residual voids) and the model cell sizes (for accurate modelling / predictions).
- The model can simulate possible contaminant migration within groundwater using particle tracking during predictive groundwater modelling.
  - The fate and transport of residual void water can be depicted using particle tracking, where flow directions, extent of migration within groundwater, and variation in flow during the post-mining rebound of groundwater levels and the saturation of sediments in the footwall and hanging wall overtime.
- Model boundary conditions, type and location (sufficiently far from the mine workings to not influence model predictions), were assessed and revised. Noting the eastern model boundary remains as a no flow boundary at the outcrop/subcrop of the Back Creek Group, uplifted along the Burton Fault (Figure 29 and Figure 30).
- The cumulative impacts of the differing mine workings, timeframes, and decommissioning across the Project.

13.2 Model Objectives

The groundwater modelling, as required for input into the PRC Plan, aimed to:

- Assess the potential groundwater related impacts at completion of mining and until conditions stabilise post rehabilitation (Section 15.0).
- Assist in demonstrating the suitability of the final landform for the post mining land uses (i.e., evaluate the residual voids included in the final landform to determine influence on groundwater resources) (Section 15.0 and 17.0).
- Demonstrate that the final landforms are non-polluting with respect to potential poor quality water leaving the mine leases within groundwater (Section 15.6 and 15.7).
- Demonstrate that there are minimal additional impacts to groundwater receptors post-closure caused by the final landforms (Section 15.8).

The predictive groundwater modelling aimed to provide understanding, for Landform Design #2.3 (as included in Section 10.1 Figures 19 to 22), of:

- Groundwater interactions with the residual voids (Section 15.4, 15.6, and 15.7).
- Changes in hydrogeological conditions (including groundwater levels) from the active mining to stable post-mining conditions (Section 15.4.3).

- Impacts to water quality off lease through migration within groundwater.
  - The prediction of potential off lease water quality impacts from mining activities was included to determine appropriate measures for the containment and management of potential contaminant impacts on EVs should these contaminants migrate within the groundwater system (Section 15.6 and 15.7).
- Long term influence on alluvial and Tertiary age hydrostratigraphic units that may host GDEs or future land users (e.g., stock water and/or non-potable domestic use) (Section 15.8).
- Influence of groundwater on surface water resources (Section 13.3.6, 15.8.2, and 17.2).
- Possible on-going water management and reduction requirements (Section 16.0).

AECOM developed a modelling approach methodology to meet the modelling objectives to inform the PRC plan/s, ensure alignment with the guideline, and consideration to address uncertainty in predicted outcomes.

13.3 Model Design

13.3.1 Approach

AECOM 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 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
- Integrated groundwater and surface water modelling (if required).

An existing numerical groundwater model was refined based on the more recent (since 2013) available data to represented current groundwater flow conditions (2020 to 2024) due to the existing GRB mine complex dewatering. The outcome of this transient modelling of the existing approved GRB mine complex impacts (drawdown extent) was used as initial conditions for the predictive model, which undertook four predictive scenarios capturing the different mine plans, decommissioning, injection, and recovery after mining ceased. The four predictive scenarios are summarised in Table 17, and discussed in the prediction Section 15.0.

Table 17 Prediction phases incorporated in the groundwater modelling

Prediction periods	Mining activities
Phase 1: 2024 to 2056	Existing Broadmeadow and Isaac pits remain dewatered Thiess, R32 South, and R32 East have pit water levels Broadmeadow GMS underground mining continues to 2031 Broadmeadow GLS underground mining 2031 to 2055 Broadmeadow underground workings remain dewatered in 2056 Goonyella open cut mining is ongoing
Phase 2: 2057 to 2060	Broadmeadow GMS underground mining altered by goaf Broadmeadow GLS underground mining altered by goaf #-years of water injection into Broadmeadow underground workings
Phase 3: 2061 to 2092	Red Hill Mining conducted 2063 to 2091 Remains dewatered during decommissioning in 2092
Phase 4: 2093 to 2199	RHM changed to goaf 3-years of water injection into RHM Recovery post 2097

The modelling approach comprised the following:

- Simulations of dewatering cones (drawdown contours) and extent at the end of mining (over time in response to different mine plans).
- Groundwater extraction volumes with time into residual voids and mine dewatering activities
  - Groundwater ingress estimates to include in residual void water balance modelling (coupled water balance).

13.3.2 Model conceptualisation

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

The conceptualisation(Section 11.0) of the groundwater resources across the Project area was developed based on geological and hydrogeological data, including 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, relevant data from hydrogeological and gas drainage studies conducted by BMA, and groundwater monitoring data.

The conceptual model, which formed the basis of the predictive model, included for the upper units of the Back Creek Group, the Blackwater Group (MCM and FCCM), and the overlying Tertiary and surficial cover units of the Bowen Basin.

The conceptualisations (as included in the Section 11.0 cross sections) allowed for the groundwater model construction to include for:

- The outcrop/subcrop of the Back Creek Group to the west of the Project (Figure 30).
- A system of thrust faults, approximately 10 kilometres (km) to the east of the RHM footprint, that result in the Back Creek Group having been uplifted against the Rewan Formation (Figure 29).
- An arbitrary distance of approximately 25 kilometres to the north and south of the GRB and RHM mines that was judged to be beyond the influence of potential mine dewatering (Figure 29).

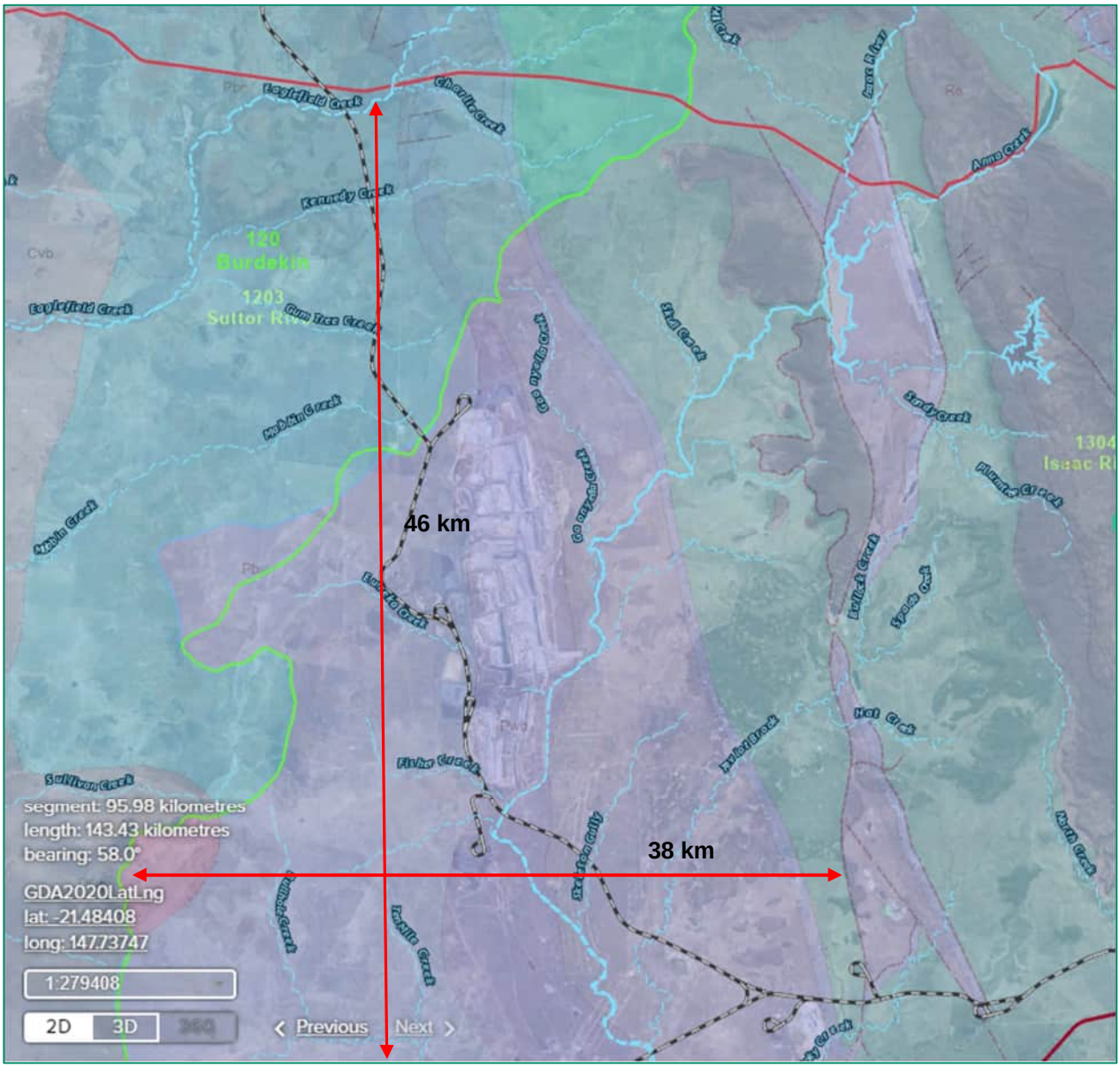
69oy56The model domain for the PRC Plans, considering the conceptualisation based on data assessment, was increased to the west, corresponding to the Isaac River catchment and further north and south, to ensure:

- The model boundaries encompassed all mine activities
- Includes for possible seepage / contaminated groundwater migration
- The model boundaries were sufficiently far from the mine activities so as not to impact on predictions (Figure 30).

13.3.3 Model extent and grid

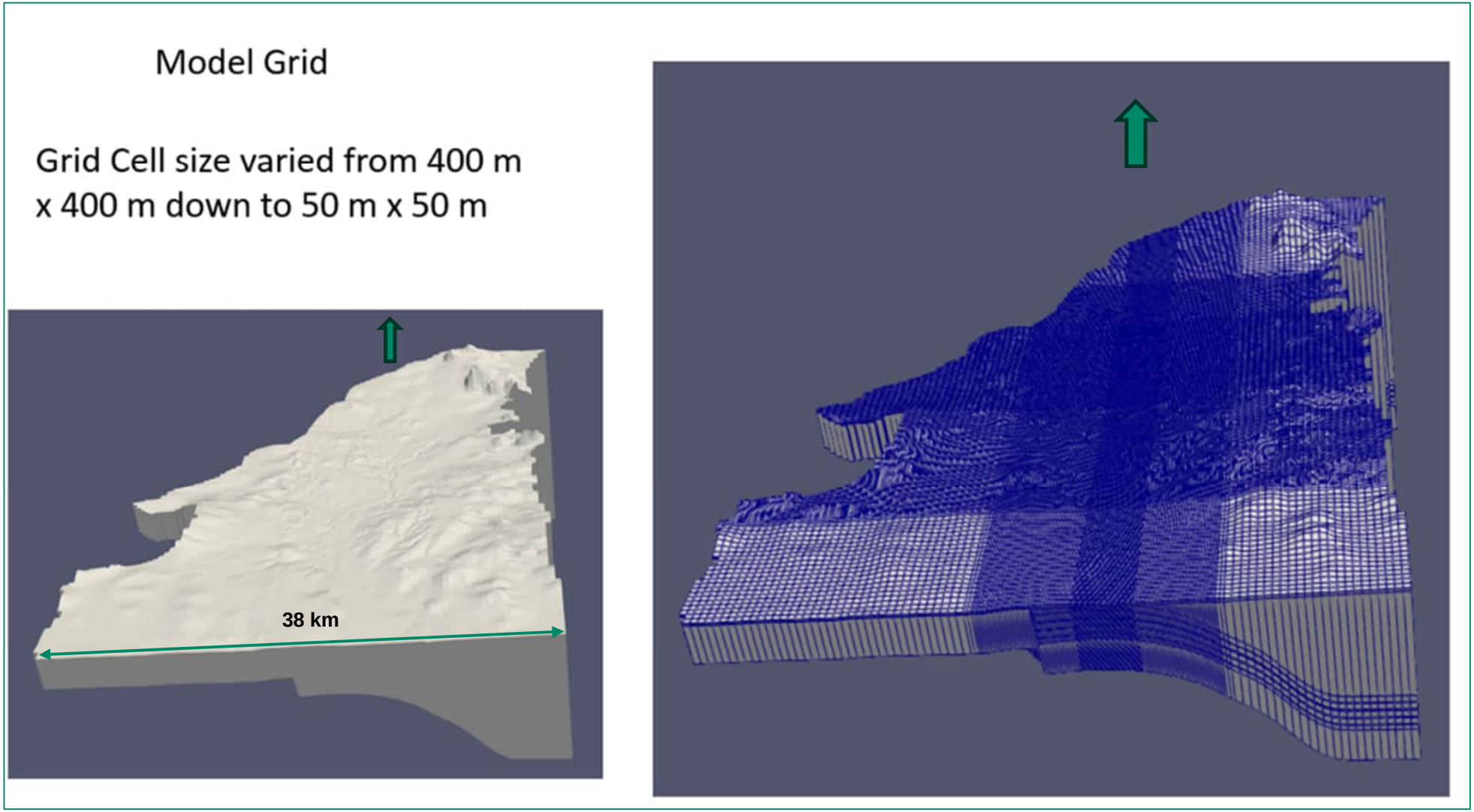
The refined numerical groundwater model was constructed across an area of 46 km by 38 km as shown in Plate 14 and Figure 30, with the Project area situated towards the centre of the model domain based on boundary conditions.

Plate 14 Catchment and geological structure boundaries



The model was constructed with a refined grid of 50 by 50 metres for the mining areas and with grid spacing of 100 x 100 meters up to 400 by 400 metres outside the mining areas, as shown in Plate 15.

Plate 15 Depiction of the 3D groundwater model and cells, showing dip and strike of the lithology



The finite difference model comprised:

- A model area of 1,748 square kilometres
- 422 rows and 223 columns
- 1,117,410 active cells for a fourteen-layer model.

13.3.4 Boundary conditions

Model boundaries, included on Plate 13, which indicates the active model cells (white) and the inactive model cells (black), were based on the model refinement to simulate groundwater conditions. The boundaries include:
Top inflow boundary comprising recharge and evaporation. Available precipitation and evaporation data was reviewed / verified.

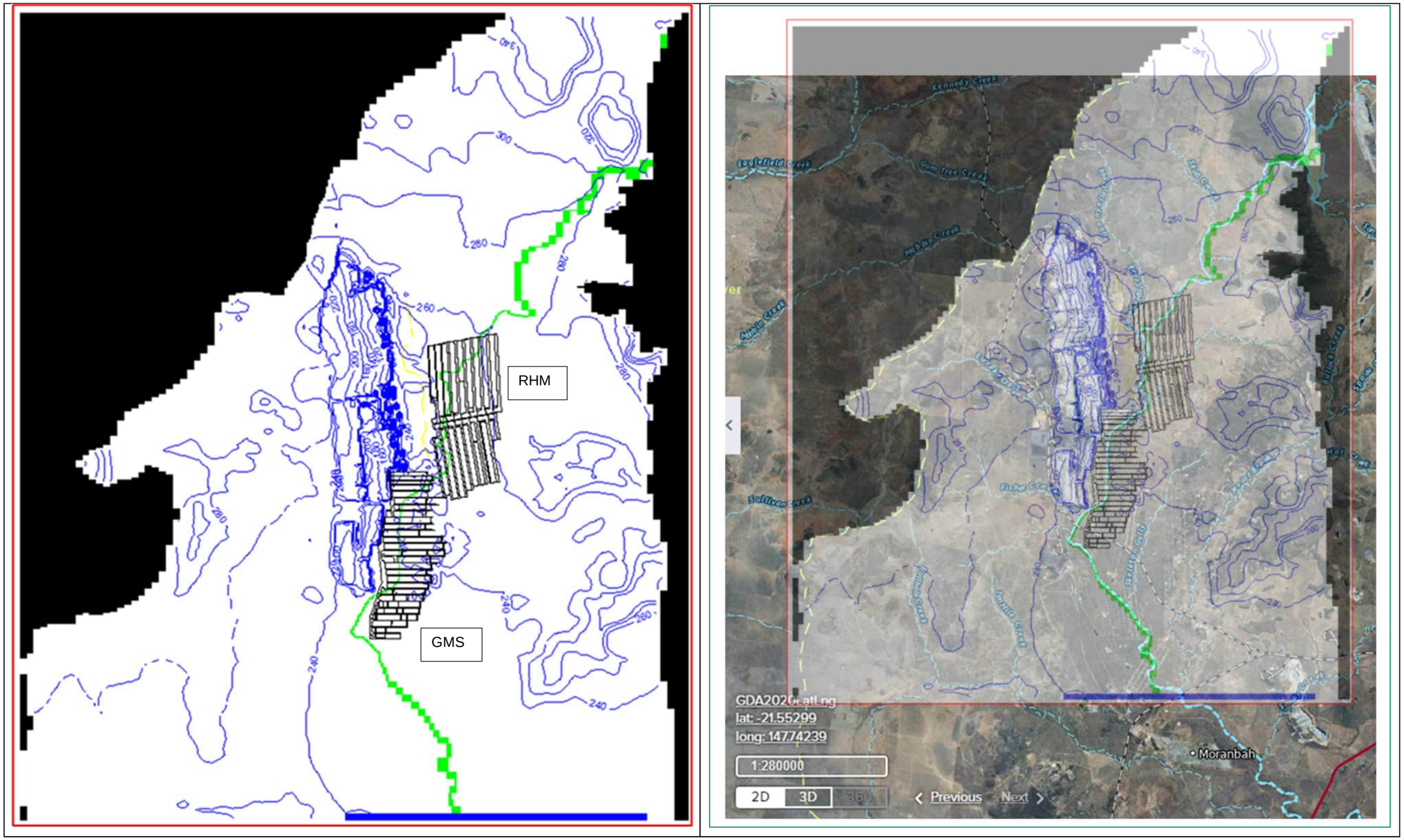
Horizontal inflow boundary based on groundwater level data, which is used to determine the model's east, west, north, and south boundary conditions. Geological log data and groundwater level information was used to set up representative prescribed head boundaries, sufficiently far from the GRB and RHM footprints as follows:

- Eastern boundary – No flow boundary due to thrust faults (Rewan Formation – Back Creek Group contact at surface)
- Western boundary – No flow boundary at the Isaac River catchment boundary, both the Back Creek Group and Tertiary units
- Northern boundaries (northwest corner) – No flow boundary for Tertiary sediments, and a range of constant head boundaries for the MCM
    - 20 mbgl for GUS
    - 25 mbgl for GP1 and GP2
    - 30 mbgl for GMS
    - 40 mbgl for GLS

    No flow the rest of the layers
- Southern boundaries – Constant head for the alluvium and Tertiary (part) at 10 mbgl (blue section along southern boundary Plate 16)
    - Similar no flow and constant heads to northern boundary
    - Since few head observations were available near the boundaries, topographic elevations were used as reference elevations relative to groundwater levels. The groundwater levels were 20 to 40 mbgl for the northern and southern boundaries based on average depth to groundwater from available observations across the survey area.

Bottom inflow boundary considered below the site. Model bottom elevations were determined from floor and roof elevation data 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.

Plate 16 Model Boundaries



LEGEND

Green model cells indicate the Isaac River

RHM – Red Hill Mine

GMS – Broadmeadow GMS mine (historic footprint)

13.3.5 Model layers

Publicly available digital elevation 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 Plate 15), and BMA topographical data was used to represent the ground surface within the refined area (100 metre grid in Plate 15). 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 MCM 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. Fourteen layers, representing the different lithological units across the survey area (Plate 15), were included in the model (Table 18).

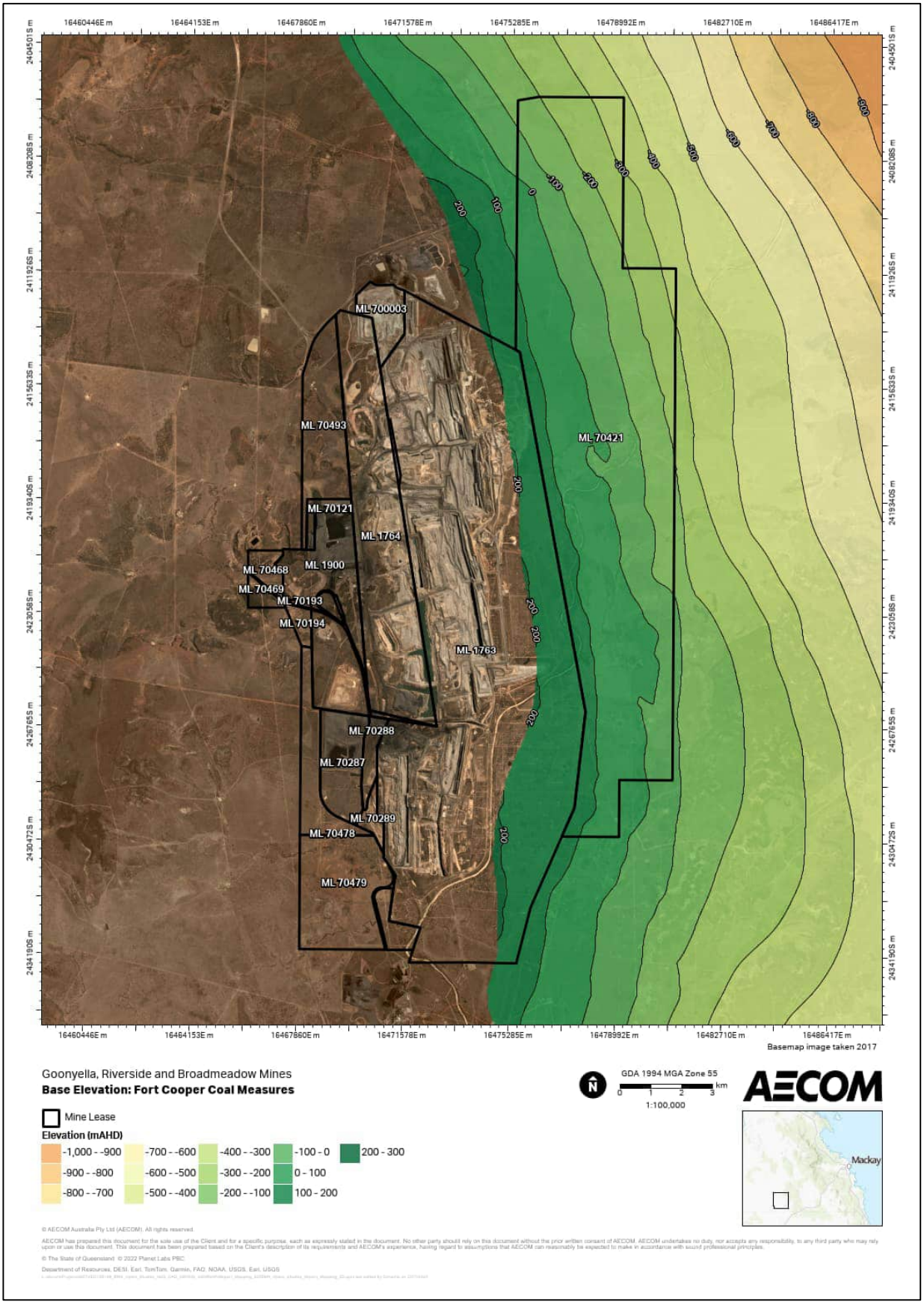
An example of the FCCM floor elevations extrapolated from west (subcrop) to east is include in Plate 17.

Table 18 Model layers

Layer	Unit
1	Tertiary, alluvium
2	FCCM[1]
3	Overburden
4	GUS coal seam
5	Interburden
6	GP1 coal seam
7	Interburden
8	GP2 coal seam
9	Interburden
10	GMS coal seam
11	Interburden
12	GLS coal seam
13	Underburden
14	Back Creek Group

[1] The FCCM is depicted in the PRC Plan model as a single model layer, including for coal seams and interburden. This simplification of this layered seam and aquitard formation was adopted to facilitate the running (calibration and predictions) of the large model domain and cell size. The use of bulk hydraulic parameters allowed for the inclusion of the FCCM in the model.

Plate 17 FCCM subcrop and floor elevation example


16460446E m
16464153E m
16467860E m
16471578E m
16475285E m
16478992E m
16482710E m
16486417E m
2404501S m
2408208S m
2411926S m
2415633S m
2419340S m
2423058S m
2426765S m
2430472S m
2434190S m
ML 700003
ML 70493
ML 70421
ML 70121
ML 1764
ML 1900
ML 70468
ML 70469
ML 70193
ML 70194
ML 1763
ML 70288
ML 70287
ML 70289
ML 70478
ML 70479
Basemap image taken 2017
Goonyella, Riverside and Broadmeadow Mines
Base Elevation: Fort Cooper Coal Measures
Mine Lease
Elevation (mAHD)
-1,000 - -900
-900 - -800
-800 - -700
-700 - -600
-600 - -500
-500 - -400
-400 - -300
-300 - -200
-200 - -100
-100 - 0
0 - 100
100 - 200
200 - 300
GDA 1994 MGA Zone 55
km
1:100,000
AECOM
Mackay

13.3.5.1 Faults

It is important to note that faults can act as both conduits for groundwater flow and, in the case of coal seams, barriers to flow. The eastern boundary of the model is along the Burton Fault, where the Rewan Formation and Blackwater Group units are significantly offset, and is considered a no flow boundary.

Within the Project area, the MCM 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 were simplified to allow continuous groundwater flow and to tie in with the interpolated levels beyond the Project 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 allowed for the assessment of impacts over a larger area.

13.3.6 Rainfall Recharge

Recorded site specific climate data is summarised in Section 4.1. The average annual rainfall around the Project area is between 500 mm and 560 mm. High rainfall and evaporation occur in the summer months (December to February). Monthly evaporation rates are higher than monthly rainfall amounts throughout the year, indicating a net loss due to evaporation (i.e., a negative climate balance which has implications for final void water levels). The average evaporation rate is approximately 2 m per year.

Through a review of available data and previous modelling), recharge rates were determined to 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.

13.3.6.1 Alluvium recharge and discharge

Variation in rainfall recharge, to assess sensitivity of rainfall recharge in the model, was included during modelling to assess recharge to alluvium. As the majority of alluvium monitoring bores were dry, allowing additional recharge to facilitate saturated conditions in the alluvium and flow towards the creeks and Isaac River. The groundwater model was used, allowing for differences in rainfall recharge, to assess the potential loss from the alluvium to the underlying hydrostratigraphic units (and resultant reduction in surface water contribution).

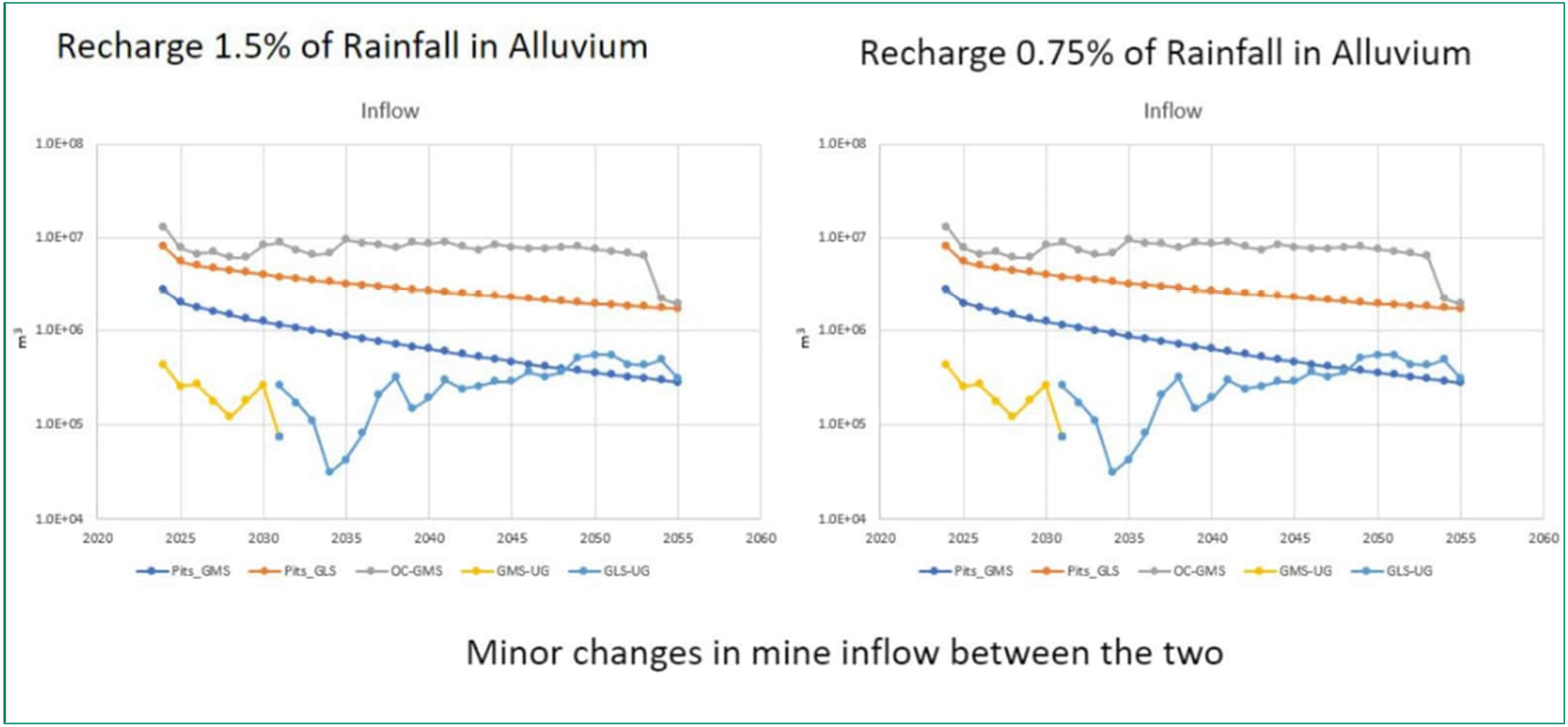
Recharge rates of 1.5 per cent (wet conditions) and 0.75 per cent (dry conditions) of annual rainfall was included in the model calibration and assessed through the model water budget (Section 14.4).

The mine inflow predictions, for the period to the end of the Broadmeadow underground mining, is included in Figure 31. This figure presents the estimates of groundwater ingress into the different mine pits, the ongoing Goonyella open cut mining, and the GMS and GLS underground mining.

The modelled inflows, allowing for wet and dry rainfall conditions to the alluvium, does not indicate increased ingress into the mine workings under the two simulations of recharge (i.e., 1.5% or 0.75% of mean annual rainfall acting as recharge).

The alluvium water table (discontinuous unconfined conditions) and the piezometric levels (confined conditions) associated with the deeper coal seam aquifer groundwater data indicate a marked separation (i.e., based on available data presented and assessed in Section 7.3.3 there is no hydraulic connection between the alluvium water table and the confined aquifers). Thus, the vertical movement from the alluvium, when saturated, is limited even taking possible subsidence alteration into account (i.e., the limited groundwater resources associated with the alluvium remains separated from the confined piezometric levels even if additional water is added to the alluvium (as recharge) or the separation between the water table and the piezometric levels are increased (due to mine dewatering leading to larger vertical groundwater gradients).

Figure 31 Groundwater ingress considering recharge variation to the alluvium (ingress in m^3 per year versus years)



Pits_GMS - Inflow estimates into residual voids which target the GMS seam
Pits_GLS – Inflow estimates into residual voids which target the GLS seam
OC_GMS – Inflow estimates for continued open cut GMS mining
GMS_UG – Inflow estimates for the GMS underground mining
GLS_UG – Inflow estimates for the GLS underground mining

13.3.7 Hydraulic parameters

The ranges of hydraulic conductivity (K) and storativity values, included in the original RHM model were derived from aquifer hydraulic testing and literature values where onsite data was not available. These aquifer hydraulic properties are included in Table 19 and were refined during model calibration (Section 14.3).

Table 19 Summary of calibrated parameters in the original RHM model

Model Layer	Unit	Kh (m/day)	Kv (m/day)
1	Tertiary, alluvium	0.49	0.049
2	FCCM	1.00 E-03	1.00E-04
3	Overburden	1.08E-04	1.08E-05
4	GUS coal seam	Distribution*	Distribution* x 0.1
5	Interburden	1.08E-04	1.08E-05
6	GP1 coal seam	Distribution*	Distribution* x 0.1
7	Interburden	1.08E-04	1.08E-05
8	GP2 coal seam	Distribution*	Distribution* x 0.1
9	Interburden	1.08E-04	1.08E-05
10	GMS coal seam	Distribution*	Distribution* x 0.1
11	Interburden	1.08E-04	1.08E-05
12	GLS coal seam	Distribution*	Distribution* x 0.1
13	Underburden	1.08E-04	1.08E-05
14	Back Creek Group	1.08E-04	1.08E-05

*K distribution derived from regression formula

The calibrated aquifer hydraulic parameters plus method used to derive the parameters are include in Section 14.3.4.

13.3.7.1 Simulation of mine dewatering using drains

In order to simulate 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 GLS or 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. When the groundwater level was above the bottom of the drain water was removed from the model domain at a rate determined by the head difference (within and adjacent to the workings) and the drain hydraulic conductance.

The drains were activated according to the Project mine plans (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 in order to:

- Estimate the total volume of groundwater to be removed at the end of mining
- Determine the groundwater drawdown / groundwater elevation heads prior to decommissioning and closure activities.

These data were used as initial inputs into the residual water balance modelling (Section 15.0).

Drains were then converted to constant head boundaries (MODHMS CHD package) in the model, to level predicted in the (surface water and groundwater) residual void water balance model (Section 15.4). .

The introduction of the residual void water levels (as CHD) resulted in reduced groundwater gradients, around the residual voids. Using the CHD elevations allowed for evaluation of drawdown and long term groundwater conditions when the water levels in the residual voids reach pseudo-steady state.

These closure groundwater conditions allowed for the assessment of groundwater flow, potential contaminant migration in groundwater, and impacts post-closure (Section 15.6).

13.3.7.2 Simulation of mine dewatering considering goaf alteration

To further estimate groundwater ingress during mining activities, consideration and simulation of aquifer alteration (due to longwall mining (goaf)) was undertaken. The use of EPM, as detailed in Section 7.3.4, was included to alter aquifer parameters after longwall mining was complete.

14.0 PRC Plan Landform #2.3 Model

The post-mining final GRB landform relevant to this hydrogeological assessment was provided by BMA (denoted Landform #2.3) and is shown as Figure 3. The final landform contains six residual (final) voids:

- Goonyella Pit
- Thiess / Ramp 21 Pit
- Ramp 32 East,
- Ramp 32 South,
- Broadmeadow Pit, and
- Isaac Pit.

14.1 Existing conditions

Open cut and underground mining at GRB has been ongoing since the 2013 groundwater model was constructed, as described in Section 1.1. The RHM original model was refined to include for the open cut mining, placement of backfill (referred to as spoil), the various pits plus the Broadmeadow GMS mining panels, which had been mined since the original model set-up.

The model was constructed using the historic mine plans to replicate the mine conditions for 2020 (the start of the transient groundwater calibration period), including the location of pits, spoil, and longwall panels (Plate 18).

The pits, highlighted in blue on Plate 18, are labelled in Figure 2.

The spoil, for use in the zone budget (refer to Section 14.2) required to estimate groundwater ingress sources (spoil or natural, for example), was further refined in the model set-up. Plate 19 indicates the subdivisions of the spoil as follows:

- Red outlined areas – Historic spoil areas in 2020
- Yellow highlight areas – GMS open cut mining between 2012 and 2019 (backfilled with spoil)
- Pink areas – surface areas to be mined (open cut), 2019 to 2059).

The Broadmeadow mine areas, included as goaf in the model set-up, are shown in Plate 20.

The GMS mining is delineated as:

- Yellow areas – GMS underground mining (2010 to 2019) based on historic mine plan
- Green areas- future GMS longwall panels post 2019.

Plate 18 2020 pit locations and spoil locations (red areas)

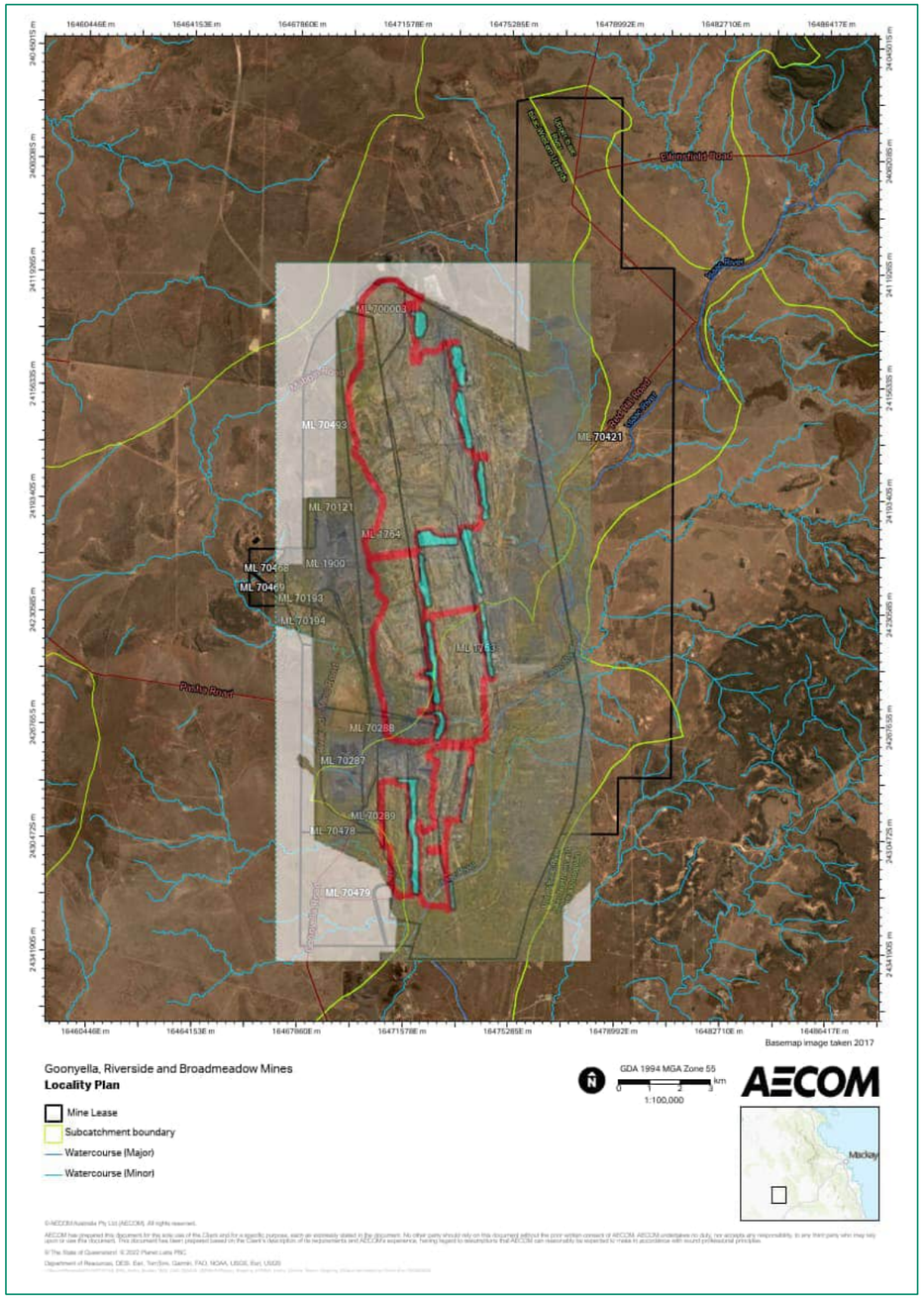


Plate 19 2020 spoil subdivisions

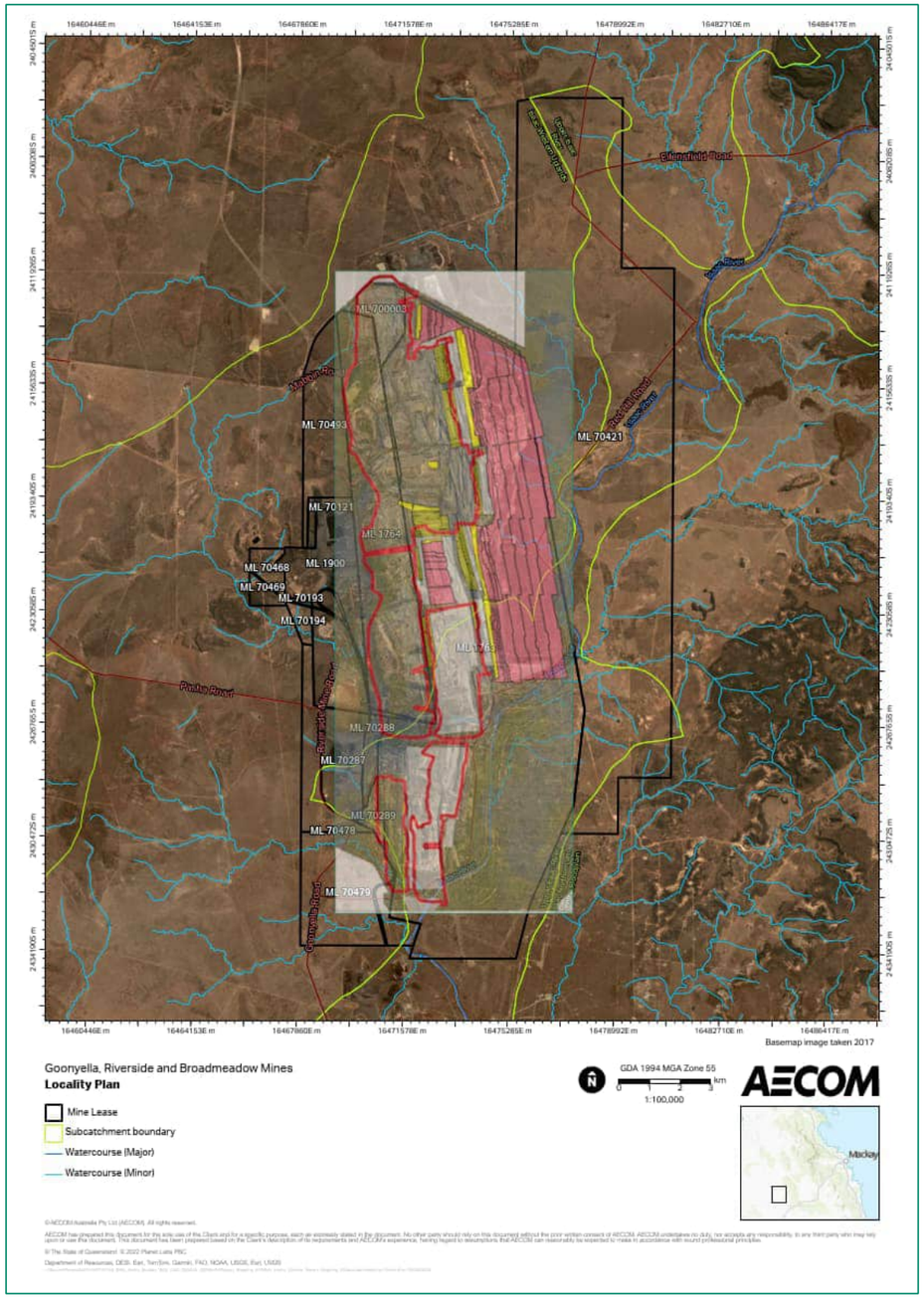


Plate 20 Goaf areas in 2019

14.2 Model Setup

The mine plan/s (Plate 21) schedules (overlapping and continual over time), decommissioning, and alteration of geology and groundwater (aquifer hydraulic parameters) required the model to be set-up to simulate mine dewatering, water injection into the underground workings, and alteration (goaf and spoil backfill areas).

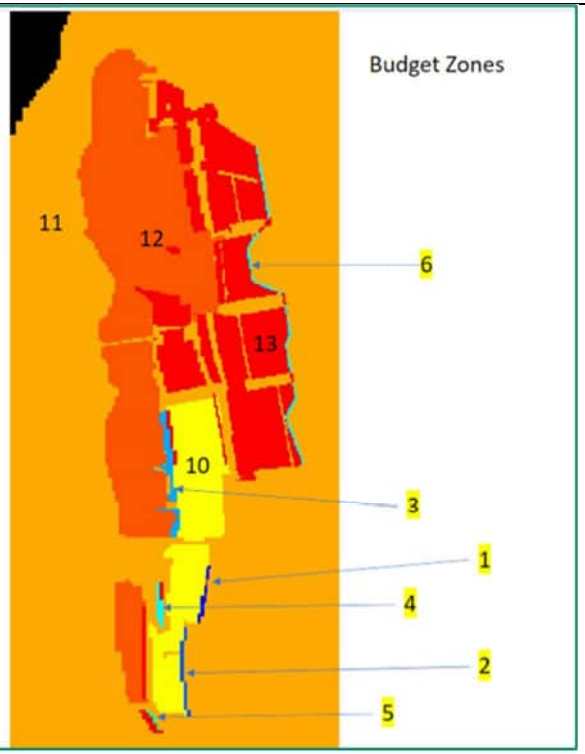
The objective of the groundwater modelling was to provide input (predictions of groundwater ingress into the residual voids post closure) to the water balance model, which considers all inputs and outputs from the residual voids. Long term pit water levels can then be estimated.

To provide the groundwater contribution, from spoil and natural geology, the model was set-up to include zones. The predictive model can then be used to assess ingress or outflow from the residual voids using a model zone budget.

The water budget zones, corresponding to mine areas (pits, spoil, or natural / undisturbed geology), are included in Figure 32.

Figure 32 Budget zones

Water Budget Zones	Starting date	Down to Layer	Zone
Broadmeadow	2009	10 (GMS)	1
Issac	1997	10 (GMS)	2
Thiess & Ramp 21	2016	12 (GLS)	3
R32 East	2037	12 (GLS)	4
Ramp 32 South	2026	12 (GLS)	5
Goonyella	2060	12 (GLS)	6
GW		All layers	11
Spoil to Layer 10	2020	10 (GMS)	10
Spoil to Layer 12	2020	12 (GLS)	12
Spoil in Goonyella Open cuts	2060	12 (GLS)	13



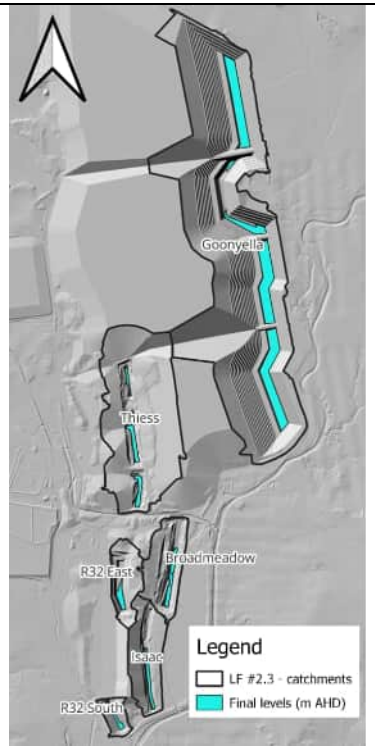
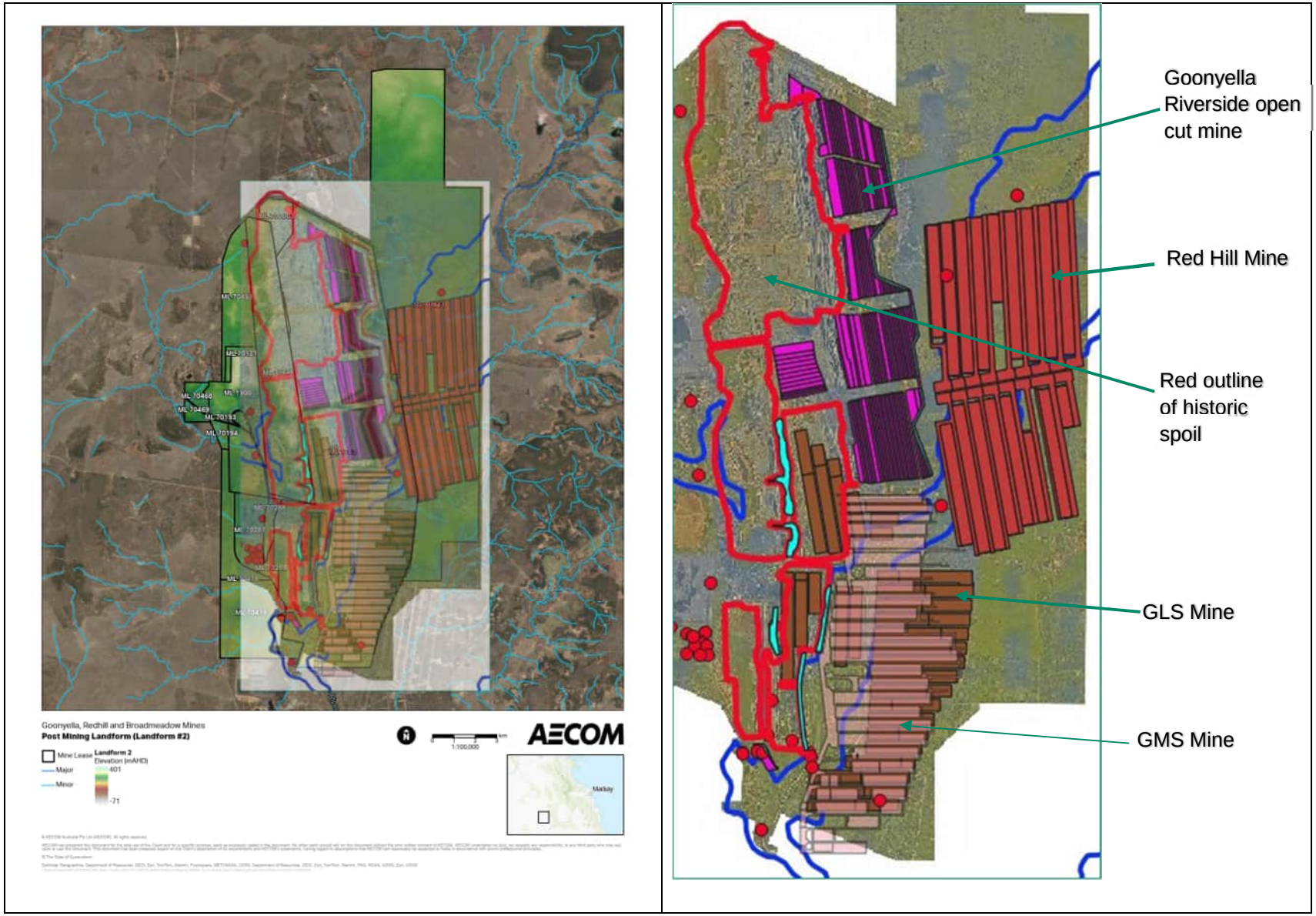


Plate 21 Mine areas historic and future



14.2.1 Introduction of water into the underground workings

Geotechnical assessments at the Project recommended the filling of the underground workings with water to ensure long term stability. The introduction of water into the underground workings, as part of the decommissioning (Table 15), was included in the modelling.

Options to simulate the introduction of water included changing the mine workings drain cells to constant head boundaries (based on the portal entrance elevations), injection down the portals, or simulating injection via vertical bores.

BMA, based on historic groundwater volumes removed from the Broadmeadow GMS workings and mine plans, provided estimates of water to be introduced into the underground workings over three (3) years.

The Broadmeadow underground mining areas received 5.34 GL over a 3 year period. Red Hill Mine received 4.94 GL over a 3 year period. This approach was adopted to aid with the PRC Plan assessment, it is considered that the timing of the introduction of water may lengthen based on water availability.

To best simulate this volume of water over a three year period the model was set-up to allow for the injection of water into the model cells across the mine footprints.

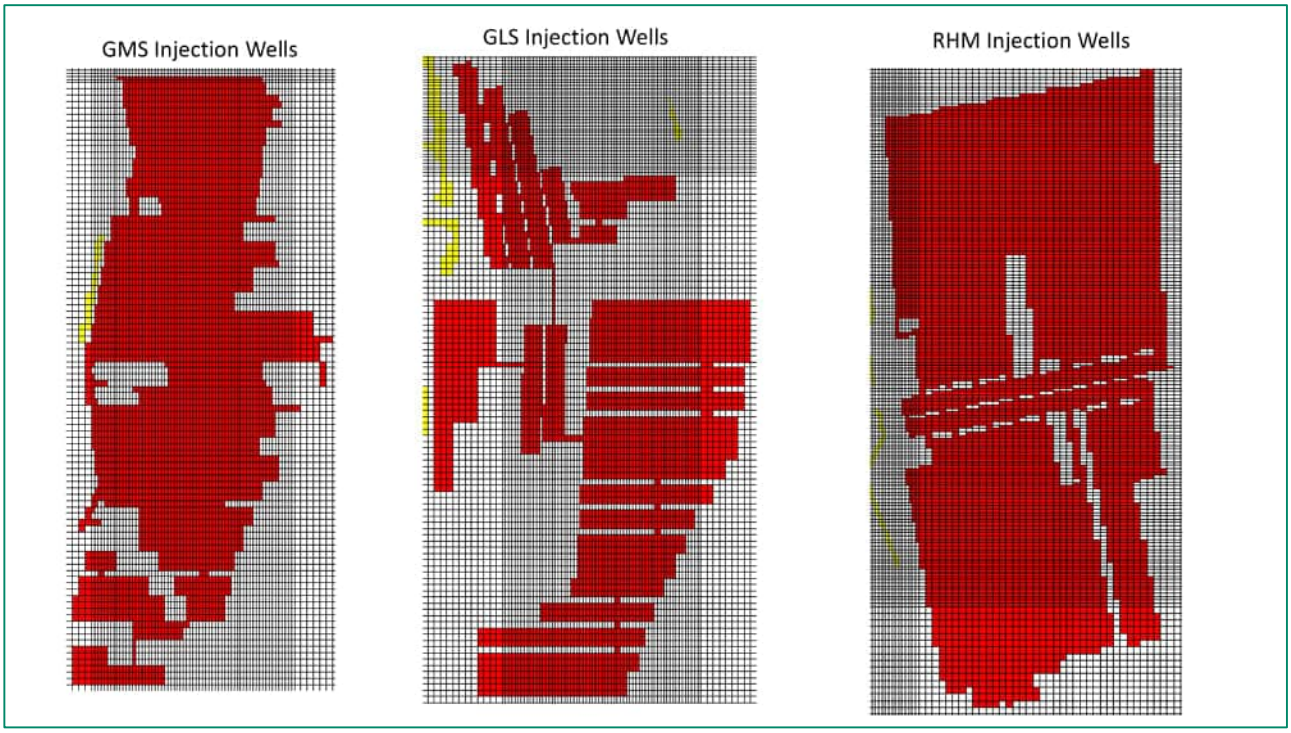
The introduced water was divided up between the two Broadmeadow underground mines based on size.

- The Broadmeadow GMS mine plan covered an area which contained 4,171 model cells. Injection was simulated by introducing 6.22 m^3/day into each of the model cells for 3 years.
- The Broadmeadow GLS mine plan covered an area which contained 3,684 model cells. Injection was simulated by introducing 6.18 m^3/day into each of the model cells for 3 years.

The RHM mine plan covers 6,005 model cells, the injection into each model cell was 7.51 m^3/day for 3 years.

Areas at the underground workings, which will receive the introduced water, are included on Plate 22.

Plate 22 Red model cells allowing for the introduction of water in the model



14.3 Calibration

The refined numerical groundwater includes a transient calibration (2020 to 2024) based on the most recent groundwater monitoring data. The initial conditions were derived from the prior pseudo-steady conditions covering the period from 1996 to 2009 plus the historic mining (2010 to 2019), and average climate conditions during these periods.

The calibration used 260 target heads for 50 bores at GRB (Figure 8). The transient calibration captured the historical mining at GRB. Mining was represented in the model using the MODFLOW drain package, with the drain cells set to the base of the target coal seam for each pit, and within the target GMS coal seam for the Broadmeadow underground mine.

Calibration of the model was carried out with the objective being to replicate the groundwater levels measured at and adjacent to GRB, as well as some registered bores, in accordance with Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

The calibration targets, datasets and monitoring points, plus corresponding model layers are included in **Appendix C**.

14.3.1 Approach

The calibration approach included:

1. Model calibration to depict the hydrogeological framework, aquifer hydraulic properties, and boundary conditions.
2. Achieve correlation between the model output and measured/observed field data.
3. Determine optimal set of parameter values and boundary conditions that minimise the discrepancy between simulated and observed data.

The calibration targets included:

- Transient Head Targets, for data available from 2020 to 2024 (Q1).
- Aquifer test data (hydraulic conductivity parameter constraints).

The modelling tools used included PEST++ with the Iterative Ensemble Smoother algorithm, referred to as PESTPP-IES.

The calibration results were assessed through the evaluation of calibration criteria, including:

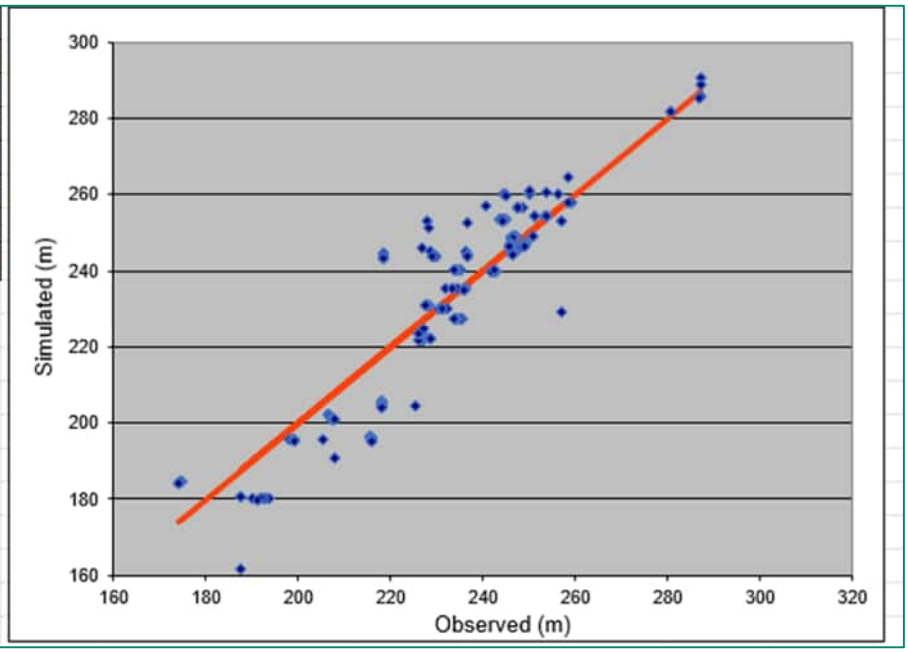
- The root mean square error (RMSE)
- The mean error (ME)
- Coefficient of determination (R^2).

14.3.2 Calibration statistics

Calibration for the model (Plate 23) achieved the following statistics: a 9.55 m root mean square (RMSE) error, equating to an 8.4% scaled root mean square (SRMSE) error, which is within the recommended range (i.e. 10%) in the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

Plate 23 Calibration results (entire dataset)

Mean Error	-0.23
RMSE	9.55
SD	9.57
Head range	113.27
Scaled ME	-0.20%
Scaled RMSE	8.4%
Scaled SD	8.4%
R^2	0.85



Two groundwater monitoring bores, GRM_BH2A and GRM_BH3A, located immediately adjacent to a mine water dam (Plate 24), could not readily be calibrated. The water levels within these bores were markedly lower than the surround monitoring bores and there is no obvious mine dewatering impacts (within the Tertiary sediments above the Back Creek Group basement lithology).

Removal of these two anomalous groundwater elevation data points (possibly related to poor bore construction grouting) allowed for an improvement in the transient groundwater model calibration statistics (Plate 25).

The revised calibration statistics (Plate 25) included an 8.66 m root mean square (RMSE) error, equating to a 7.6% scaled root mean square (SRMSE) error.

Plate 24 GRM_BH2A and GRM_BH3A bores

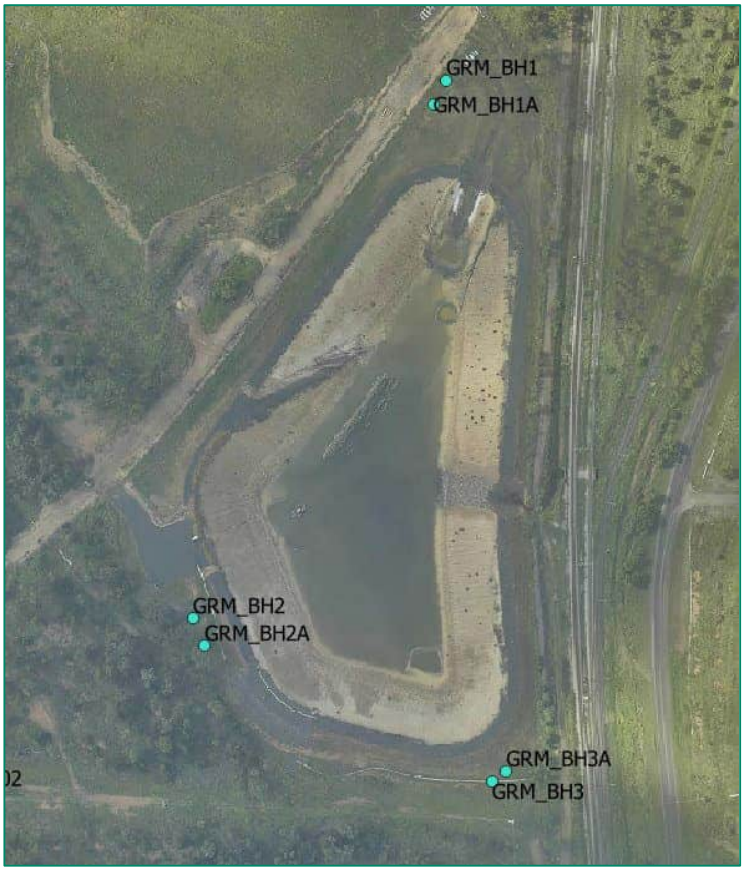
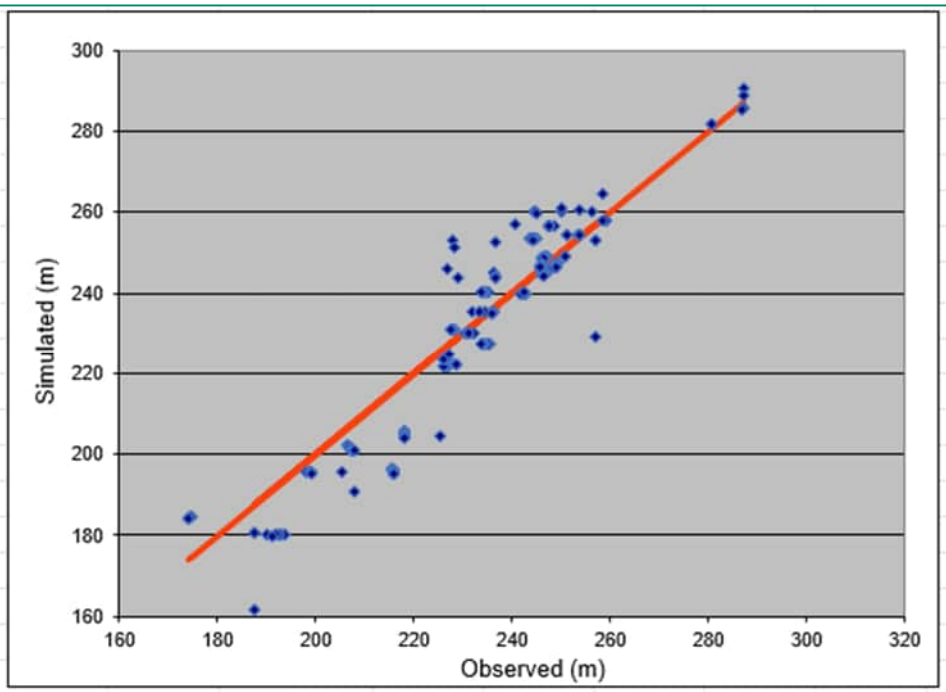


Plate 25 Edited dataset calibration results

Mean Error	0.73
RMSE	8.66
SD	8.65
Head range	113.27
Scaled ME	0.64%
Scaled RMSE	7.6%
Scaled SD	7.6%
R^2	0.89



14.3.3 Transient data hydrographs

The transient water level data recorded between 2020 to 2024 is presented in hydrographs with the model simulation results. The hydrographs indicate trend matching across the model domain (Figure 33).

14.3.4 Calibrated aquifer hydraulic parameters

The calibration approach, Section 14.3.1, using the parameter estimation software (PEST) allowed for the estimation of aquifer parameters for each of the model layers. Table 20 presents the parameters, hydraulic conductivity and storage, plus the depth range for each layer across the model domain.

The method for deriving the aquifer hydraulic properties included:

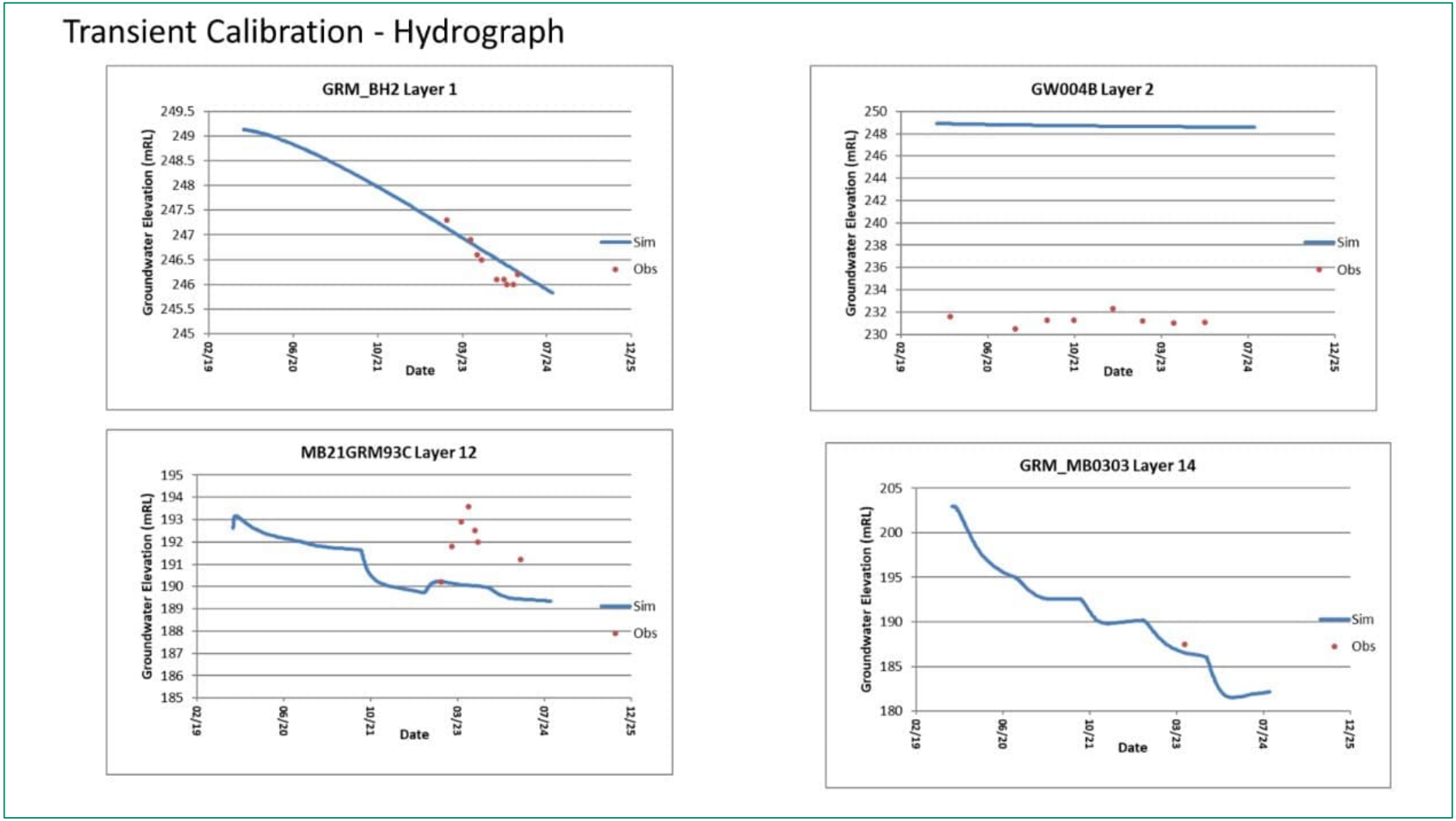
- Pilot – Using pilot points within the model domain
- Uniform – Homogeneous distribution in the aquitard layers
- Pilot plus regression, where the cut-off depth for switching between pilot point and regression estimates is determined by PEST.
    - Noting that for depths shallower than the cut-off then the pilot pointe estimate is adopted, if deeper than the cut-off then the value from the regression equation is adopted.

The regression equation is aa*exp(-bb*depth), where:

aa = 0.2703
bb = 0.016

Layer	Kx_Max	Kx_Min	Cut-off depth (m)	
4	0.025	1.00E-05	500	
6	0.025	1.00E-05	267.49	
8	0.025	1.00E-05	0	Only regression, no pilot point estimates
10	0.025	1.00E-05	336	
12	0.025	1.00E-05	435.64	

Figure 33 Groundwater model calibration transient hydrographs examples



Blue line – simulated (sim) model water level hydrograph

Obs – Available transient groundwater level measurements

Table 20 Summary of hydraulic parameters in the PRC Plan model

Model Layer	Unit	Kh / Kv (anisotropy)	Kh min (m/day)	Kh max (m/day)	Sy min	Sy max	Sc min	Sc max	Thickness From (m)	Thickness To (m)	Method
1	Tertiary, alluvium	10	1.0E-02	1.0E+01	5.0E-02	2.0E-01	1.0E-06	1.0E-04	15	20	Pilot
2	FCCM	10	1.0E-05	1.0E-01	5.0E-03	1.0E-01	1.0E-06	1.0E-04	42	880	Pilot
3	Overburden	100	1.0E-05	5.0E-02	1.0E-02	1.0E-01	1.0E-06	1.0E-04	30	50	Uniform
4	GUS coal seam	100	1.0E-05	5.0E-02	5.0E-03	5.0E-02	1.0E-06	1.0E-04	2.5	5	Pilot+Reg.
5	Interburden	100	1.0E-05	5.0E-02	1.0E-02	1.0E-01	1.0E-06	1.0E-04	25	40	Uniform
6	GP1 coal seam	100	1.0E-05	5.0E-02	5.0E-03	5.0E-02	1.0E-06	1.0E-04	2.5	4	Pilot+Reg.
7	Interburden	100	1.0E-05	5.0E-02	1.0E-02	1.0E-01	1.0E-06	1.0E-04	15	40	Uniform
8	GP2 coal seam	100	1.0E-05	5.0E-02	5.0E-03	5.0E-02	1.0E-06	1.0E-04	2.5	5	Regression
9	Interburden	100	1.0E-05	5.0E-02	1.0E-02	1.0E-01	1.0E-06	1.0E-04	30	40	Uniform
10	GMS coal seam	100	1.0E-05	5.0E-02	5.0E-03	5.0E-02	1.0E-06	1.0E-04	2.5	8	Pilot+Reg.
11	Interburden	100	1.0E-05	5.0E-02	1.0E-02	1.0E-01	1.0E-06	1.0E-04	30	50	Uniform
12	GLS coal seam	100	1.0E-05	5.0E-02	5.0E-03	5.0E-02	1.0E-06	1.0E-04	2.5	5	Pilot+Reg.
13	Underburden	100	1.0E-05	5.0E-02	1.0E-02	1.0E-01	1.0E-06	1.0E-04	30	40	Uniform
14	Back Creek Group	100	1.0E-05	5.0E-02	1.0E-02	1.0E-01	1.0E-06	1.0E-04	200	500	Pilot

Pilot + Reg. - Pilot plus regression

The resultant distribution of the aquifer parameters within the model layers and spatially across the model domain is presented in Figure 34, the horizontal hydraulic conductivity included in the model.

The horizontal hydraulic conductivity values included in the surficial sediments (model layer 1), GMS (model layer 10), and GLS (model layer 12) is included in Figure 35, Figure 36, and Figure 37, respectively.

These figures include the Isaac River (black line) and mine footprints (light blue or brown as hydraulic conductivity changes with depth) and show the heterogeneity of the sediments, after all mining activities (at the end of P4), included in the model.

14.3.4.1 Aquifer hydraulic parameters for historic spoil and goaf

As per Section 14.1, the model was set-up to include for historic mine workings prior to model predictions (2024 Q2 onwards) and for inclusion in the transient calibration period (2020 to 2024 Q1).

The location and extent of spoil within the model set-up is shown in Figure 38. The areas of historic goaf within the model are as included in Plate 20.

The aquifer hydraulic parameters for the goaf, are as detailed in Section 7.3.4.3, included:

- GMS goaf Horizontal hydraulic conductivity (Kh) = 1.1 m/day
- GMS goaf Vertical hydraulic conductivity (Kv) = 5E-05 m/day
- GMS goaf Specific capacity (Sc) confined storage = 1.5E-03
- GMS goaf Specific yield (Sy) unconfined storage = 0.15

The Kv in the overlying model layer (interburden aquitard) was also increased to 0.0005 m/day.

For the spoil, using model parameters supplied by BMA as used in the Saraji Mine PRC Plan (SLR, 2023), was assigned the following aquifer hydraulic parameters:

- Spoil Horizontal hydraulic conductivity (Kh) = 1.0 m/day
- Spoil Vertical hydraulic conductivity (Kv) = 0.1 m/day
- Spoil Specific capacity (Sc) confined storage = 1.5E-04
- Spoil Specific yield (Sy) unconfined storage = 0.15

The recharge across the spoil was increased to 1.0% of the mean annual rainfall.

These hydraulic parameters are included in the model layers 1 to 10 (if mining targeted the GMS) or model layers 1 to 12 (GLS), where the lithology has been mined and replaced with backfill.

Figure 34 Depiction of the hydraulic conductivity distribution spatially and with depth across the model

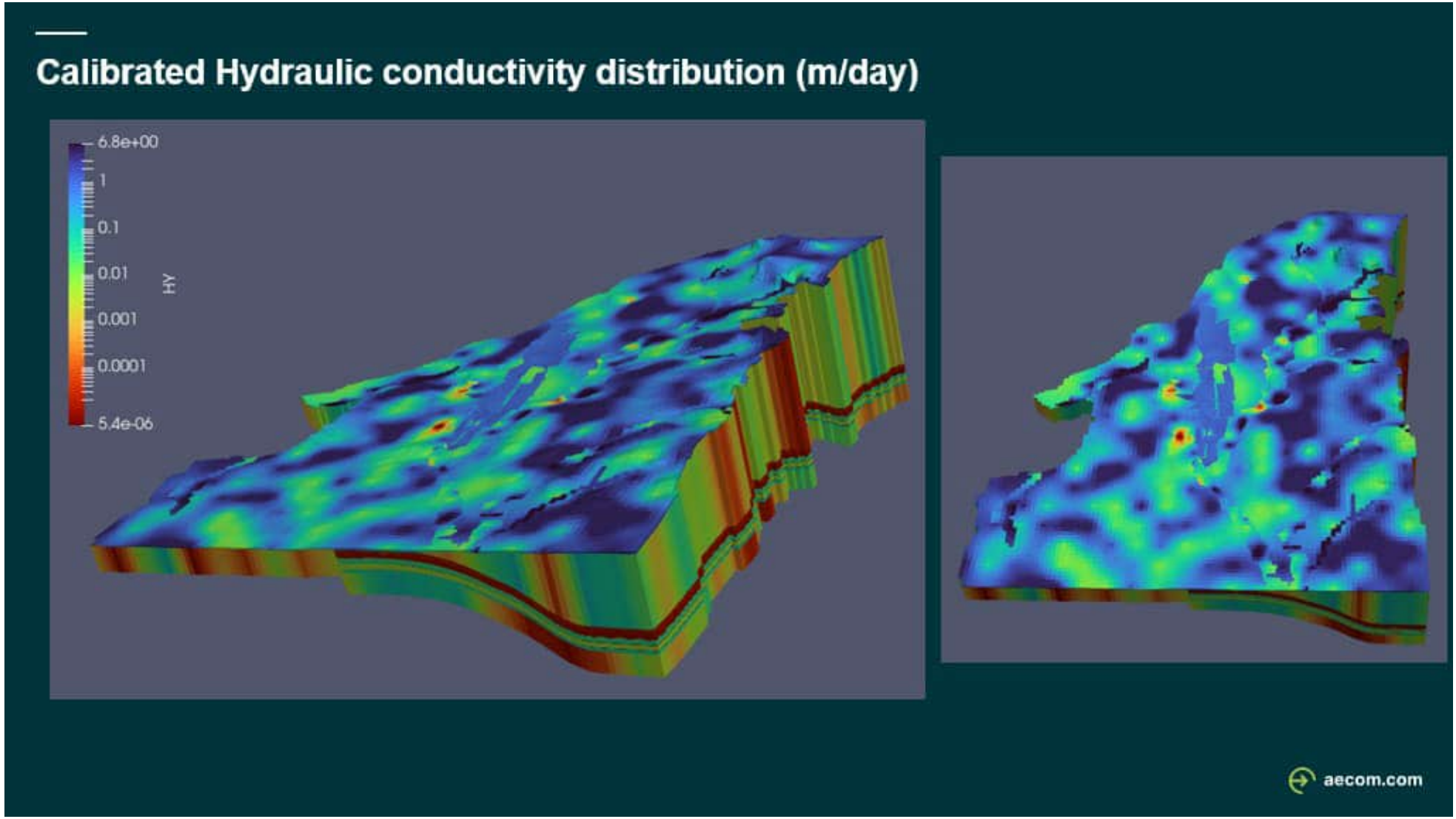


Figure 35 Hydraulic conductivity within the surficial sediments

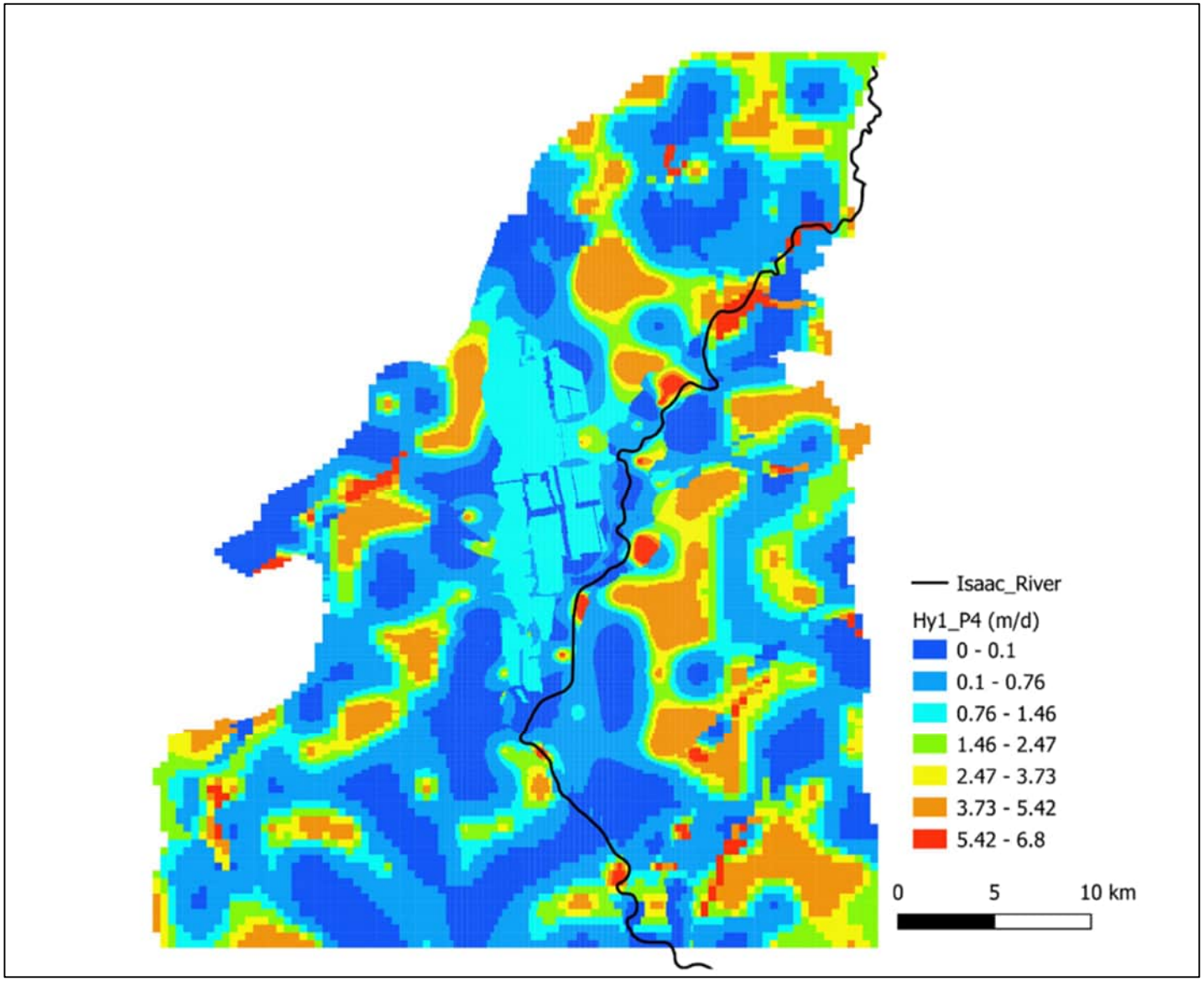


Figure 36 Hydraulic conductivity within the GMS model layer 10

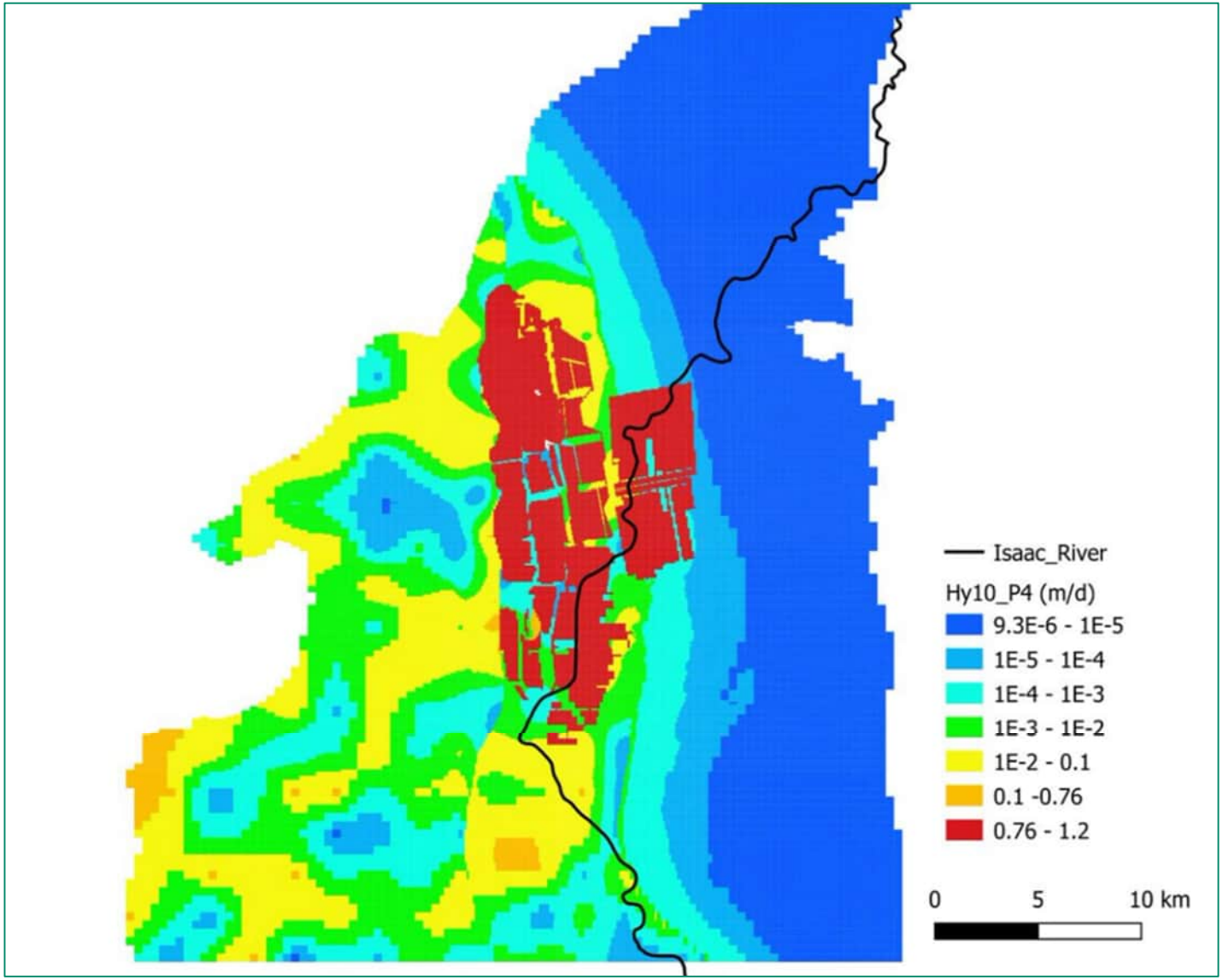


Figure 37 Hydraulic conductivity within the GLS model layer 12

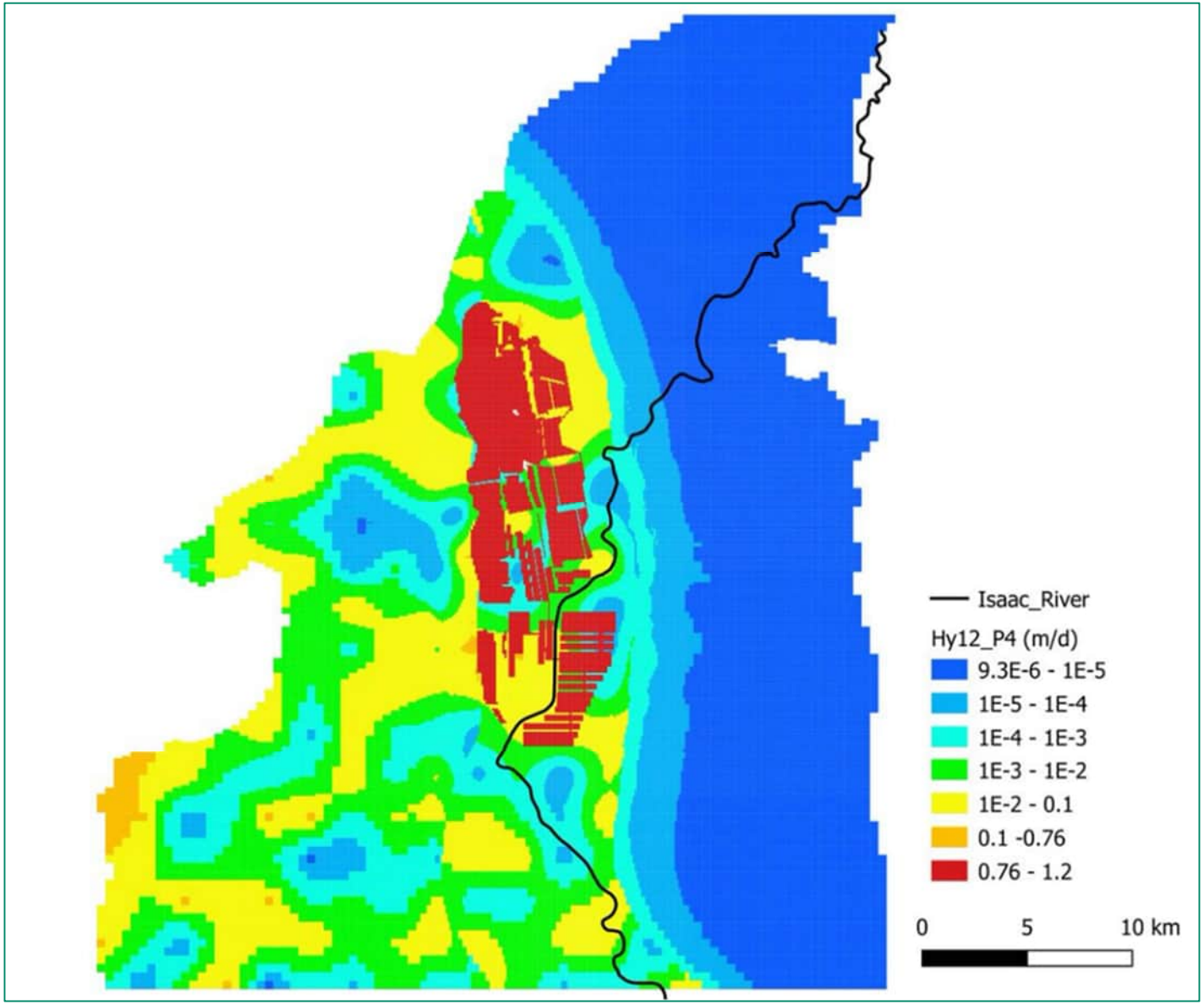
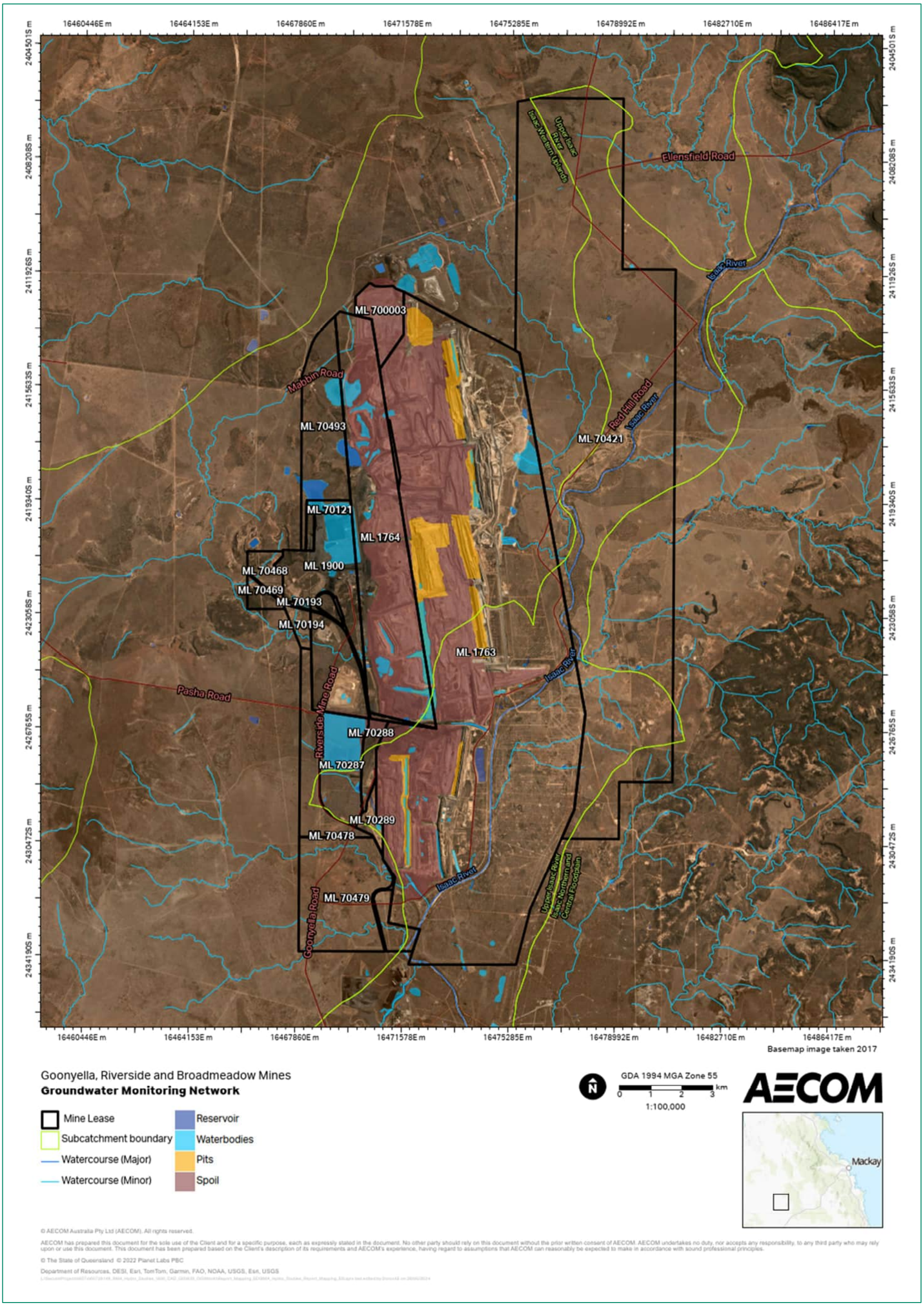


Figure 38 Historic spoil included in the model for the start of predictions in 2024



14.4 Model Water Budget

A model water budget was compiled for the calibration period 2020 to end of 2023 (actual Q1 2024), considering the inflows and outflows from the model.

The resultant model water budget is included in Table 21.

Table 21 Calibration model water budget (2020 to 2023)

Cumulative Volumes	IN (m^3)	OUT (m^3)
Storage	80,040,064	31,753,570
Constant Head	1,715,496	189,055
Drains	0	52,179,584
Recharge	14,250,555	0
Evaporation	0	10,426,460
River leakage	0	1,547,646
TOTALS	96,006,115	96,096,315
IN - OUT	-90,200	
Percent discrepancy	-0.09	

The predictive groundwater model included four different phases of prediction, as discussed in Section 15.0. A model water budget was generated for a predictive run, which included the underground mining and continued open cut mining (at Goonyella Pit). This predictive run, 2024 to 2055, allowed for the evaluation of alluvium recharge (discussed in Section 13.3.6.1) as well as an assessment of in and out flows in the numerical model. These results are included in Table 22.

The percent discrepancy is close to 0% for the calibration water budget and approximately 0.1% for the predictive water budget, indicating good model convergence. The inflow storage (IN storage) is a significant inflow to the groundwater system, contributing a major portion to mining dewatering (drains), which indicates substantial extractions from aquifer storage.

Table 22 Prediction model water budget (2024 to 2055)

Cumulative Volumes	IN (m^3)	OUT (m^3)
Storage	4.46E+08	1.11E+08
Constant Head	8,439,281	999,161.9
Drains	0	3.82E+08
Recharge	90,986,808	0
Evaporation	0	47,265,681
River leakage	0	4,635,597
TOTALS	5.45E+08	5.46E+08
IN - OUT	-599,647	
Percent discrepancy	-0.11	

14.5 Model Performance and Limitations

The groundwater modelling was conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), the Murray Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline (MDBC, 2001) and the released IESC Explanatory Note for Uncertainty Analysis (IESC, 2018). **Note:** These are mostly generic guides and do not include specific guidelines on special applications, such as underground coal mine modelling.

The 2012 Australian Groundwater Modelling Guidelines has replaced the model complexity classification of the previous MDBC guideline by a "model confidence level" (Class 1, Class 2, or Class 3 in order of increasing confidence) typically depending on:

- Available data (and the accuracy of that data) for the conceptualisation, design and construction.
- Calibration procedures that are undertaken during model development.
- Consistency between the calibration and predictive analysis.
- Level of stresses applied in predictive models.

The model confidence level for a transitional PRC Plan is not readily identified, as the model will be revised on a regular basis in response to additional data compilation, changes in mine activities and mine schedules, plus ongoing remediation and decommissioning activities and plan changes. It is noted that the 2012 Australian Groundwater Modelling Guidelines state that a Class 2 model may be used for assessing impacts associated with mine dewatering (Barnett et al. 2012).

The subjective qualitative criteria allowing model classification, per Table 2.1 of the 2012 Australian Groundwater Modelling Guidelines is compiled in Table 23. The classification of the PRC Plan model was assessed subjectively by the groundwater modeller and reviewed by a Technical Director level hydrogeologist, whereby:

1. The classification table was subjectively reviewed, and the specialists mutually decided, in their professional opinion, which box most appropriately describes the various characteristics of the model.
2. Thereafter, the assessors assigned an overall classification class for the model based on the characteristics selected, i.e. which class has the most selected characteristics.

The assessment shown in Table 23 indicates that, overall, the GRB-RHM groundwater model can be classified as primarily Class 2 using the 2012 Australian Groundwater Modelling Guidelines classification system. This is considered an appropriate level for this transitional PRC Plan context.

The PRC plan model is considered to contain components of Class 1, Class2 and Class 3, which is typical of groundwater models.

Table 23 Groundwater Model Classification Table

Class	Model Characteristics					
	Data		Calibration		Prediction	
1		Few or poorly distributed data points		Not possible		Predictive timeframe >> calibration timeframe
		Unavailable or sparse data in areas of greatest interest		Unacceptable levels of error		Temporal discretisation is different to calibration
		No metered groundwater extraction data	X	Inadequate distribution of data		Transient prediction but steady state calibration
		Remote climate data		Targets incompatible with model purpose		Unacceptable validation
		Little or no useful data on land-use, soils, or river flows and stage elevations				
2	X	Some data but may not be adequate throughout domain	X	Reasonable calibration statistics with errors in parts of the model	X	Predictive timeframe > calibration timeframe
	X	Some metered groundwater extraction data	X	Long-term trends not replicated in all parts of domain	X	Long stress periods compared to calibration
	X	Streamflow and stage measurements are available at some points		Transient calibration not extending to present day		New stresses not in calibration
		Reliable irrigation application data available in part		Weak seasonal replication		Poor validation
				No use of calibration targets compatible with model purpose		
			X	Validation not undertaken		
3		Spatial and temporal distribution of data adequate	X	Scaled RMS error or other calibration statistics are acceptable		Predictive timeframe ~ calibration timeframe
	X	Clearly defined aquifer geometry	X	Long-term trends adequately replicated where important	X	Temporal discretisation in predictive model consistent with transient calibration
		Reliable metered groundwater extraction data		Seasonal fluctuations adequately replicated	X	Similar stresses to those in calibration
	X	Rainfall and evaporation data is available	X	Transient calibration is current		Steady state prediction consistent with steady state calibration
	X	Aquifer testing data to define key parameters	X	Model is calibrated to heads and fluxes		Model validation suggests calibration is appropriate
	X	Good quality and adequate spatial coverage of DEM	X	Key modelling outcomes dataset used in calibration		Steady-state predictions when the model is calibrated in steady-state
		Streamflow and stage measurements are available at many points				

Class	Model Characteristics					
	Data		Calibration		Prediction	
		Reliable land-use and soil-mapping data available				
		Reliable irrigation application data available				

Notes: Based on Table 2.1 of the 2012 Australian Groundwater Modelling Guidelines (Barnett et al. 2012)2.
Grey highlighted cells = model has been subjectively assessed to meet the classification criteria for that Class

15.0 Predictions

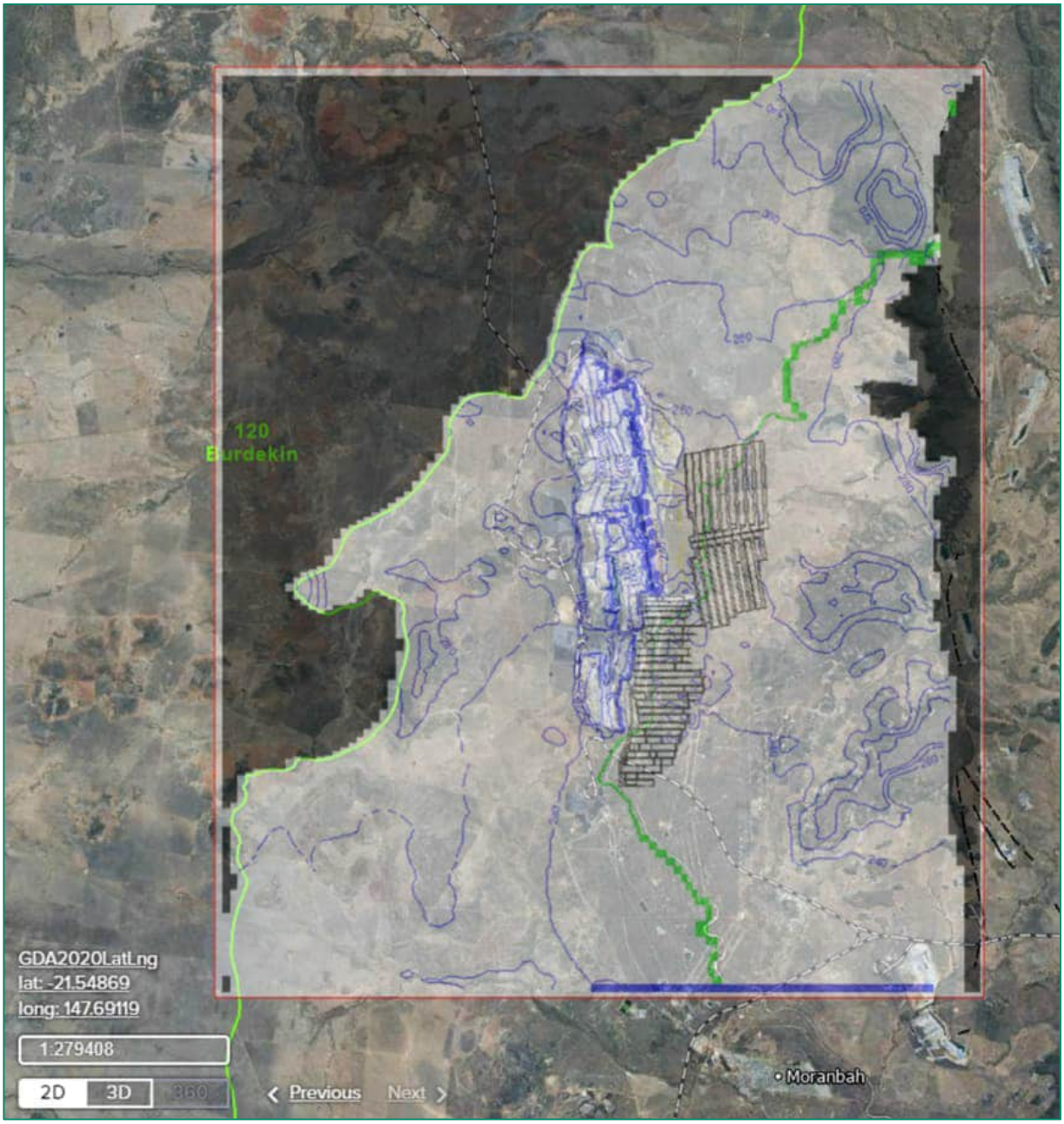
15.1 Prediction Conditions

As per Section 14.3 the refined numerical groundwater model included initial groundwater conditions based on prior pseudo-steady conditions covering the period from 1996 to 2009 plus the historic mining (2010 to 2019). The model included transient calibration using data from 2020 to 2024.

This allowed for the establishment of groundwater heads (elevations) across the model domain, including drawdown as a result of active (mine dewatering) and passive (seepage ingress into pits) plus artificial recharge from residual pits which contain or store water.

Examples of the head contours, for alluvium, GMS, and GLS (target coal seams), at the start of model predictions are included in Figure 39.

For reference the layout of the head contours across the model domain are as included in Plate 16 and as included below.



15.2 Prediction Periods

To capture the complex interaction between the different mine plans, decommissioning, and injection, activities, as detailed in Table 15 and summarised in Table 17, four distinct periods were included in the predictive modelling.

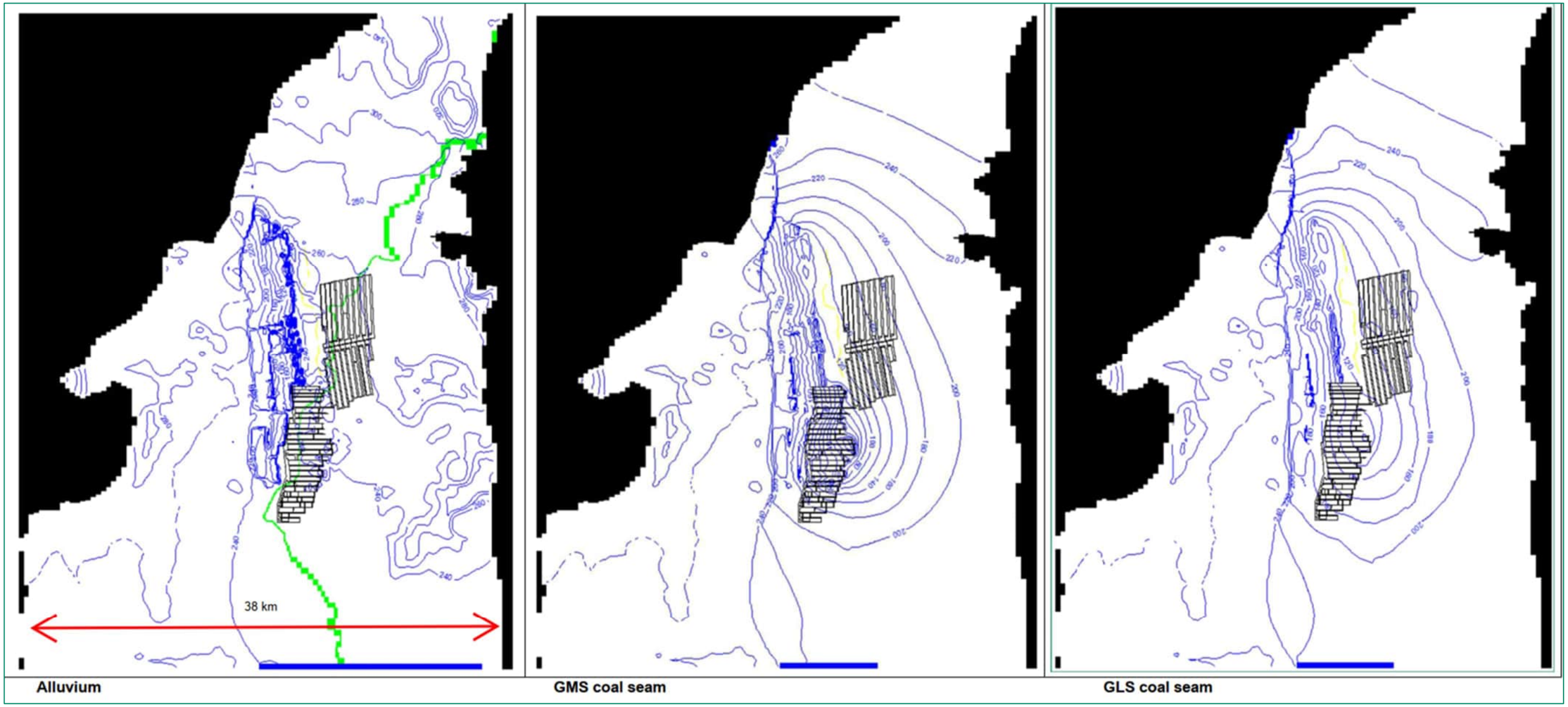
The activities and changes in the model for each prediction period were made to accurately capture:

- The cumulative impacts of the different mining (target seams, schedules, mining methods, and locations).
- The periods of decommissioning and introduction of water into the underground workings.
- The areas and timing of rehabilitation (backfilling of open cuts with spoil).
- The incorporation of residual voids (historic and over time).

The prediction phases are summarised as:

- **Prediction phase 1 (2024 to 2056)**
  - Broadmeadow and Isaac pits (GMS) remain dewatered to facilitate Broadmeadow underground mining (2024 to 2056)
  - Ramp 32 East is mined from 2027 to 2031 (drain model cells then converted to CHD, as per Section 13.3.7)
  - Ramp 32 South is mined up to 2036 and converted to CHD in 2037
  - Thiess Pit is included as CHD from 2024
  - Broadmeadow GMS underground includes historic goaf 2007 to 2023, continues longwall mining to 2031, and then remains dewatered till 2055 (to accommodate GLS underground mining)
  - Broadmeadow GLS underground occurs between 2031 to 2055
  - Broadmeadow GMS and GLS, in 2056, remain dewatered during decommissioning
  - Goonyella pit open cut mining continues (2024 to 2059) and includes historic spoil (2012 to 2023).
- **Prediction phase 2 (2057 to 2060)**
  - 2057, change Broadmeadow GLS underground (2031 to 2055) to goaf (parameters as per Section 7.3.4)
  - 2057, change Broadmeadow GMS underground (2007 to 2031) to goaf
  - 2057, change Goonyella open cut mining (2024-2056) to spoil
  - 2057, drain cells at both Broadmeadow GLS and GMS underground removed (1-yr decommissioning)
  - 3-yr injection into both Broadmeadow GLS and GMS underground workings.
  - Broadmeadow and Isaac pits and Goonyella Pit (GLS) have drain cells and remain dewatered
  - CHD for residual void water levels in Thiess (2057-2060), Ramp 32South (2057-2060), and Ramp 32East (2057-2060).
- **Prediction phase 3 (2061 to 2092)**
  - 2061, change Goonyella open cut mining (2057 to 2059) to spoil
  - 2061, CHD included in Broadmeadow, Issac, Thiess, Ramp 32 East, Ramp 32 South (2061-2092) pits
  - 2063 to 2091, Red Hill Mine mining (drain cells) included, finishing in 2091, Goonyella pit remains dewatered to facilitate RHM mining
  - 2092, Red Hill Mine completion year, stay dewatered during decommissioning.
- **Prediction phase 4 (2093 to 2199)**
  - 2093, 1-year decommissioning (drain cells in RHM removed, only Goonyella pit remain), change RHM to goaf (parameters as per Section 7.3.4)
  - Drain cells in Goonyella pit (2093-2096)
  - CHD in Broadmeadow, Issac, Thiess, Ramp 32 East, Ramp 32 South (2093-2199)
  - CHD in Goonyella Pit (2097 to 2199)
  - 2094 to 2096, 3-years injection into RHM
  - 2097 to 2199 all mining activities ceased, recovery period.

Figure 39 Head contours at the start of Prediction Modelling (2024)



15.3 Initial Ingress Estimates

For the closure plan input, the predictive model aimed to assess groundwater ingress into the mine voids that will remain post-closure. These pits are as included in Section 14.2, Figure 32 as incorporated in the model set-up and zones.

The estimate of groundwater ingress, adopting drains in all of the residual mine pits, during the entire prediction period/s, allowed for the evaluation of **maximum groundwater extraction** and evaluation of the influence of reinjection, plus input into the residual mine water balance.

The estimates of groundwater ingress, as m^3/year, for each pit are included below.

Plate 26 Broadmeadow Pit initial estimates of ingress

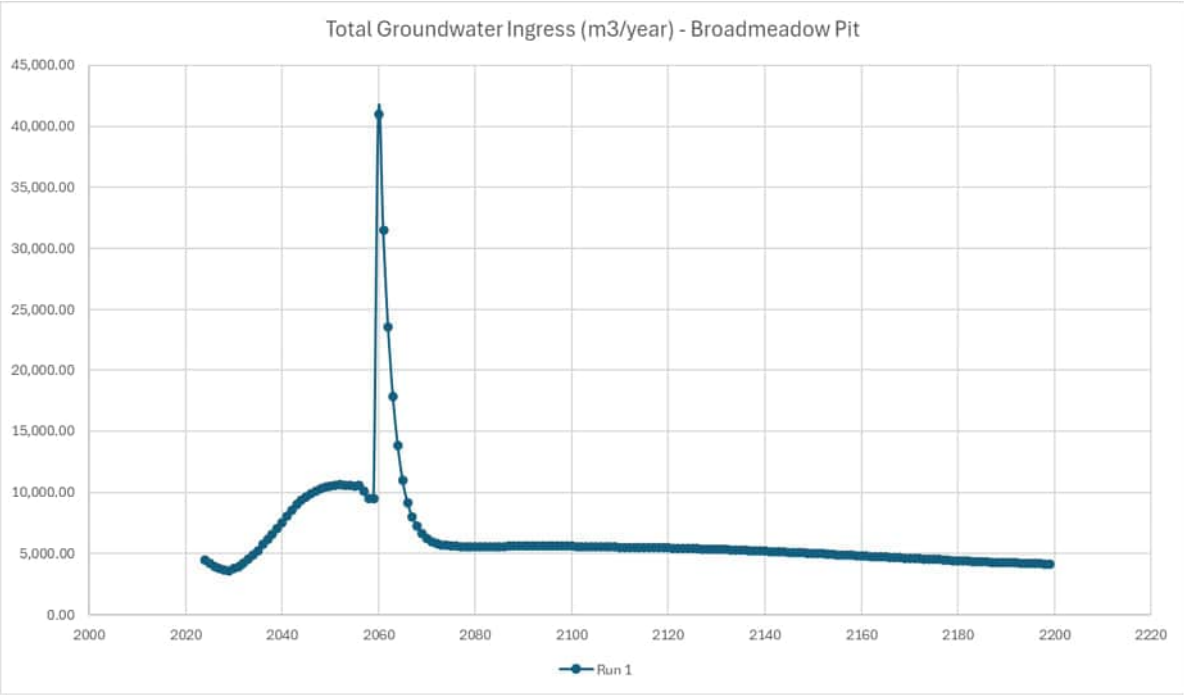


Plate 27 Isaac Pit initial estimates of ingress

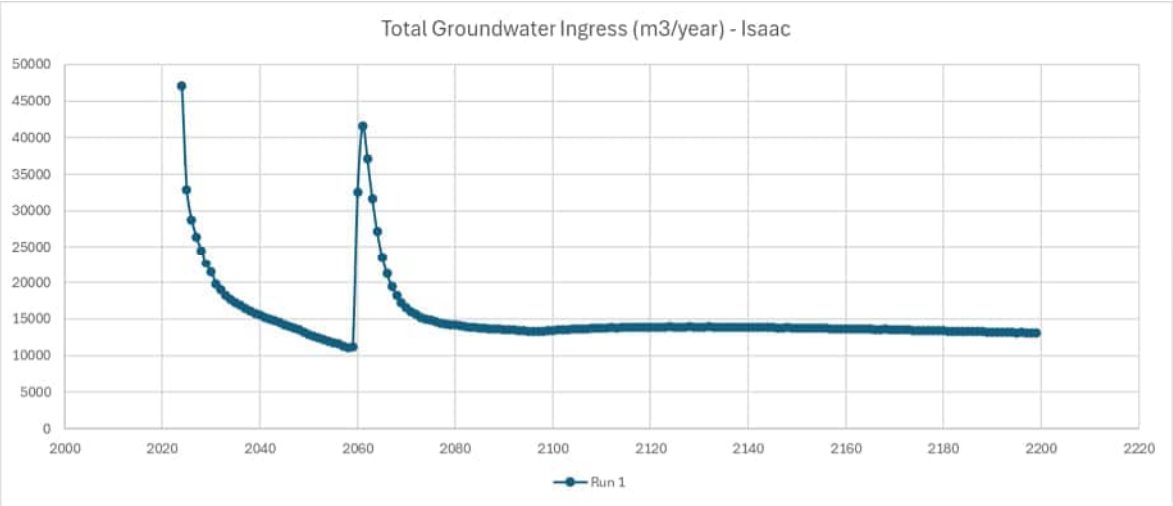


Plate 28 Thiess Pit initial estimates of ingress

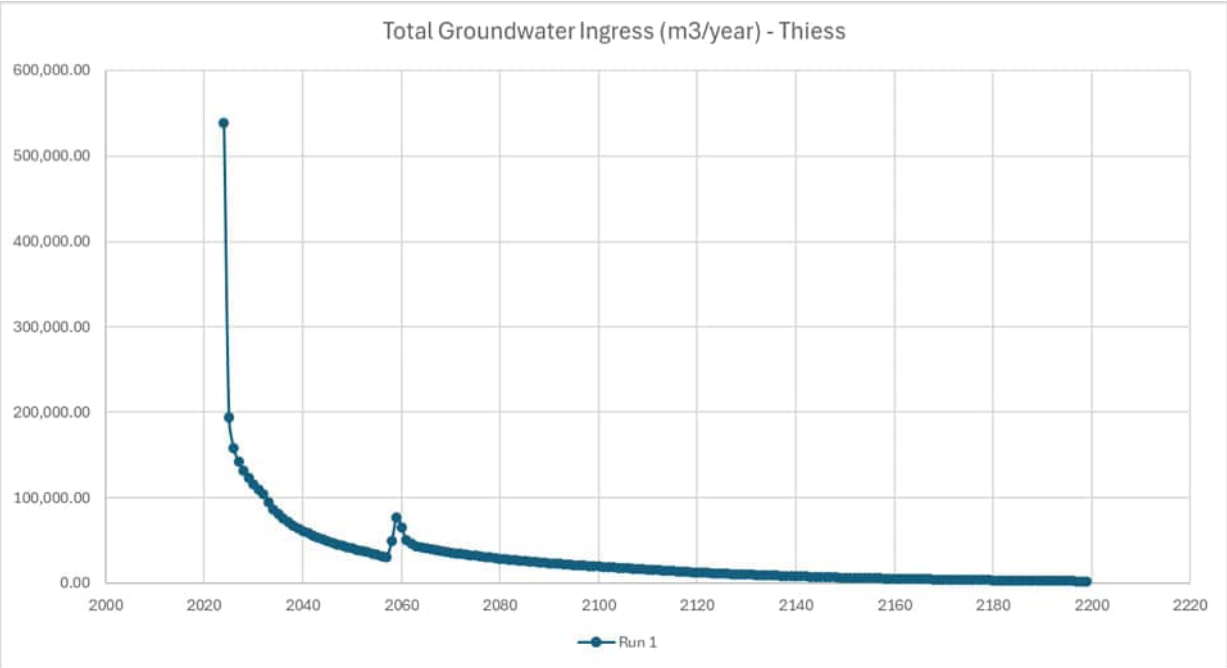


Plate 29 Ramp 32 East Pit initial estimates of ingress

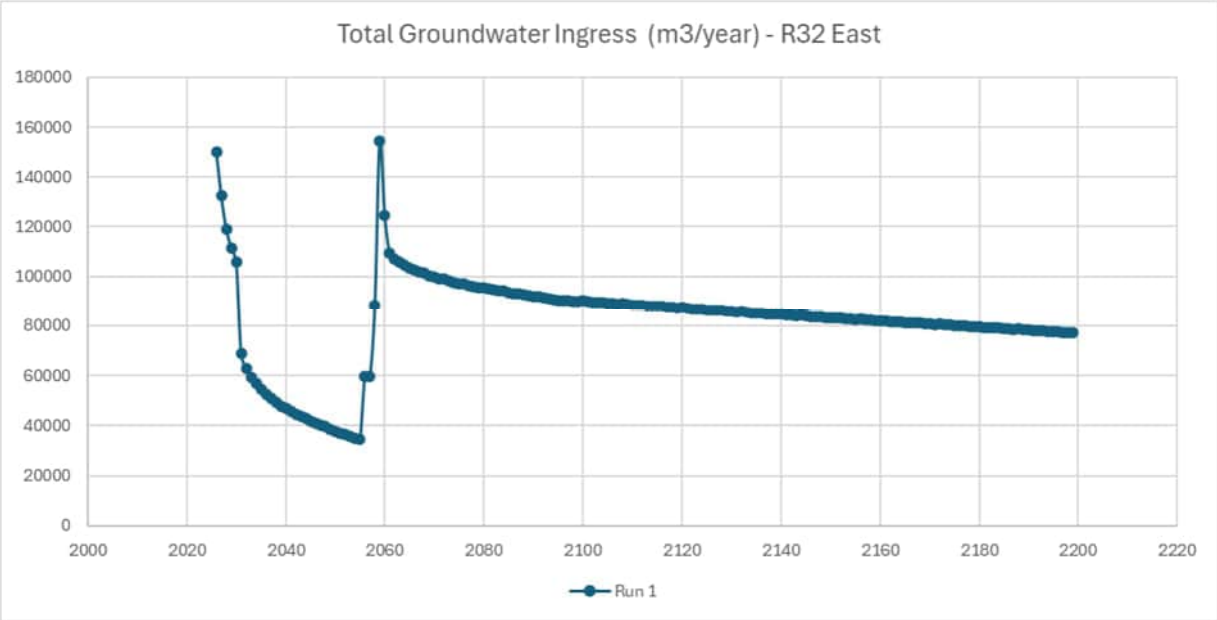


Plate 30 Ramp 32 South Pit initial estimates of ingress

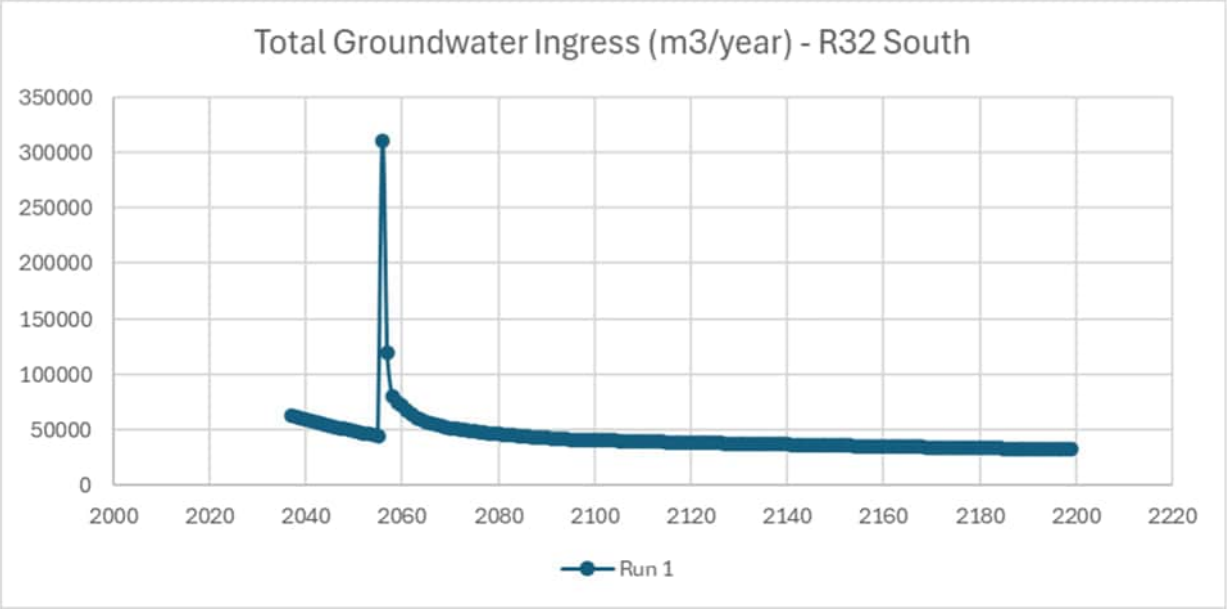
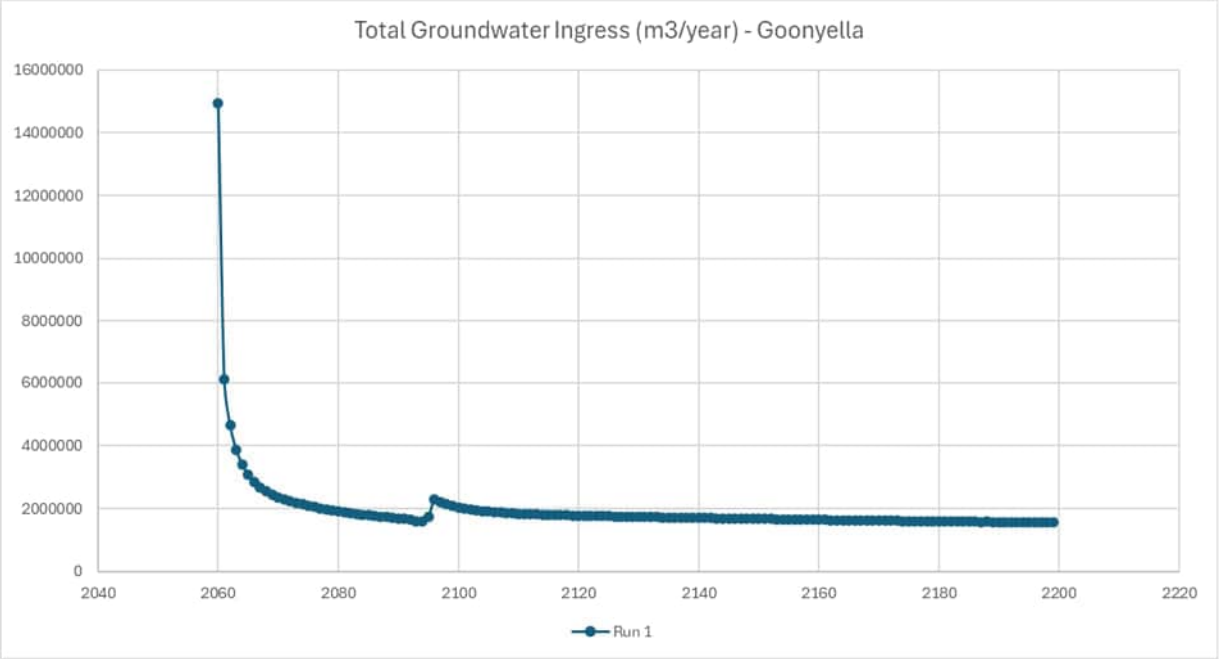


Plate 31 Goonyella Pit initial estimates of ingress



Note: These initial ingress estimates were based on the open cut pits being drained to base of the pits, such that the ingress estimates are based on surrounding groundwater levels and the permeability of the host material containing and adjacent to the open cut pits (where spoil has higher hydraulic conductivity to the natural rock). Thus, these estimates of ingress are maximum expected ingress rates and do not readily compare to the estimates in Section 10.2.

15.4 Integration with Residual Void Water Balance Model

The hydrogeological assessment was provided to the specialists commissioned to undertake the residual void/s water balance modelling.

The approach adopted followed the process detailed in the approach of mining closures compiled in the Review of current approaches to model residual mine voids for rehabilitation planning, technical paper 11 (Tomlin et al, 2023).

The approach consisted of coupled water balance and groundwater models, allowing for the capture and assessment of the key aspects of residual void water balances. The groundwater flow model ingress predictions were used with the surface water balance predictions, as a method referred to as 'quasi-coupling', to predict residual void water levels.

The coupled water balance approach allowed for:

- Iterative approach, which allowed for the refinement of the residual void water levels through including pit water levels in the groundwater model, revising the groundwater ingress rates (m^3/year), which was then used to generate the next set of pit water levels.

  Predictions from the transient groundwater flow model includes the use of a high conductance to simulate the 'lake'. This allows for the production of groundwater inflow predictions for the estimation of residual void water elevation (during rebound and to the pseudo-steady state residual void water level).

  It is noted that the surface water modelling allowed for the evaluation of climate (rainfall and evaporation) plus runoff on a daily basis across the prediction periods. Due to the large data sets, large groundwater model (117,410 active cells for a fourteen-layer model), and limited variation (groundwater ingress versus surface water contributions reliant on climate), the average annual residual void water levels (derived from the surface water balance modelling) were included in the groundwater modelling.

- Validation stage, the re-running of the groundwater model using the revised set of pit water levels was conducted for four iterations. Once the model simulations closely matched the previous ingress (surface water and groundwater predictions) as reflected in the pit water levels (i.e., converging data) no further iterations were necessary.

- Consistency Between Models – The model outputs exhibited good agreement in terms of water balances, fluxes, and water levels at these interfaces such that the interactions between the two systems were deemed adequately represented.

15.4.1 Iterations

Four iterations of ingress and pit water levels were included in the residual water balance modelling, these included:

- Pit water levels (Rev A) and groundwater Model Run 1 using drain cells predictions (Section 15.3 data), which produced Pit water levels (Rev B)

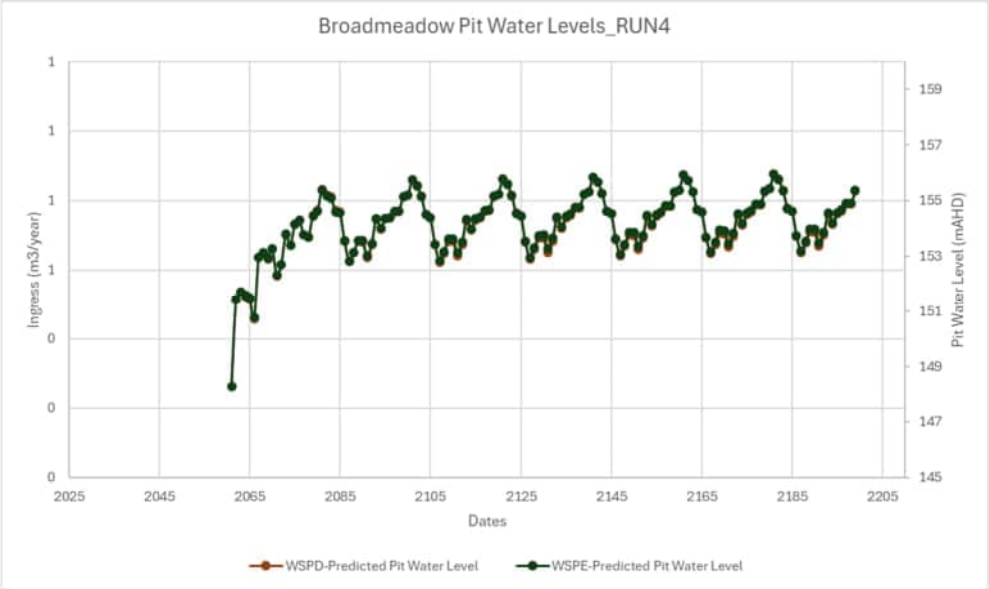
- Pit water levels (Rev B) and groundwater Model Run 2 using CHD cells predictions, which produced Pit water levels (Rev C)

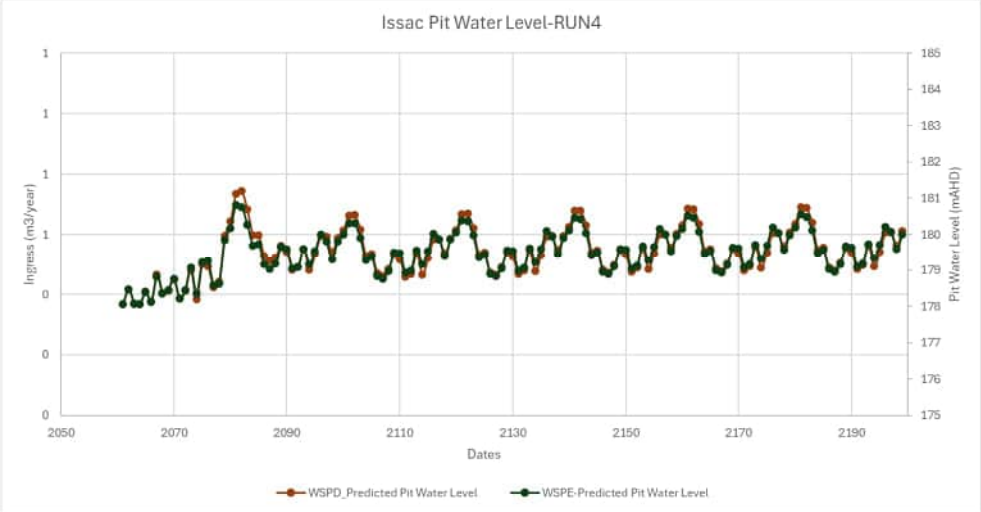
- Pit water levels (Rev C) and groundwater Model Run 3 using CHD cells predictions, which produced Pit water levels (Rev D)

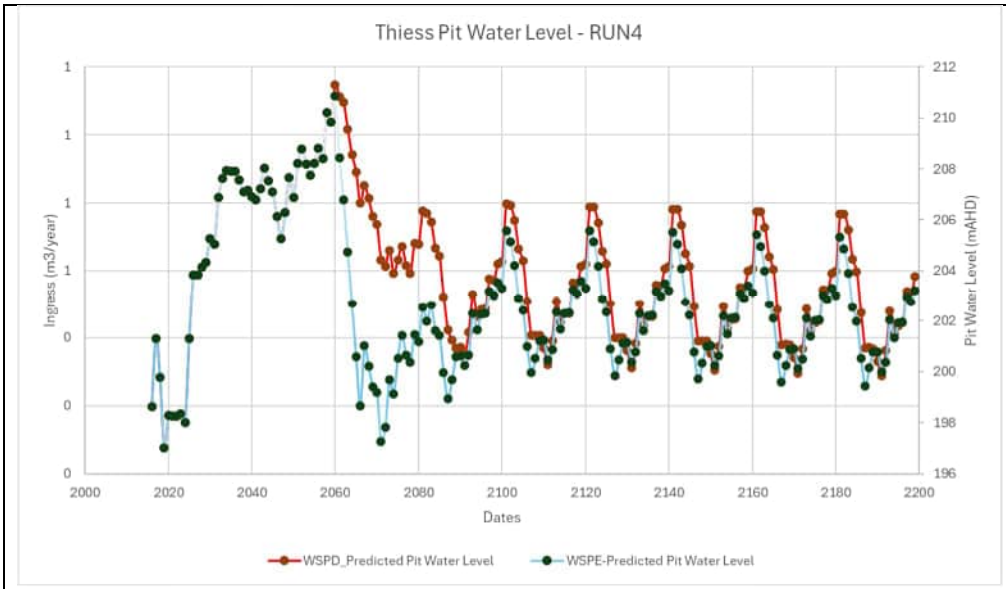
- Pit water levels (Rev D) and groundwater Model Run 4 using CHD cells predictions, which produced Pit water levels (Rev E).

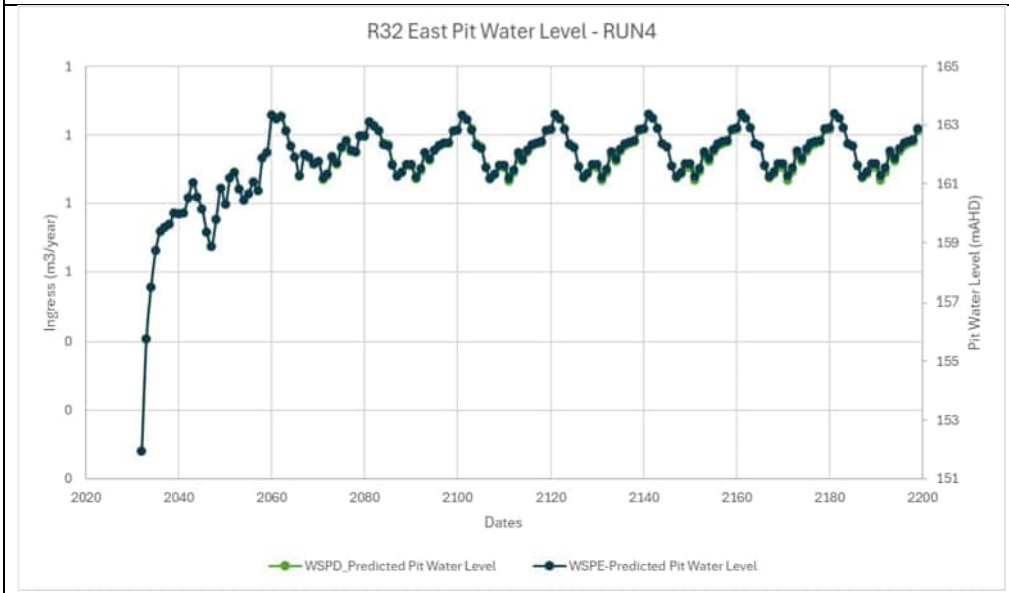
The Pit water levels Rev D and Rev E were closely matched, as included below (Plate 32).

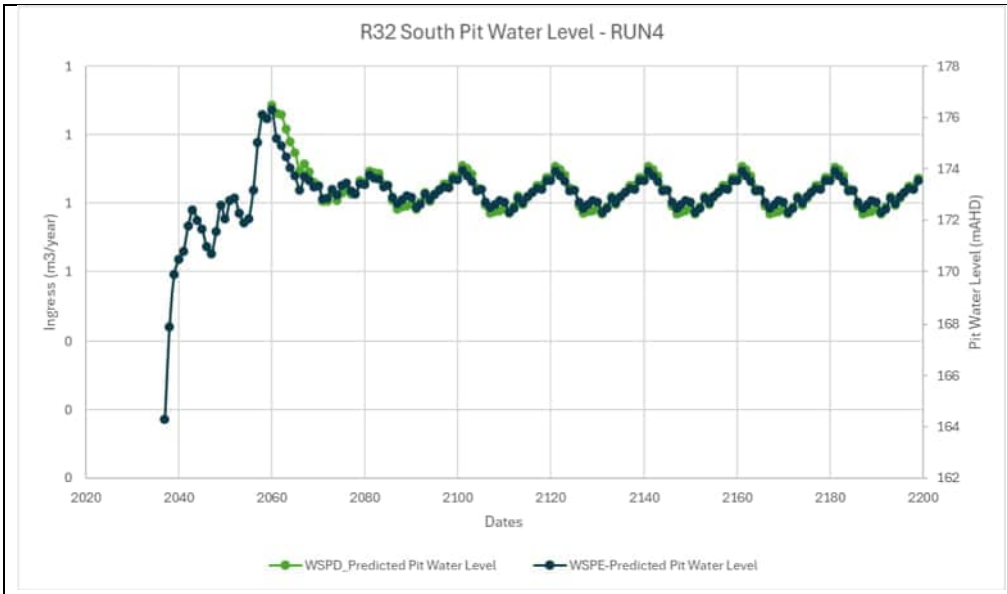
Plate 32 Residual void water levels Rev D and Rev E

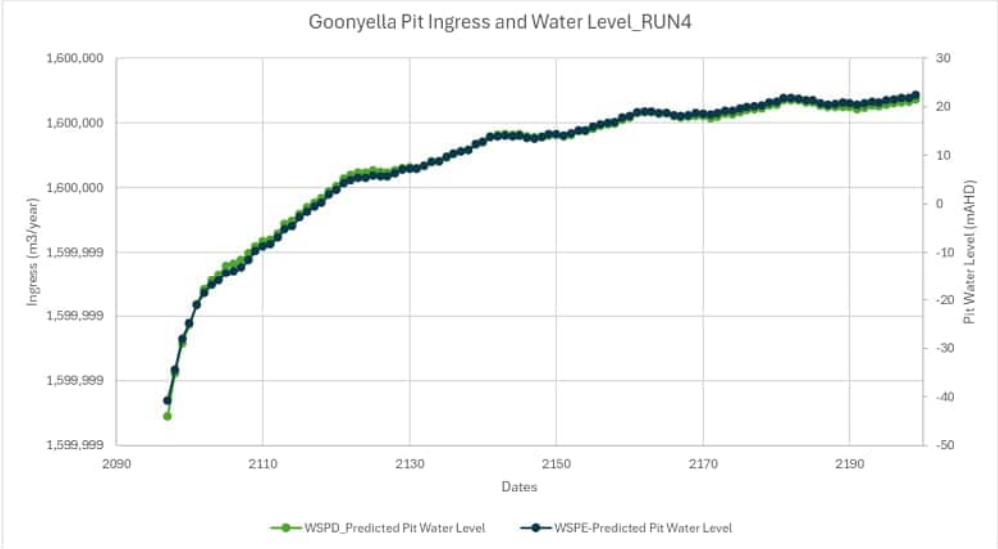





Thiess Pit Water Level - RUN4
Ingress (m3/year)
Pit Water Level (mAHD)
Dates
WSPD_Predicted Pit Water Level
WSPE-Predicted Pit Water Level


R32 East Pit Water Level - RUN4
Ingress (m3/year)
Pit Water Level (mAHD)
Dates
WSPD_Predicted Pit Water Level
WSPE-Predicted Pit Water Level





15.4.2 Residual Void Groundwater Inflow

The final predicted groundwater inflows to the residual voids from the groundwater model, using the Model Run 4 predictions. The net groundwater flux into or out of the residual voids, using the Model Run 4 predictions, were assessed using the groundwater model zone budget. This allowed for the evaluation of contribution from (or to) the spoil and natural / unmined geology, as detailed in Section 14.2.

The pit water levels from Rev D / Rev E compared to the groundwater elevation surrounding the residual voids determined the flow direction in or out of the surrounding saturated hydrostratigraphic units, including the spoil (installed to GMS or GLS depending on the historic mining).

It is noted that the residual void water balance modelling included consideration of wet, dry and mid climate conditions on a daily basis. The groundwater modelling adopted the average residual void levels from these three climate condition simulations. This approach, plus undertaking uncertainty analysis (Section 16.0), was adopted for the ingress predictions. This was done due to:

- The large groundwater model domain
- Long prediction periods,

- Complex alteration of the model to match mining activities during each prediction period.

Thus, the groundwater model (zone budget) provided annual groundwater flux estimates in or out of the different zones (spill, natural geology, etc,).

15.4.2.1 Broadmeadow Pit

The groundwater model zone budget indicates that ingress into this pit occurs predominantly from the spoil to the west of the pit (refer to Figure 32). Groundwater from the unmined geology to the east (down dip of Broadmeadow Pit) is limited with the potential for pit water to move towards the east (Plate 33).

Initial ingress into the Broadmeadow Pit is related to the change of the pit from drain cells (water level drawdown down to the base of the pit) and then including a CHD to simulate the pit water levels (including fluctuations). This change in the water level relates to the model requiring water from the surrounding model cells to fill the residual voids (from the drain elevation to the CHD residual void level instantaneously in the model) until gradients stabilise. This would occur over time once the mine dewatering ceases, and groundwater and surface water can enter the residual void. This is included in the model to facilitate the assessment of groundwater flux post-closure.

It is noted that ingress from the spoil into the Broadmeadow residual void will occur in perpetuity, driven by evaporation from the residual void. Groundwater from the surrounding natural (unmined) formations will flow into the residual void when groundwater elevations are higher than the residual void water level. Predictions indicate that the pit water will also flow into the natural formation due to lower groundwater levels after mining.

Hydrographs of hypothetical water level observation points in the model were generated to assess the residual void water level and groundwater 100 m up and down dip (west and east) of the Broadmeadow Pit. The full hydrographs, across the entire prediction phases, are included in **Appendix D**. These water level hydrographs (Figure 40) indicate:

- The hydrographs reflect the mine decommissioning and water introduction activities in P4 prediction period (Section 15.2).
- The residual void water level fluctuates around 154 mAHD
- Groundwater levels in the GMS to the west (up dip) are some 160 mAHD (flow towards the pit)
- Groundwater levels in the GMS to the east (down dip) are some 143.5 mAHD (flow away from the pit).

These data plus groundwater drawdown contours (Section 15.4.3) are considered when evaluating flow path simulations (Section 15.6).

Plate 33 Broadmeadow groundwater flux predictions

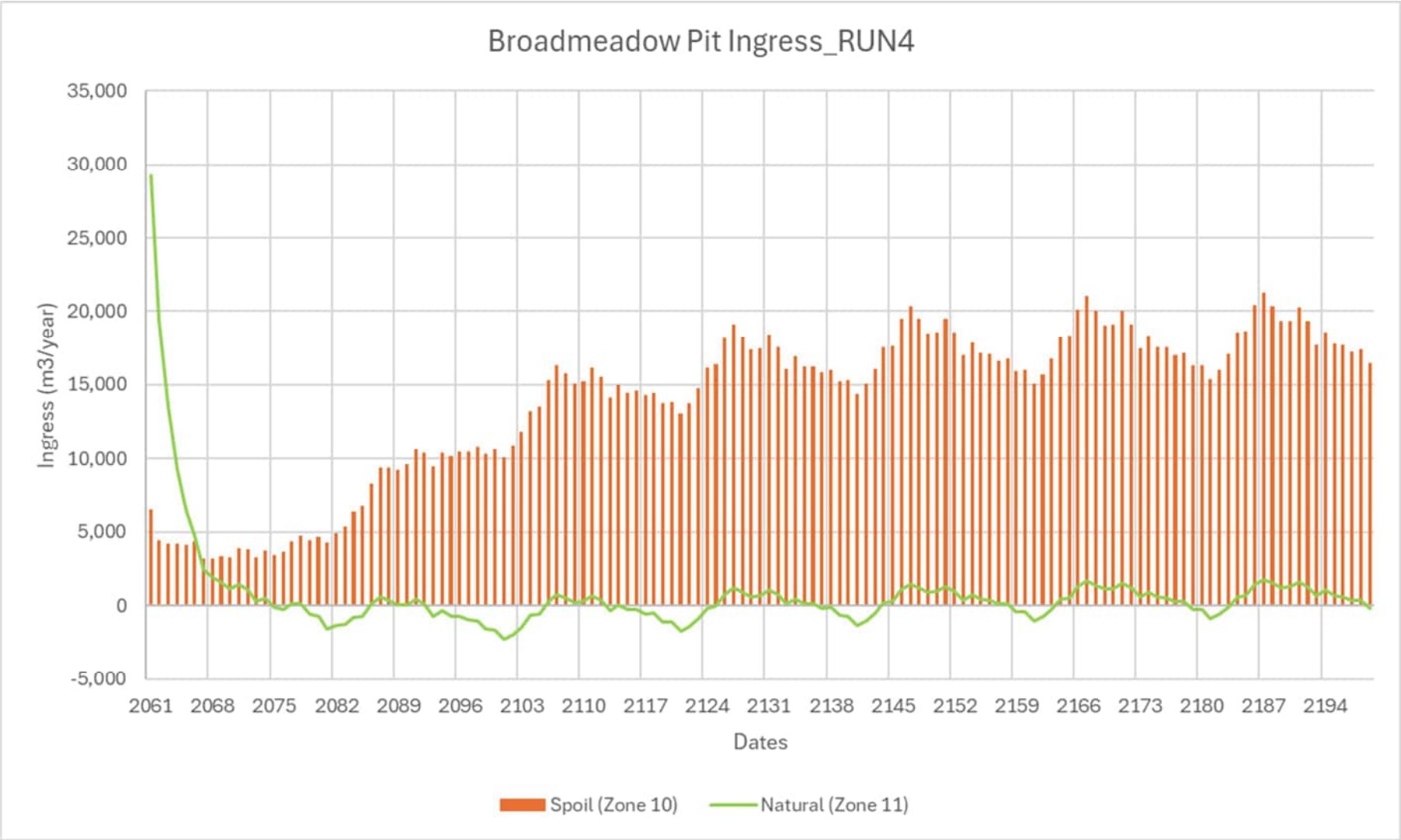
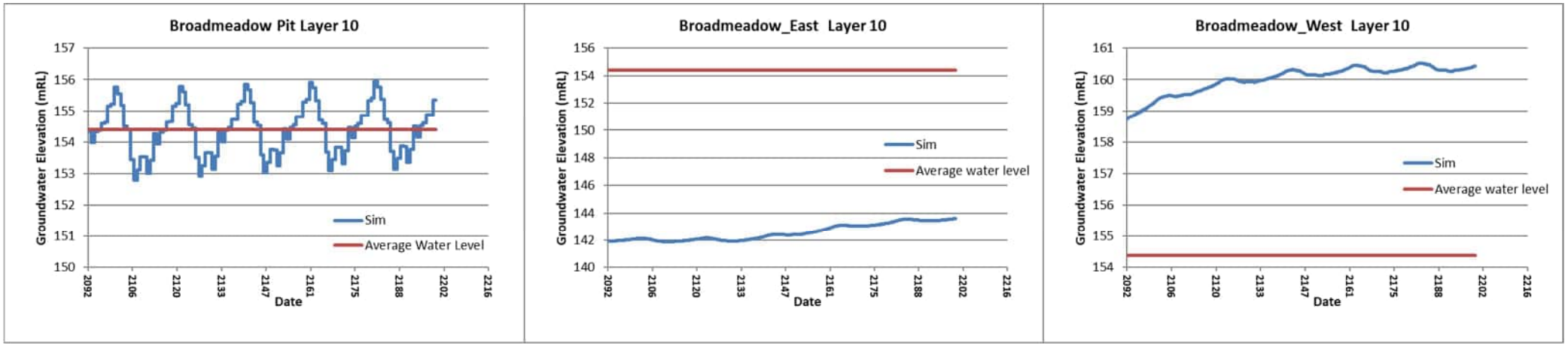


Figure 40 Broadmeadow Pit simulated water level hydrographs (2093 to 2199)



Where:

Broadmeadow Layer 10 provides predictions of residual void water level (red line is the average pit water level for reference)

Broadmeadow_East Layer 10 provides (simulated (sim)) groundwater levels in the GMS seam down dip of Broadmeadow Pit

Broadmeadow_West Layer 10 provides (simulated (sim)) groundwater levels in the GMS seam up dip of Broadmeadow Pit

15.4.2.2 Isaac Pit

The groundwater model zone budget indicates that water from within Isaac Pit flows into both the spoil to the west of the pit and the natural surrounding units (Plate 34). Groundwater flux into the pit is minimal and no ingress from the unmined geology to the east is predicted.

Hydrographs of hypothetical observation points in the model (as per Broadmeadow Pit) were generated to assess the water levels in the pit and in groundwater 100 m up and down dip (west and east) of the pit. These water level hydrographs (Figure 41) indicate:

- A pseudo-steady residual void water level of 179.5 mAHD
- Groundwater levels in the GMS to the west (up dip) are some 179.5 mAHD (potential for flow in and out of the pit, albeit net flux is outward)
- Groundwater levels in the GMS to the east (down dip) are some 177 mAHD (facilitating flow outward from the pit).

Plate 34 Isaac pit net groundwater flux predictions

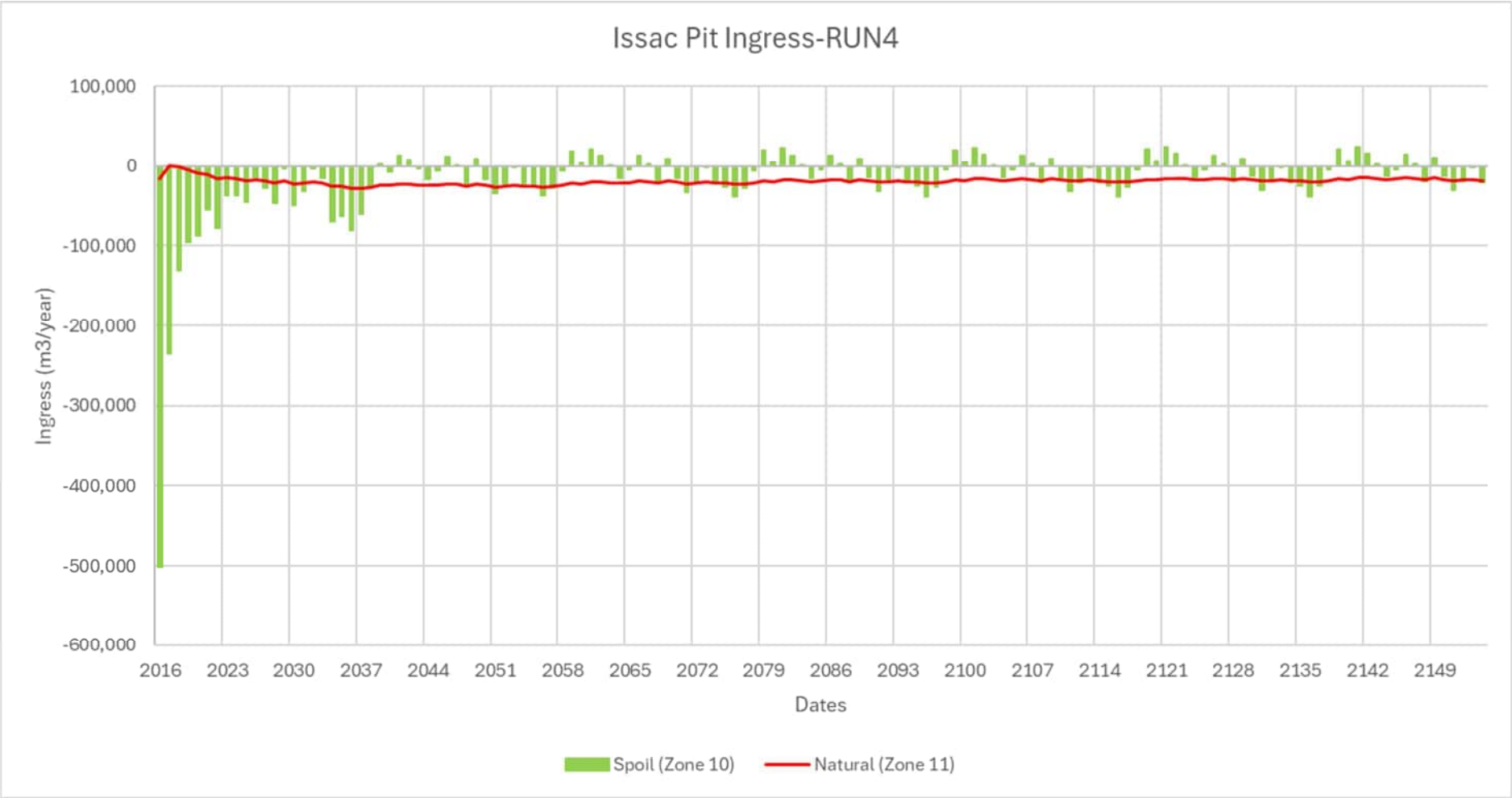
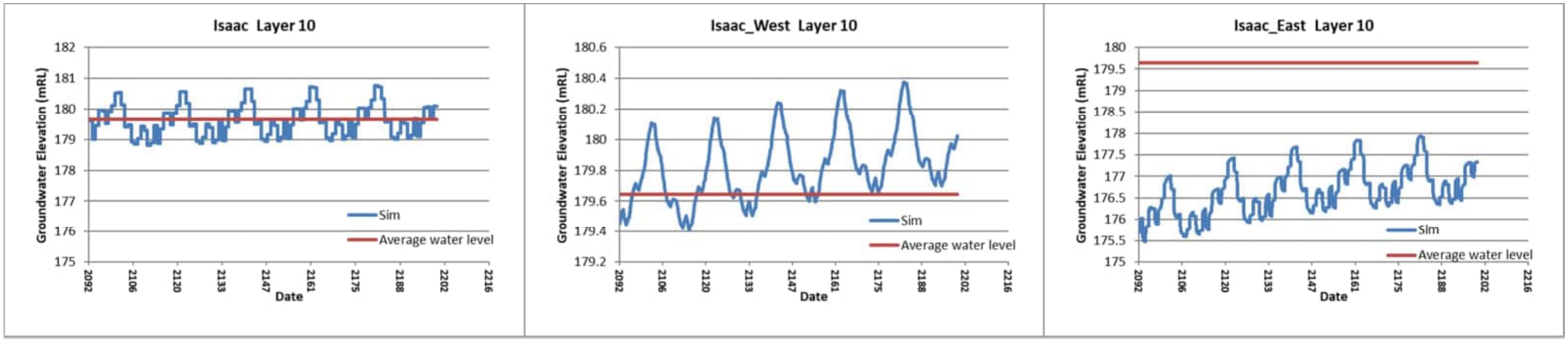


Figure 41 Isaac Pit simulated water level hydrographs (2093 to 2199)



Where:

Isaac Layer 10 provides predictions of residual void water level (red line is the average pit water level for reference)

Isaac_West Layer 10 provides predicted groundwater levels in the GMS seam up dip of Isaac Pit

Isaac_East Layer 10 provides simulated groundwater levels in the GMS seam down dip of Isaac Pit

15.4.2.3 Thiess Pit

The groundwater model zone budget indicates that water from within this pit flows into both the spoil to the west (up dip) of the pit and the surrounding natural units (Plate 35). Groundwater flow into the pit is minimal and no ingress from the unmined natural geology to the east is predicted.

Hydrographs of hypothetical observation points in the model were generated to assess the groundwater elevations 100 m up and down dip (west and east) of the pit and pit water levels. Due to the large extend of Thiess Pit, three locations along the large pit were selected for the inclusion of hypothetical observation points were included in the model to obtain simulated water level data. These water level hydrographs (Figure 42) indicate:

<u>North</u>

- Pseudo-steady residual void water level at 203 mAHD
- Groundwater levels to the west (up dip) are some 201 mAHD (facilitating flow out of the pit)
- Groundwater levels to the east (down dip) are some 203 mAHD (flow in and out of the pit albeit net flux is outward).

<u>Central</u>

- Pseudo-steady water level in the residual void is predicted to be around 203 mAHD
- Groundwater levels to the west (up dip) are some 193 mAHD (facilitating flow out of the pit)
- Groundwater levels to the east (down dip) are some 192 mAHD (facilitating flow out of the pit).

<u>South</u>

- Pseudo-steady water level in the residual void is predicted to be around 203 mAHD
- Groundwater levels to the west (up dip) are some 194 mAHD (facilitating flow out of the pit)
- Groundwater levels to the east (down dip) are some 187 mAHD (facilitating flow out of the pit).

Plate 35 Thiess pit net groundwater flux predictions

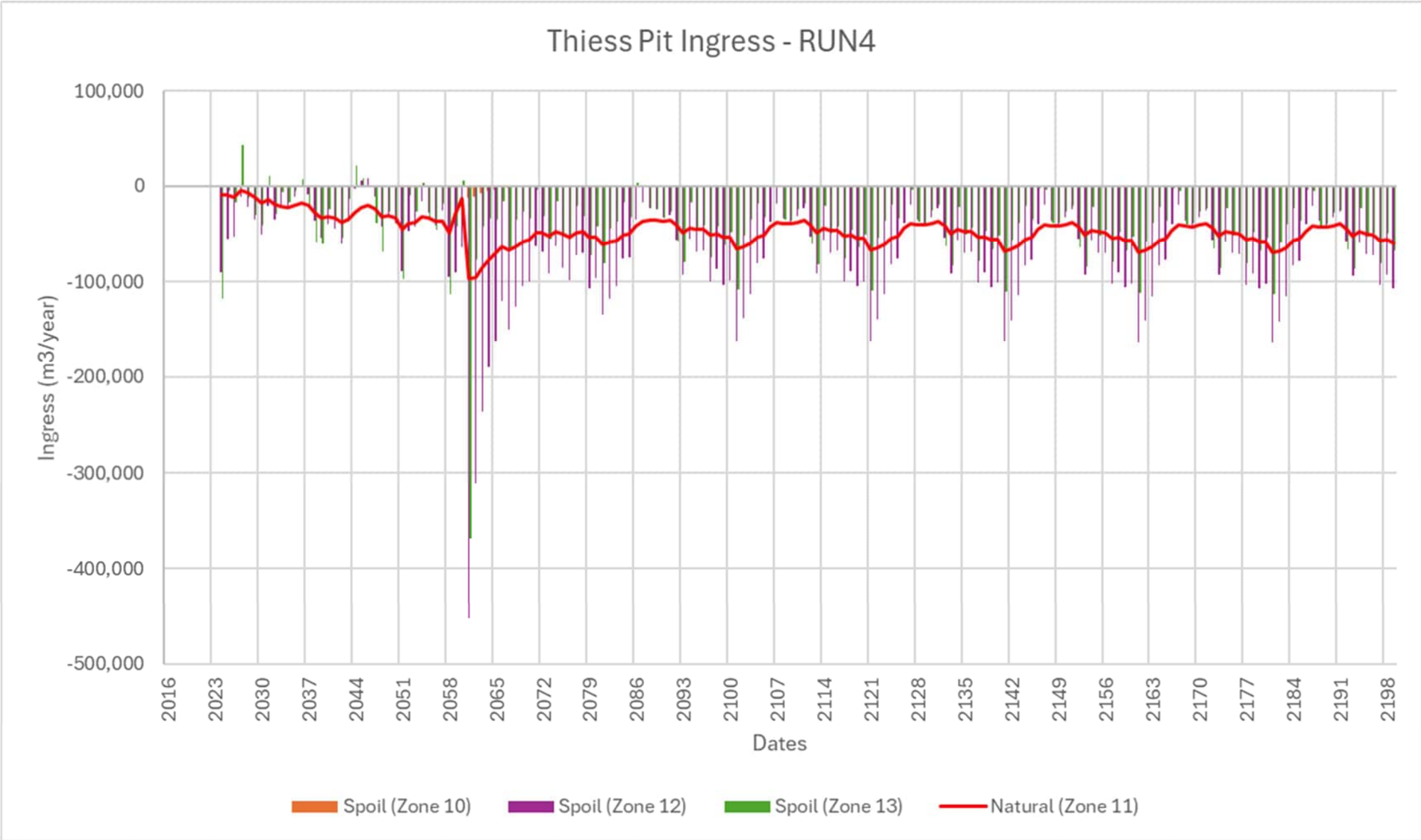
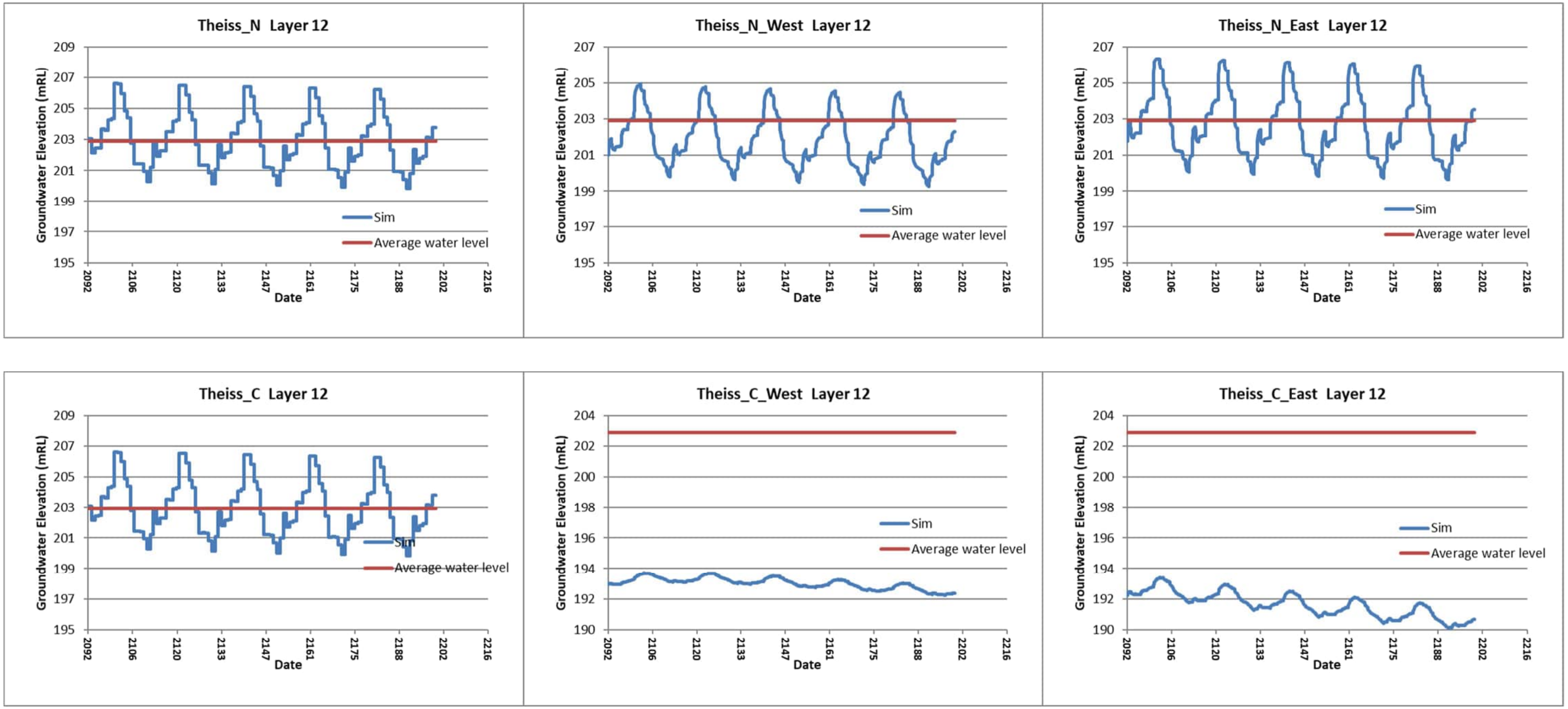
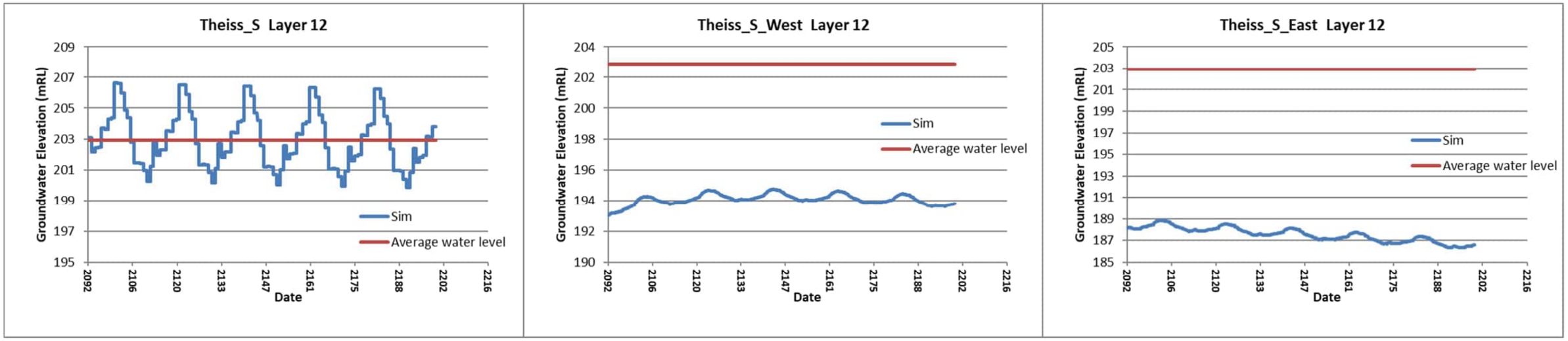


Figure 42 Thiess Pit hydrographs (2093 to 2199) north, central and south





Where:

Theiss N, Theiss C, and Theiss S provide predictions of residual void water level in the north, central, and southern portions of Thiess Pit, respectively

Theiss N West, Theiss C West, and Theiss S West Layer 12 provides predicted groundwater levels in the GLS seam up dip of Thiess Pit in the north, central, and southern portions of Thiess Pit, respectively

Theiss N East, Theiss C East, and Theiss S East Layer 12 provides predicted groundwater levels in the GLS seam down dip of Thiess Pit in the north, central, and southern portions of Thiess Pit, respectively

The red line is the average pit water level for reference

15.4.2.4 Ramp 32 East Pit

The groundwater model zone budget indicates that this pit acts as a groundwater “sink”, where groundwater from the surrounding natural rock flows into the residual void (Plate 36). Groundwater out of the pit is minimal and no ingress from the surrounding spoil is predicted.

Hydrographs of hypothetical observation points in the model were generated to assess the water levels in the pit and 100 m up and down dip (west and east) of the pit. These water level hydrographs (Figure 43) indicate:

- Pseudo-steady water level in the residual void is predicted to be around pit water 162 mAHD
- Groundwater levels to the west (up dip) are some 169 mAHD (facilitating flow into the pit)
- Groundwater levels to the east (down dip) are some 162.5 mAHD (facilitating flow into the pit).

Plate 36 Ramp 32 East pit groundwater flux predictions

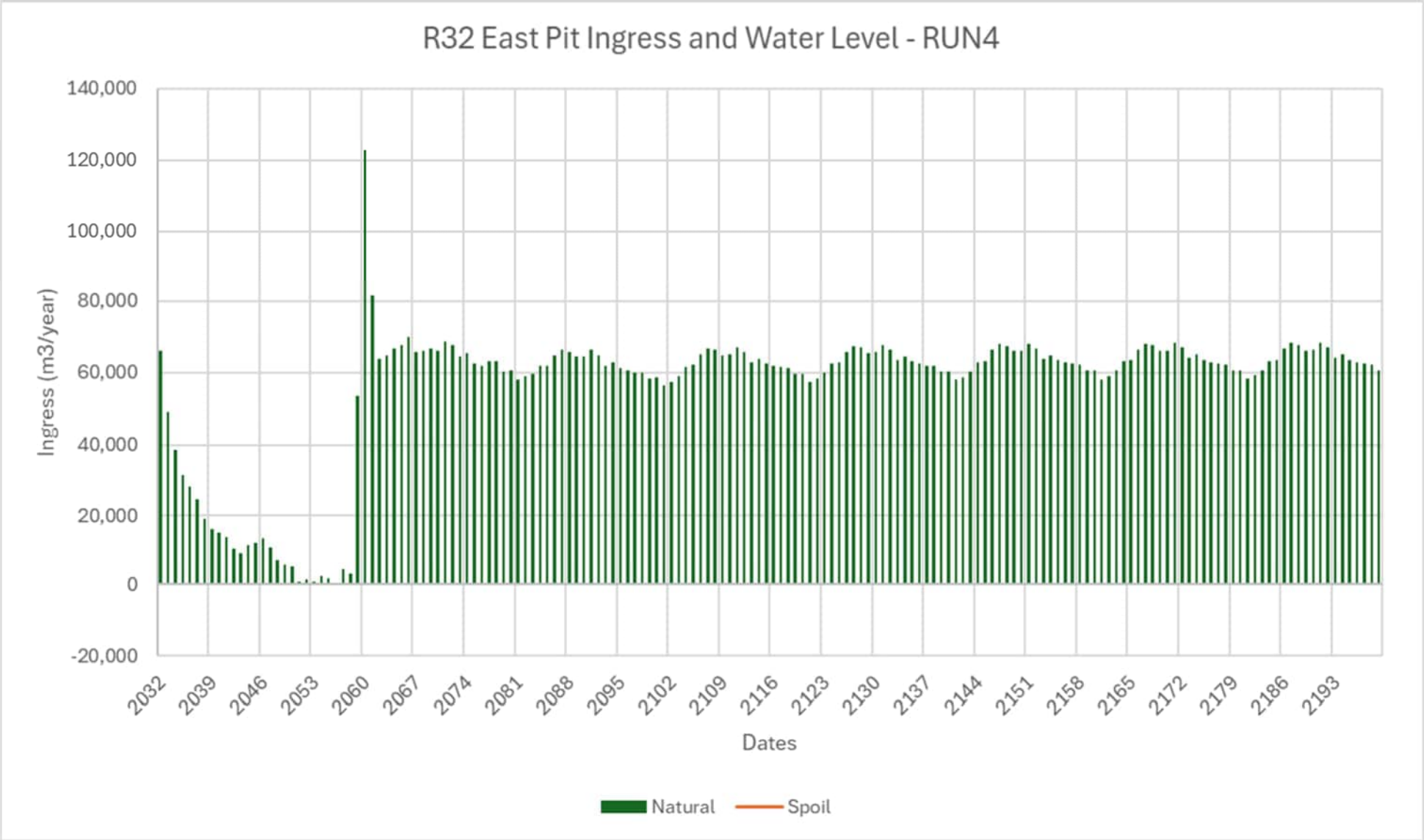
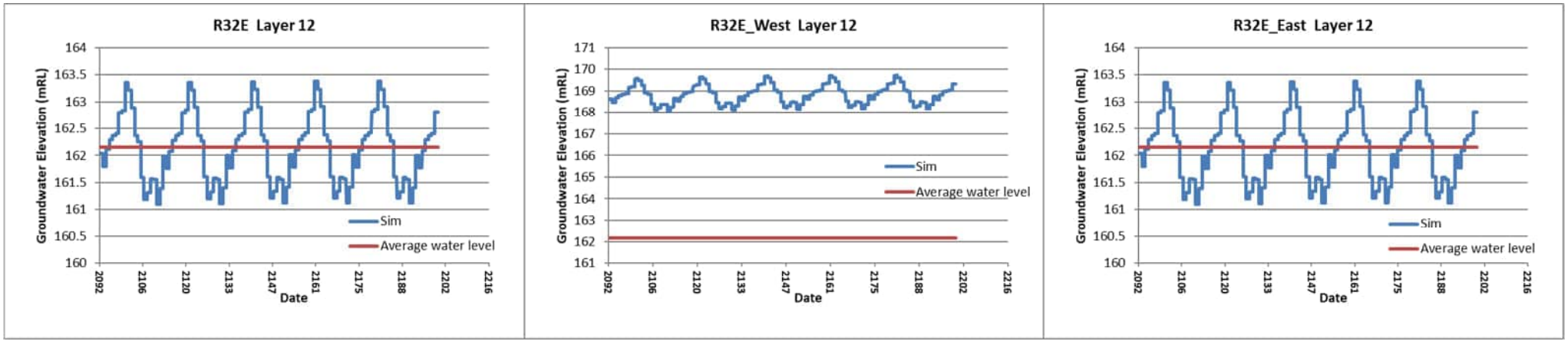


Figure 43 Ramp 32 East Pit hydrographs (2093 to 2199)



Where:

R32E Layer 12 provides predictions of Ramp 32 East residual void water level

R32E_West Layer 12 provides predicted groundwater levels in the GLS seam up dip of Ramp 32 East Pit

R32E_East Layer 12 provides simulated groundwater levels in the GLS seam down dip of Ramp 32 East Pit

The red line is the average pit water level for reference

15.4.2.5 Ramp 32 South Pit

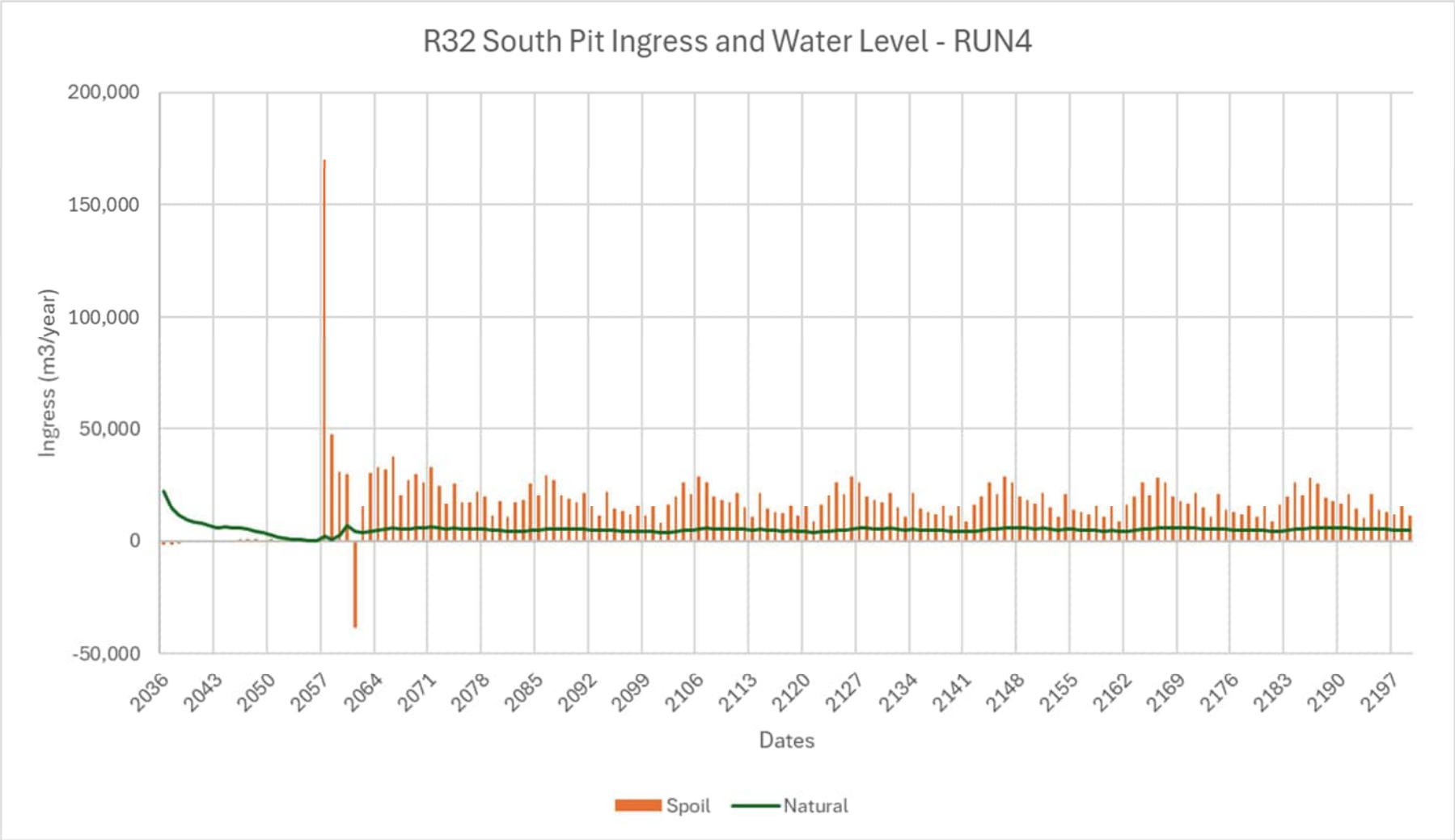
The groundwater model zone budget indicates that this pit acts as a groundwater “sink”, where groundwater from the surrounding natural rock flows into the residual void (Plate 37). Groundwater flow out of the pit is limited with ingress from the surrounding spoil and natural geology predicted.

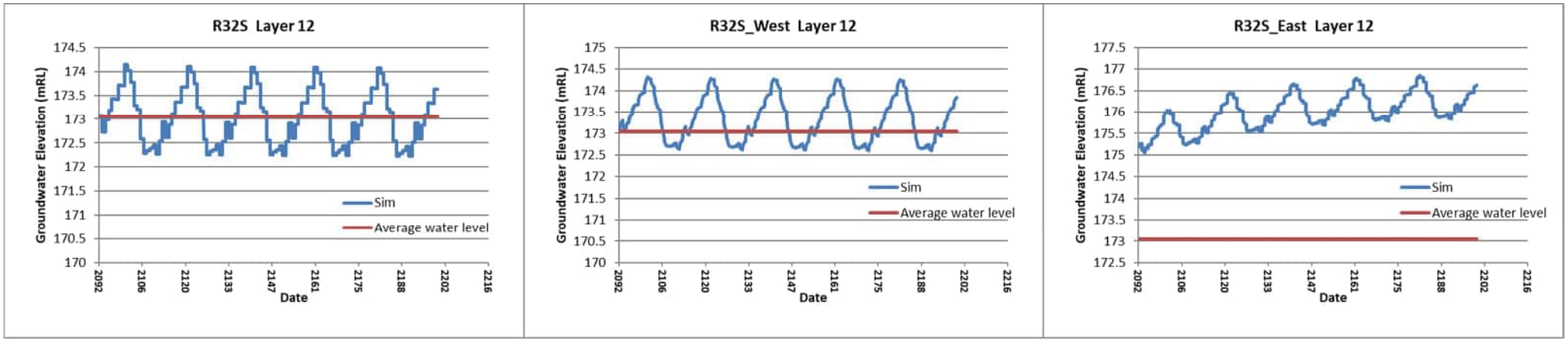
Hydrographs of hypothetical observation points in the model were generated to assess the water elevations in the pit and 100 m up and down dip (west and east) of the residual void.

These water level hydrographs (Plate 37) indicate:

- Pseudo-steady water level in the residual void is predicted to be around pit water 173 mAHD
- Groundwater levels to the west (up dip) are some 173.5 mAHD (facilitating flow into the pit)
- Groundwater levels to the east (down dip) are some 176 mAHD (facilitating flow into the pit).

Plate 37 Ramp 32 South pit groundwater flux and hydrographs





Where:

R32S Layer 12 provides predictions of Ramp 32 South residual void water level

R32S_West Layer 12 provides predicted groundwater levels in the GLS seam up dip of Ramp 32 South Pit

R32S_East Layer 12 provides simulated groundwater levels in the GLS seam down dip of Ramp 32 South Pit

The red line is the average pit water level for reference

15.4.2.6 Goonyella Pit

The residual void at the end of the Goonyella open cut mining extends along the eastern mine lease boundary and includes the deepest mining voids in GRB (some 325 m deep).

The groundwater model zone budget output indicates that this residual void acts as a groundwater "sink", where groundwater from the surrounding backfilled mine areas, residual voids (where outflow is predicted), and natural rock flow into the Goonyella residual void (Plate 38).

Hydrographs from hypothetical observation points east, west and within the void were generated at regular intervals along the length of the residual void, as indicated in Plate 39.

All of the water level hydrographs confirm that the Goonyella residual void acts as a groundwater sink and indicate that the pit water (compared to the surrounding groundwater levels) are markedly lower than the water level depths across the Project, as included in the hydrographs presented for all the other residual voids above.

<u>North</u>

- Pseudo-steady residual void water level is around 20 mAHD (> 100 m deeper than other residual void water levels)
- Groundwater levels to the west (up dip) are some 22 mAHD (facilitating flow into the pit)
- Groundwater levels to the east (down dip) are some 30 mAHD (facilitating flow into the pit).

Note: The pit floor is some -35 mAHD at this location, the pit floor adopted in the residual void (surface water) water balance model is set at a uniform -45 mAHD (it is assumed that the specialist modellers used the deepest pit floor elevation in their water balance model).

This results in the water level dip or decrease at the start of the water level hydrographs when the groundwater model drain cells (at bottom of pit) are changed to CHD and adopt the predicted water balance model pit water levels (Section 15.4.1). This dip in the water level hydrographs is recognised in all of the hypothetical observation point hydrographs. This is particularly evident in the middle set of hydrographs where the Goonyella open cut mine only extends to a depth of around 25 mAHD in this area (mining is shallower in this area due to environmental constraints in this area).

The predictive groundwater model recovery over the long term allows for the prediction of pseudo-steady state water levels over time. This allows for the evaluation of post-closure conditions (groundwater levels, residual void levels, and groundwater flow patterns). This indicates that the difference in the start (depth of pit water level) does not influence the Goonyella residual void acting as a sink in the long term.

Plate 38 Goonyella Pit groundwater flux

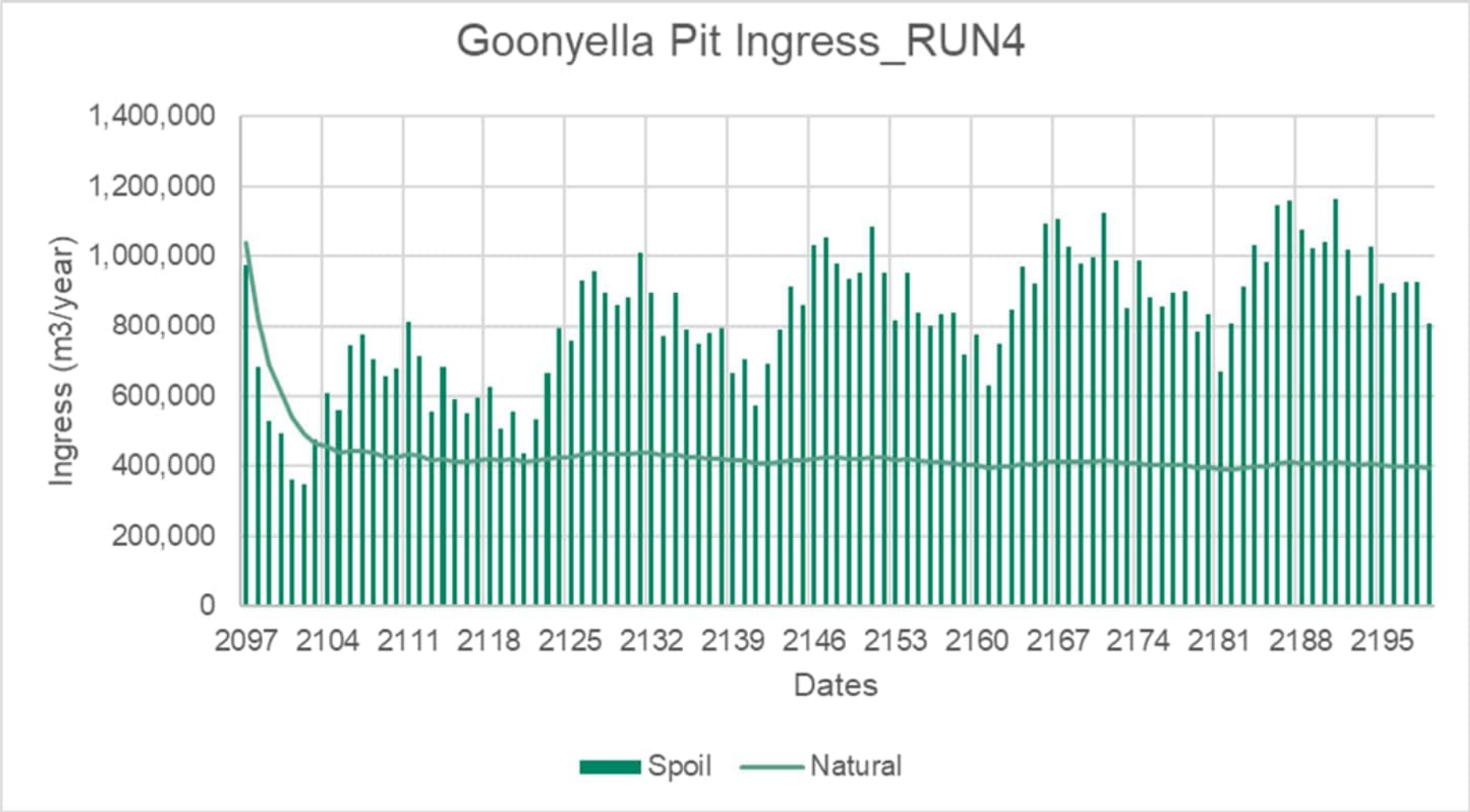
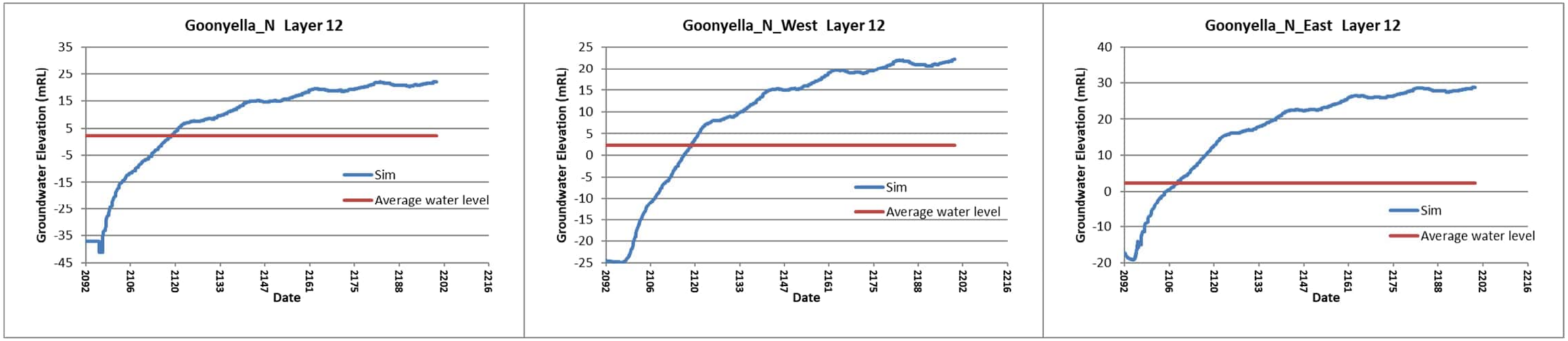
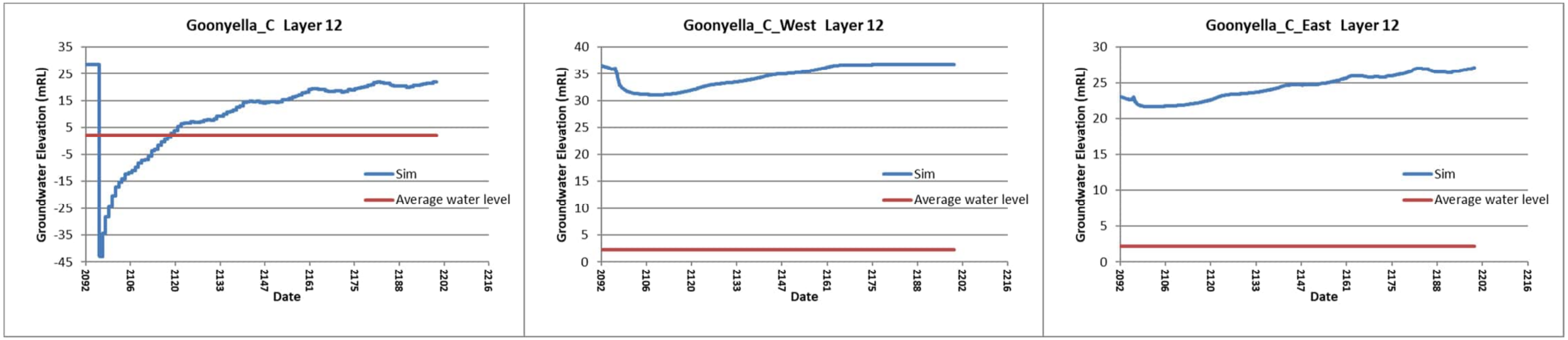
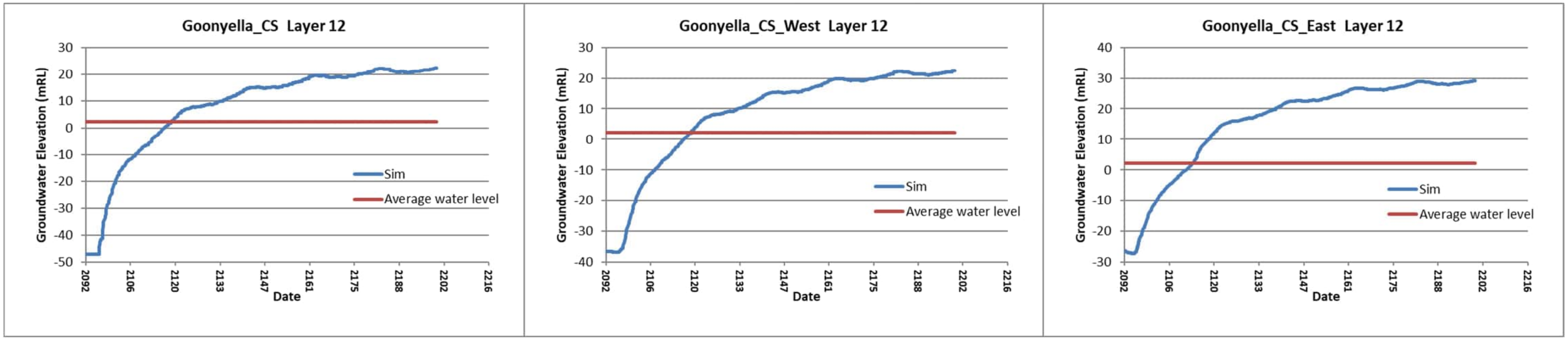
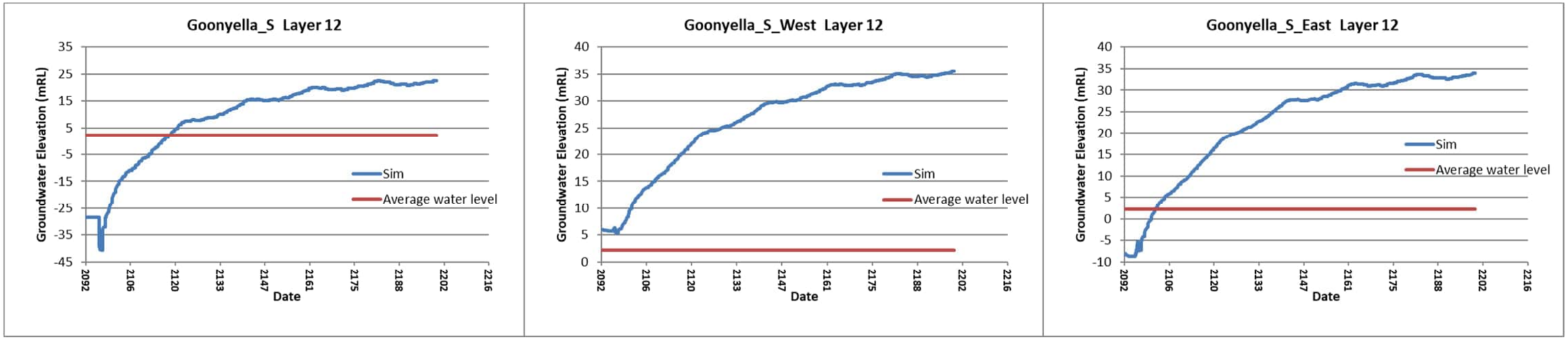


Plate 39 Goonyella pit hydrographs









Where:
Goonyella_N (north), Goonyella_C (middle), Goonyella_CS (central), and Goonyella_S (south) Layer 12 provide predictions of water levels in the north, middle, central, and south portions of the Goonyella residual void, respectively
Goonyella_N West, Goonyella_C West, Goonyella_CS West, and Goonyella_S West Layer 12 provide predictions of water levels up dip of the north, middle, central, and south portions of the Goonyella residual void, respectively
Goonyella_N East, Goonyella_C East, Goonyella_CS East, and Goonyella_S East Layer 12 provide predictions of water levels down dip of the north, middle, central, and south portions of the Goonyella residual void, respectively
The red line is the average pit water level for reference

Middle

- Pseudo-steady residual water level is around 20 mAHD
- Groundwater levels to the west (up dip) are some 36 mAHD (flow into the pit)
- Groundwater levels to the east (down dip) are some 27 mAHD (flow into the pit).

Note: The change from actual drawdown in the shallower portion of the Goonyella Pit in this area and the adopting of the CHD to match the residual void water balance pit levels (Section 15.4.1) results in the decrease in water levels to the west and east of the pit, due to sudden dewatering (dropping the level to match the uniform -45 mAHD obtained from the residual void water balance model). This will not occur in reality. As per the statement included above the difference in the start (depth of pit water level) does not influence the Goonyella residual void acting as a sink in the long term.

Central

- Pseudo-steady residual void water level is around 20 mAHD
- Groundwater levels to the west (up dip) are some 20 mAHD (flow into the pit)
- Groundwater levels to the east (down dip) are some 30 mAHD (facilitating flow into the pit).

South

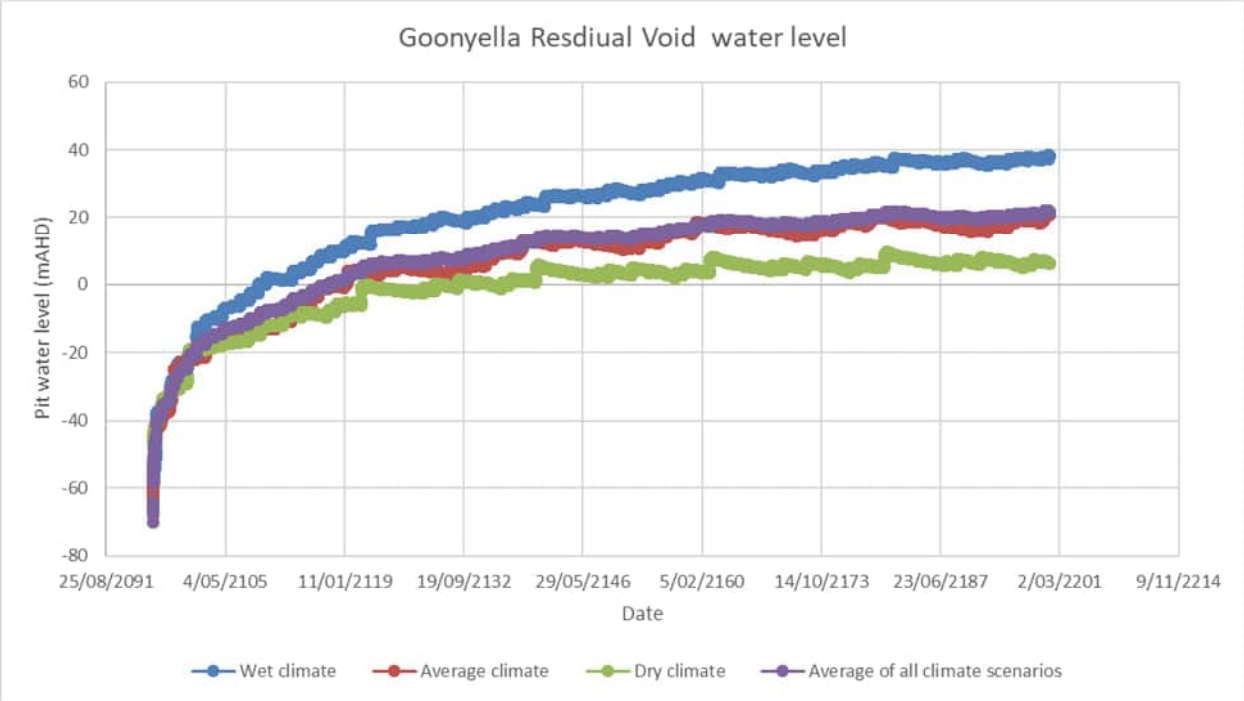
- Pseudo-steady pit water level is around 20 mAHD
- Groundwater levels to the west (up dip) are some 35 mAHD (facilitating flow into the pit)
- Groundwater levels to the east (down dip) are some 33 mAHD (facilitating flow into the pit).

15.4.3 Residual void water levels

The residual void water balance modelling included for wet, average, and dry climate conditions as inputs into the model predictions, this allowed for an assessment of variability in the residual void water levels and assessment of potential for decant and void water migration.

An example of the variation in the residual void water level, for the Goonyella residual void, is included in Figure 44.

Figure 44 Goonyella residual void predicted water level (WSP water balance model)



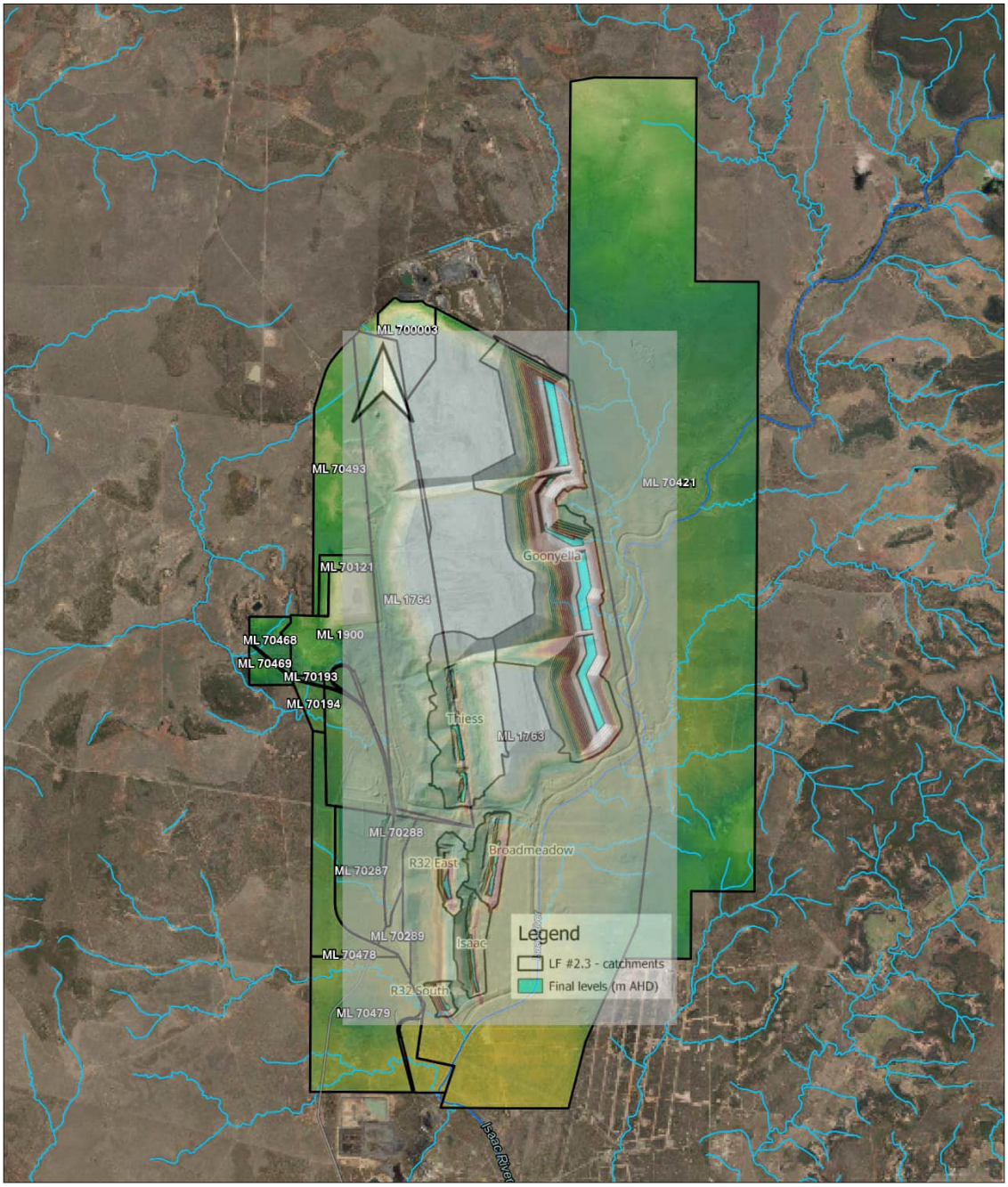
The void water level resulting from the average of the climate scenarios was adopted for the groundwater model predictions.

To allow for the potential variability of the residual void water levels with regards to the groundwater flux component an assessment of groundwater contribution into the water balance was conducted (Section 16.3.1).

An uncertainty analysis of the groundwater flux predictions was then conducted to allow for a validation of residual voids acting as sources or sinks as well as a more detailed evaluation of potential for void water migration within the groundwater. These groundwater flux assessments are included in Section 16.3.

A depiction of the residual void water levels post-closure associated with Landform #2.3 is included in Figure 45.

Figure 45 GRB residual voids containing water post-closure (source: WSP, 2024)



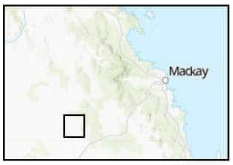
Goonyella, Redhill and Broadmeadow Mines
Post Mining Landform (Landform #2)

Mine Lease
Major
Minor

Landform 2
Elevation (mAHD)
401
-71

0 1 2 3 km
1:100,000

AECOM



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15.5 Predicted Groundwater Levels

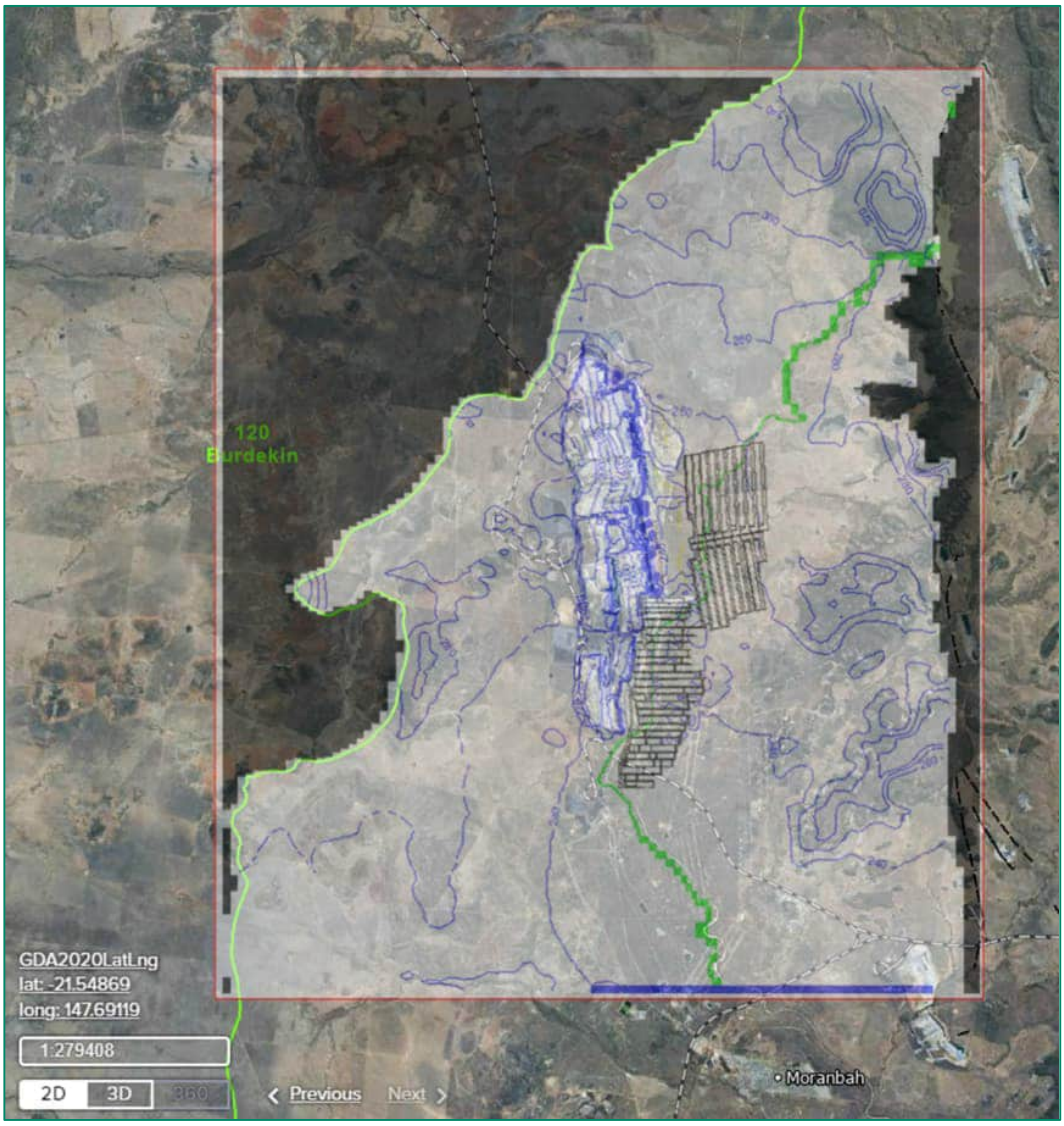
Groundwater level changes during the predictions periods were compiled and assessed to understand the change in groundwater flow patterns and gradients as a result of active (mine dewatering), the introduction of water into the underground workings, and passive (seepage ingress into) plus artificial recharge from residual pits which contain pit water.

Groundwater contours over time assisted with flow path simulations (using particle tracking) in Section 15.6 and understanding changes at receptors (Section 15.8).

Section 15.1 describes the groundwater elevation estimated for the start of model predictions in 2024. The groundwater elevation data indicates the groundwater contours, flow patterns and gradients that are predicted to occur across the model domain in 2024.

Complex mine activities detailed in Section 15.2 indicate the dewatering and recharge activities over time that will determine the groundwater levels at the end of mining activities, in 2097. The closure (end of all mining activities at GRB and RHM) groundwater levels and flow patterns are predicted post 2097 within prediction period P4 (Section 15.2).

Note: As reference the modelled contours include for the entire model domain as included in Plate 16 and Section 15.1 and presented below.



15.5.1 Water level change in the surficial cover

The drawdown and recovery of the groundwater levels in Model Layer 1 (Table 18), which includes surficial cover either alluvium or Tertiary sediments, was predicted based on the calibration groundwater elevations at the start of prediction period P1.

The changes at the end of each of the prediction phases including the end of P4 (considered representative of closure after an extended period of recovery, 2199) are included in Figure 46.

The water level change from 2024 over time indicates:

- Limited change over time (limited expansion or contraction of the extent of drawdown around the residual voids from P2 to P4)
- No change to the zero (no drawdown) contour across the Issac River (green model cells)
- The extent of drawdown in Model Layer 1, when comparing groundwater drawdown contours (location and extent) in 2024 (derived from calibration for start of predictions) reduces and then is recognised to stabilise over time (end of P3 and end of P4).

15.5.2 Water level change in the GMS target coal seam

The drawdown and recovery of the groundwater levels in the GMS (Model Layer 10, Table 18), was assessed based on the change in groundwater levels relative to levels derived at the start of P1.

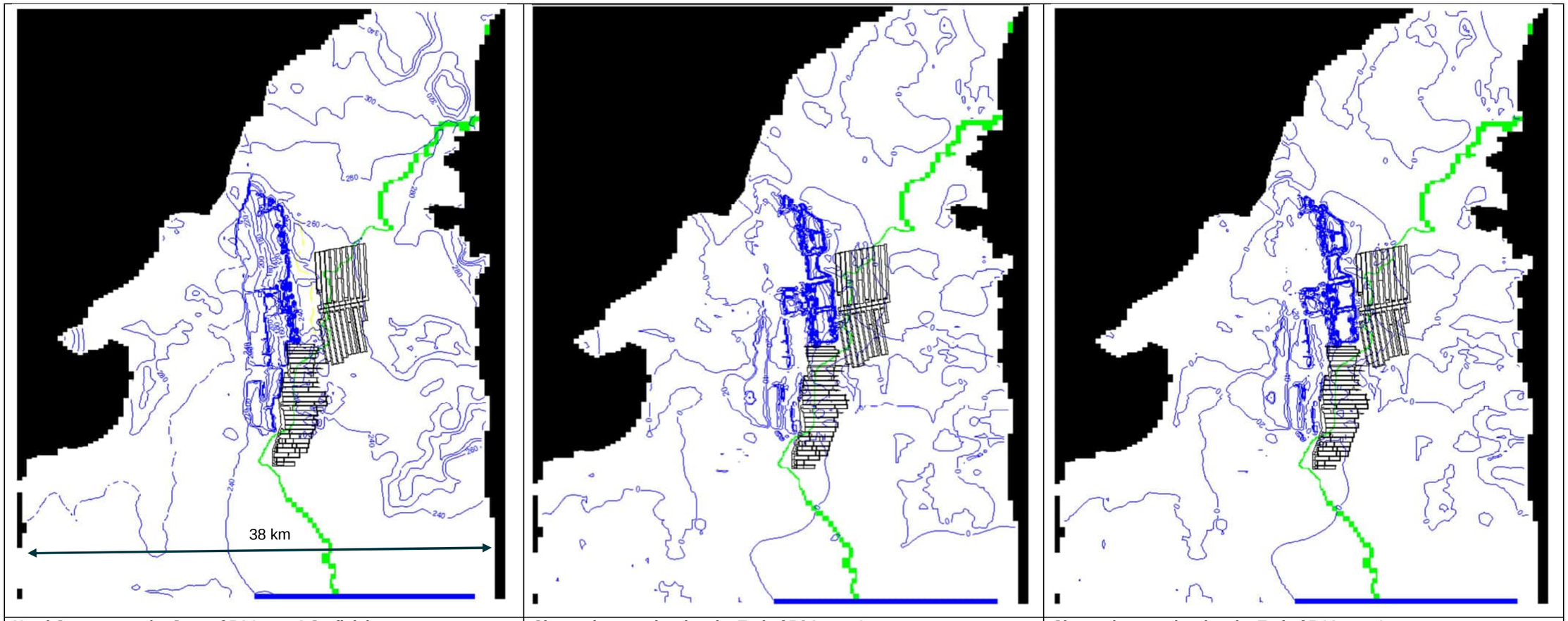
The changes at the end of each of the prediction phases including the end of P4 (considered representative of closure after an extended period of recovery, 2199) are included in Figure 47.

The water level change over time indicates:

- The influence of RHM is evident in P3 water levels, resulting in larger drawdown
- Water introduced into the underground workings reduces the RHM drawdown to the east, as evident in P4 drawdown contours
- Water levels in portions of the Broadmeadow GMS workings do not recover to the 2024 (P1) levels, even after the introduction of water, due to the proximity to the Broadmeadow, Isaac, and Goonyella residual voids, which continue to remove water from the system
- The GMS dewatering is not predicted to result in induced flow from the Tertiary and Back Creek Group to the west of the mining areas.

To assist in comparing the change in water levels from mining activities (mining, rehabilitation, decommissioning, and water introduction during the prediction periods) to post-closure the difference in water level (rise and fall) is included in Plate 40.

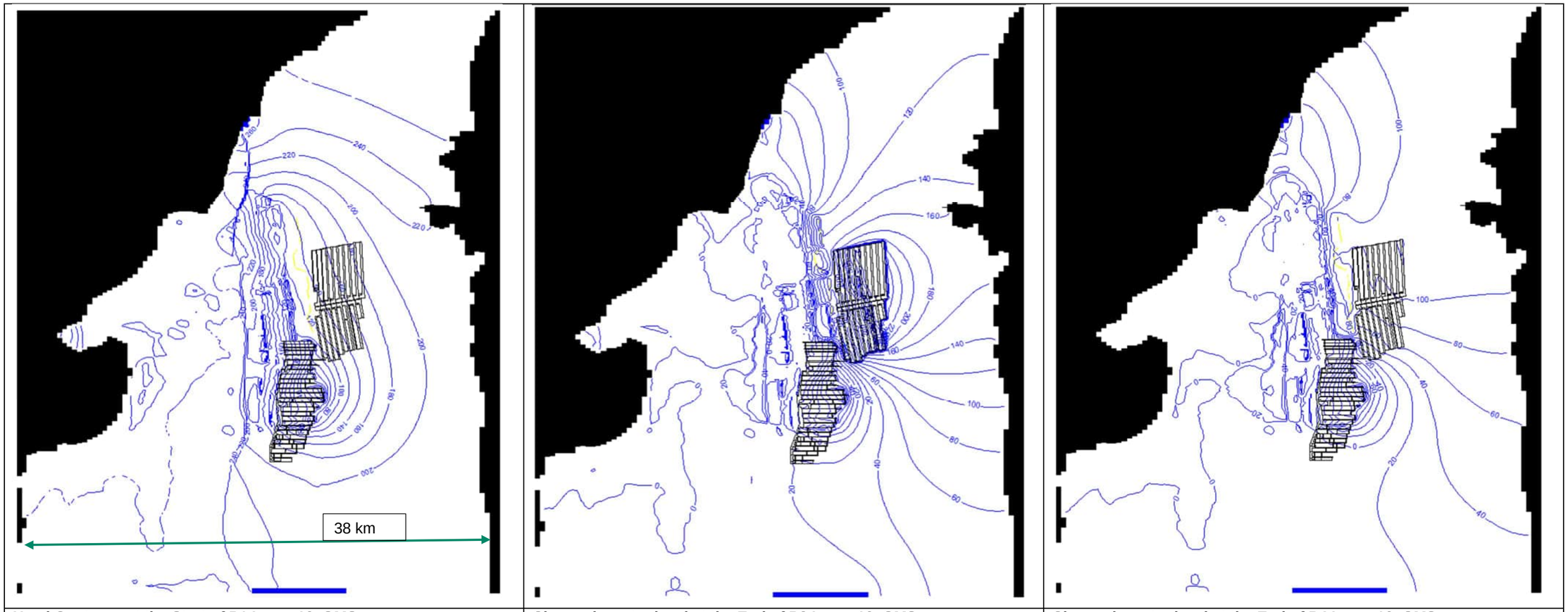
Figure 46 Initial groundwater elevation at start of P1 and change in water level (in m) at end of P3 and P4 in Model Layer 1



Head Contours at the Start of P1 Layer 1 Surficial cover	Change in water level at the End of P3 Layer 1	Change in water level at the End of P4 Layer 1

Green model cells are the Isaac River
Yellow model cells are the Goonyella residual void
RHM and Broadmeadow GMS mine layouts for reference

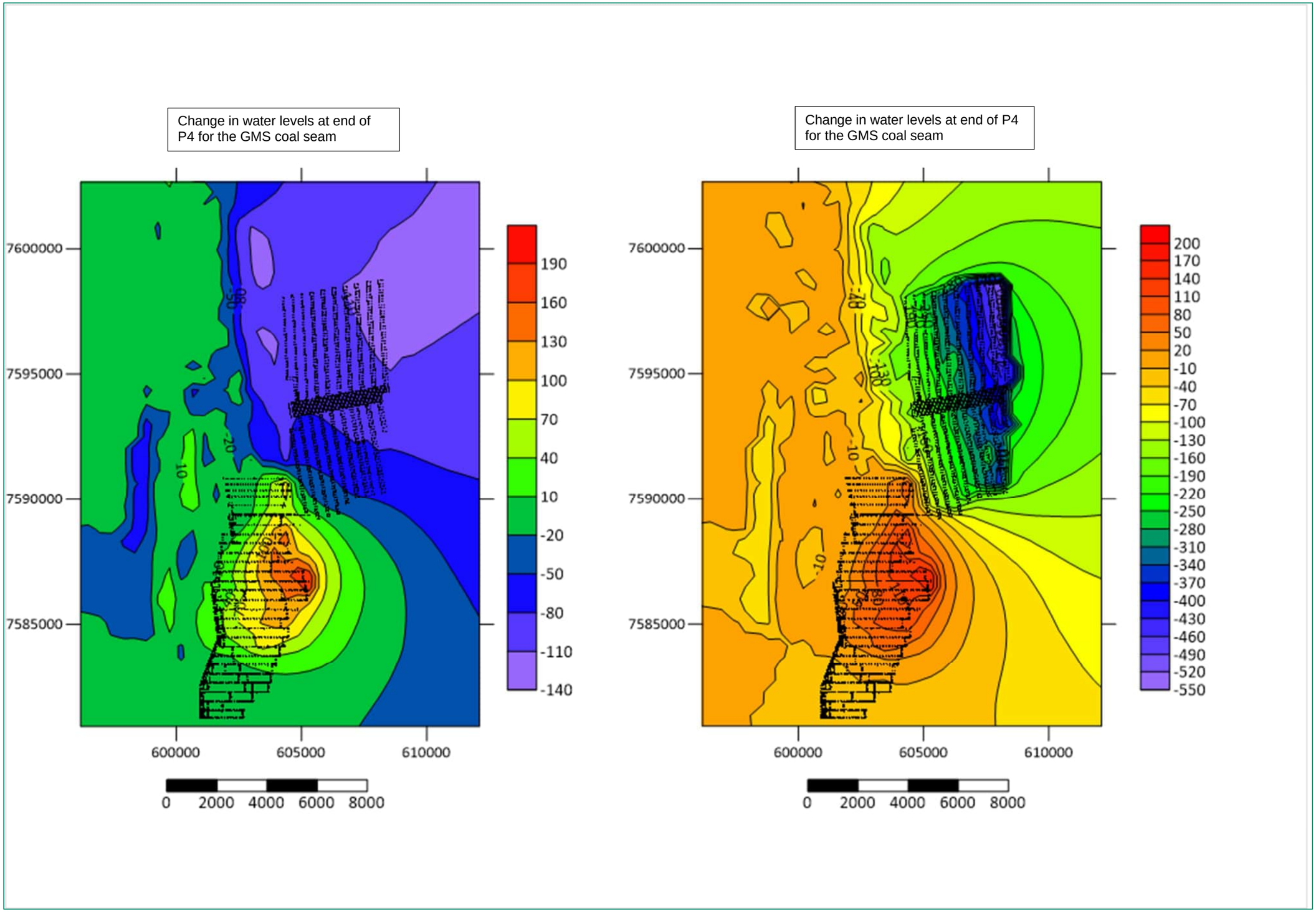
Figure 47 Groundwater elevations at start of P1 and water level change end of P3 and P4 (in m)in Model Layer 10 GMS

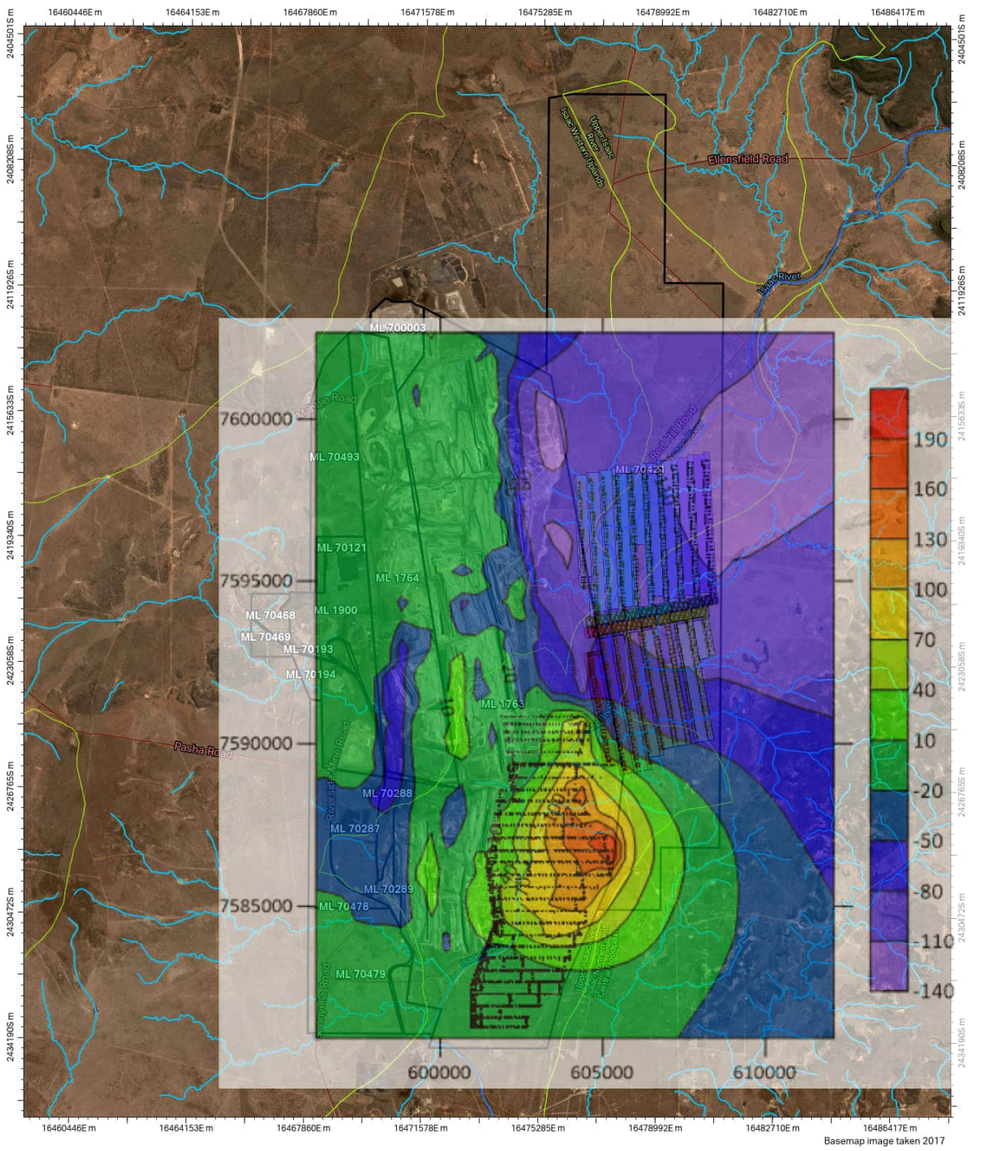


Head Contours at the Start of P1 Layer 10, GMS	Change in water level at the End of P3 Layer 10, GMS	Change in water level at the End of P4 Layer 10, GMS

Green model cells are the Isaac River
Yellow model cells are the Goonyella residual void
RHM and Broadmeadow GMS mine layouts for reference

Plate 40 GMS water level difference from the initial groundwater heads at start of P1 (water level change in m)





Goonyella, Riverside and Broadmeadow Mines
Mining Activities: Redhill Mine (GMS)

GDA 1994 MGA Zone 55
1:100,000

AECOM

Mine Lease
Subcatchment boundary
Watercourse (Major)
Watercourse (Minor)

2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091

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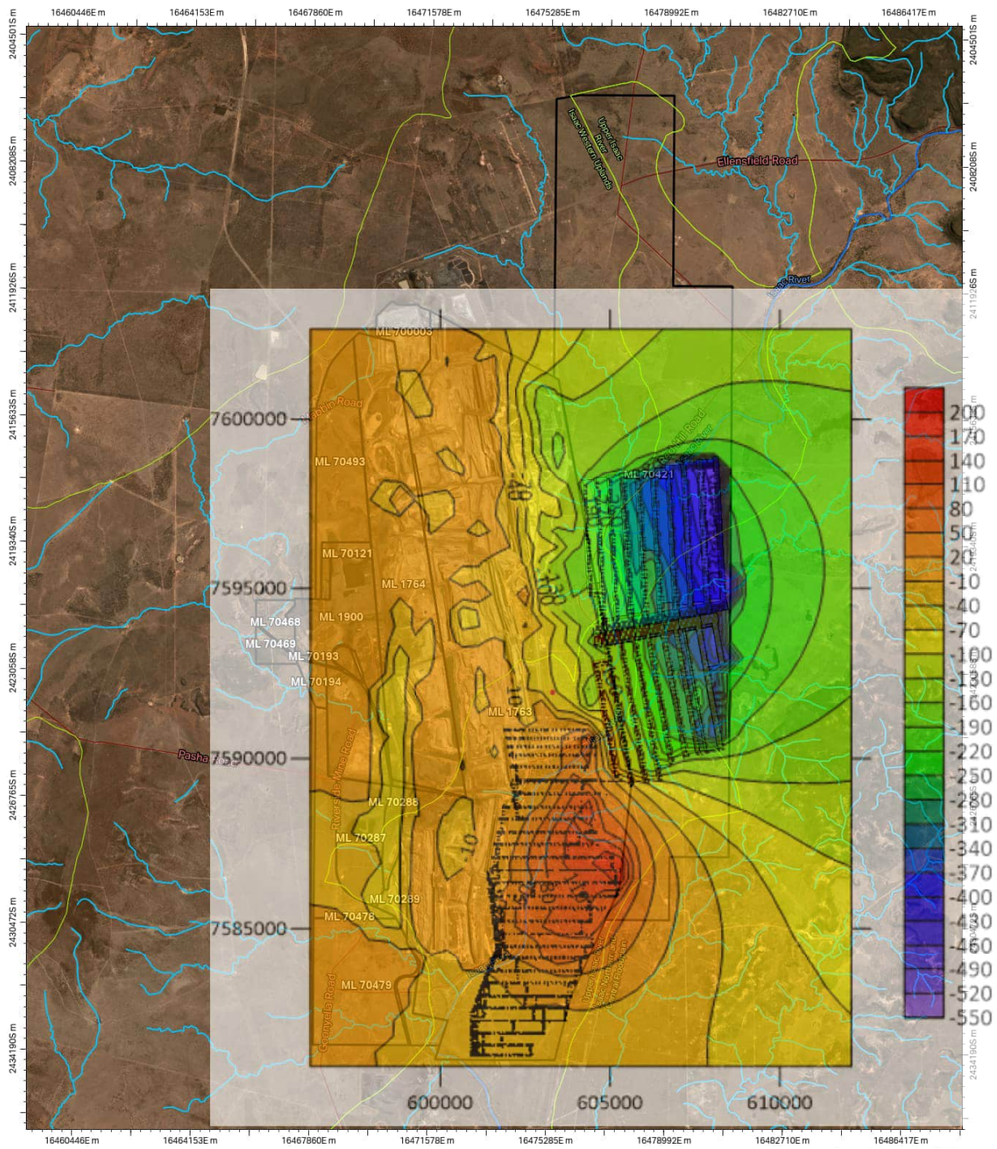

Goonyella, Riverside and Broadmeadow Mines
Mining Activities: Redhill Mine (GMS)

GDA 1994 MGA Zone 55
1:100,000

AECOM

Mine Lease
Subcatchment boundary
Watercourse (Major)
Watercourse (Minor)

2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091

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Department of Resources, DESI, Esri, TomTom, Garmin, FAO, NOAA, USGS, Esri, USGS

The predictive modelling, considering change in groundwater levels from the 2024 initial calibrated elevations, indicate:

- The drawdown in GMS at the end of P3 2092, at the end of Red Hill Mine mining, is up to 550 m at the deepest part of the Red Hill Mine (Plate 40).
    - The drawdown below the initial groundwater levels (P1) ranged from +200 m (water introduced into Broadmeadow GMS) and – 550 m (deepest mine workings in RHM) at the end of P3.
- During P4 the Red Hill Mine is filled with water plus recovery and groundwater stabilisation occurs, as included in the P4 predictions at the end of 2199 (Figure 47).
- The water level change from P1 levels in GMS at the end of P4 2199 (prolonged recovery and stabilisation after mining and the introduction of water) range from +190 m (water introduced into Broadmeadow GMS) and -140 m (in proximity to the Goonyella residual void).
    - Water introduced into the Broadmeadow GMS underground workings caused a 200 m change (rise) in 2092, which decreased slightly to 190 m in 2199. This reduction is related to the Goonyella residual void.

15.5.3 Water level change in the GLS target coal seam

The drawdown and recovery of the groundwater levels in the GLS (Model Layer 12, Table 18), was predicted based on changes relative to the initial groundwater levels and contours derived during model calibration and included at the start of prediction period P1.

The water level changes at the end of each of the prediction phases including the end of P4 (considered representative of post-closure after an extended period of recovery, 2199) are included in Figure 48.

The water level comparison to start of P1 over time indicates:

- The influence of RHM is evident in P3 water level change
- The introduction of water reduces the RHM drawdown to the east, as evident in P4 drawdown contours
- Broadmeadow GLS is not readily drawn down after water introduced into the underground workings, even due to the proximity to the Goonyella residual void
- GLS dewatering is not predicted to result in induced flow from the Tertiary and Back Creek Group to the west of the mining areas (0 m water level change contours).

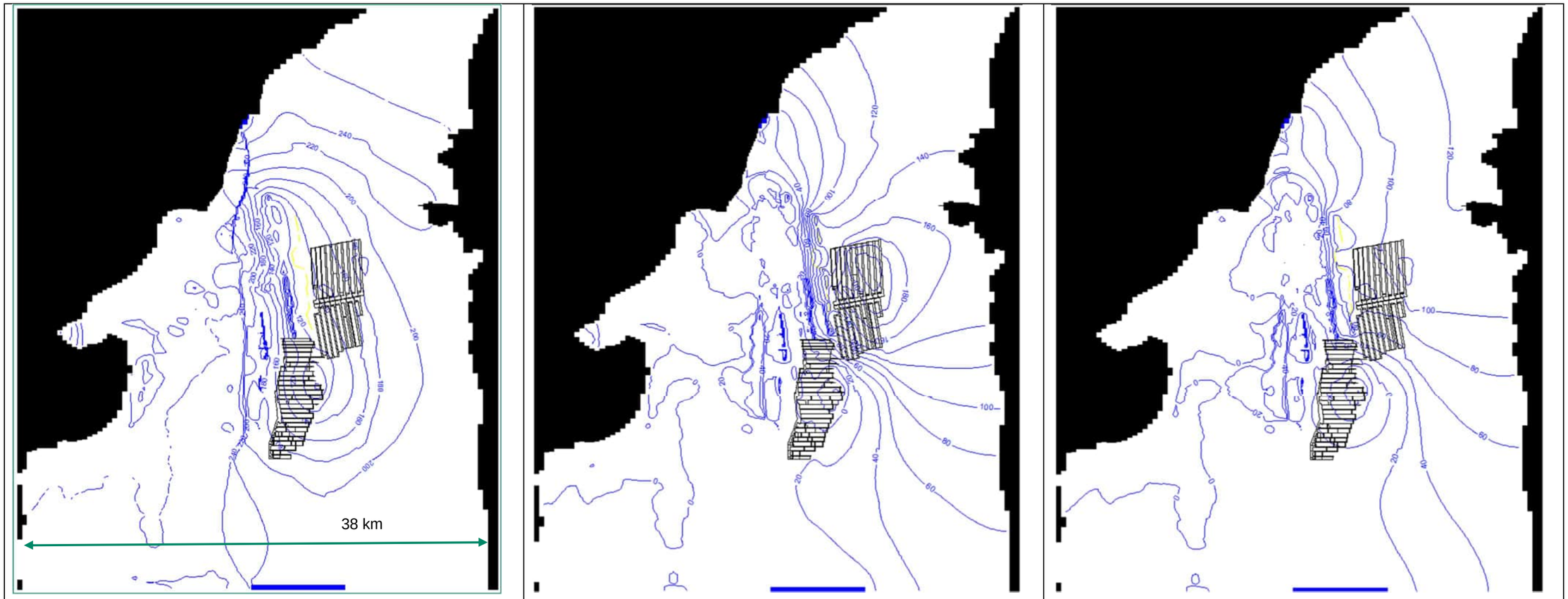
To assist in comparing the change in water levels from mining activities (mining, rehabilitation, decommissioning, and water introduction during the prediction periods) to post-closure the difference in water level (rise and fall) is included in Plate 41.

The predictive modelling, considering change in groundwater levels from the 2024 initial calibrated elevations, indicate:

- The drawdown in GLS at the end of P3 2092, at the end of Red Hill Mine mining, is up to 240 m centred around the Red Hill Mine (Plate 41).
    - The drawdown below the initial groundwater levels (P1) ranged from +60 m (water introduced into Broadmeadow GLS) and – 240 m (RHM) at the end of P3.
- During P4 the Red Hill Mine is filled with water and recovery and groundwater stabilisation occurs, as included in the P4 predictions in 2199 (Plate 41).
- The water level change from P1 levels in GLS at the end of P4 2199 (prolonged recovery and stabilisation after mining and the introduction of water) range from +50 m (water introduced into Broadmeadow GLS) and -240 m (in proximity to the Goonyella residual void).

- Water introduced into the Broadmeadow GLS underground workings caused a 60 m change (rise) in 2092, which decreased slightly to 50 m in 2199. This reduction is related to the Goonyella residual void.

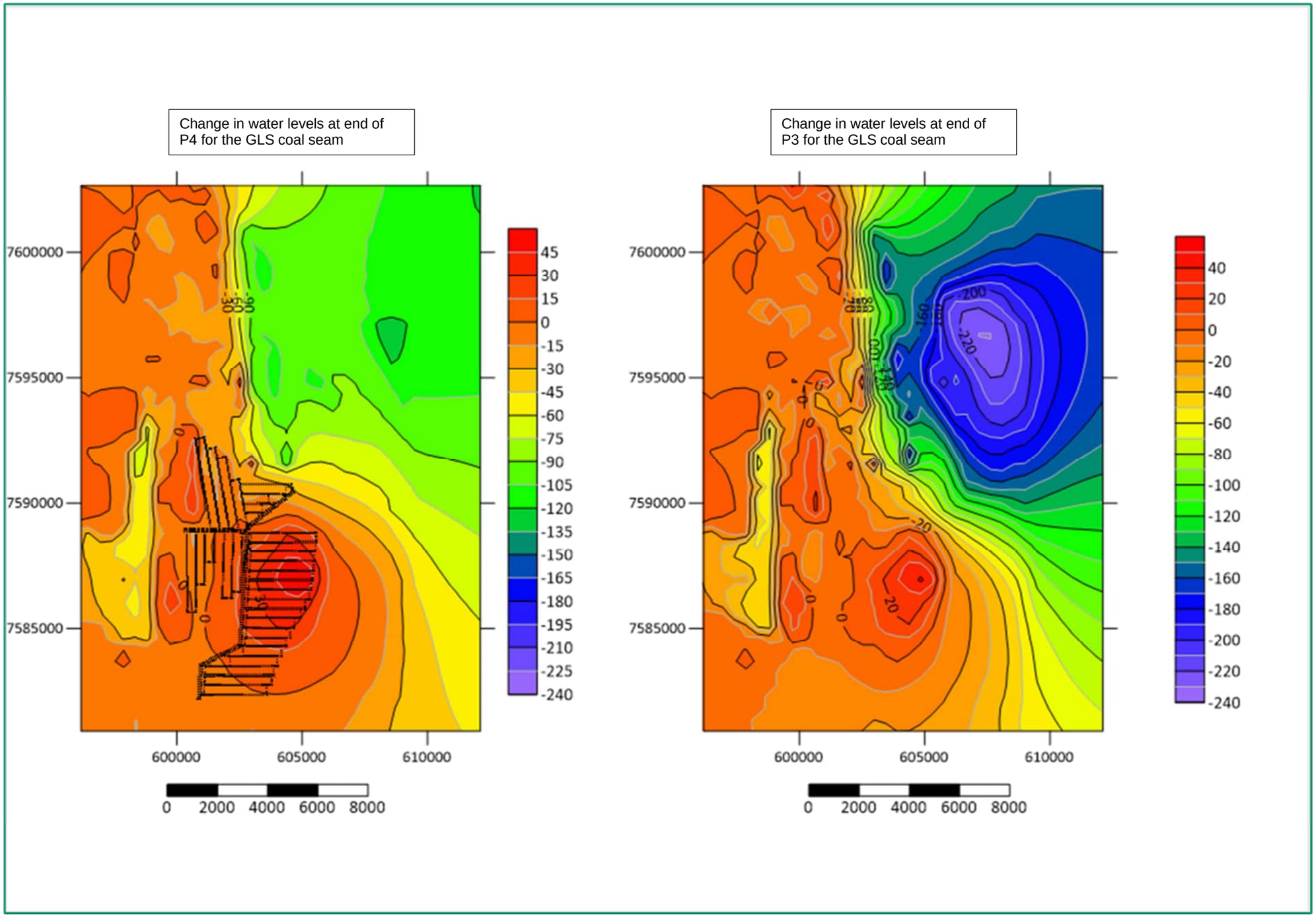
Figure 48 Groundwater elevation in GLS at start of P1 and water level change (in m) at the end of P3 and P4 for in Model Layer 12 GLS

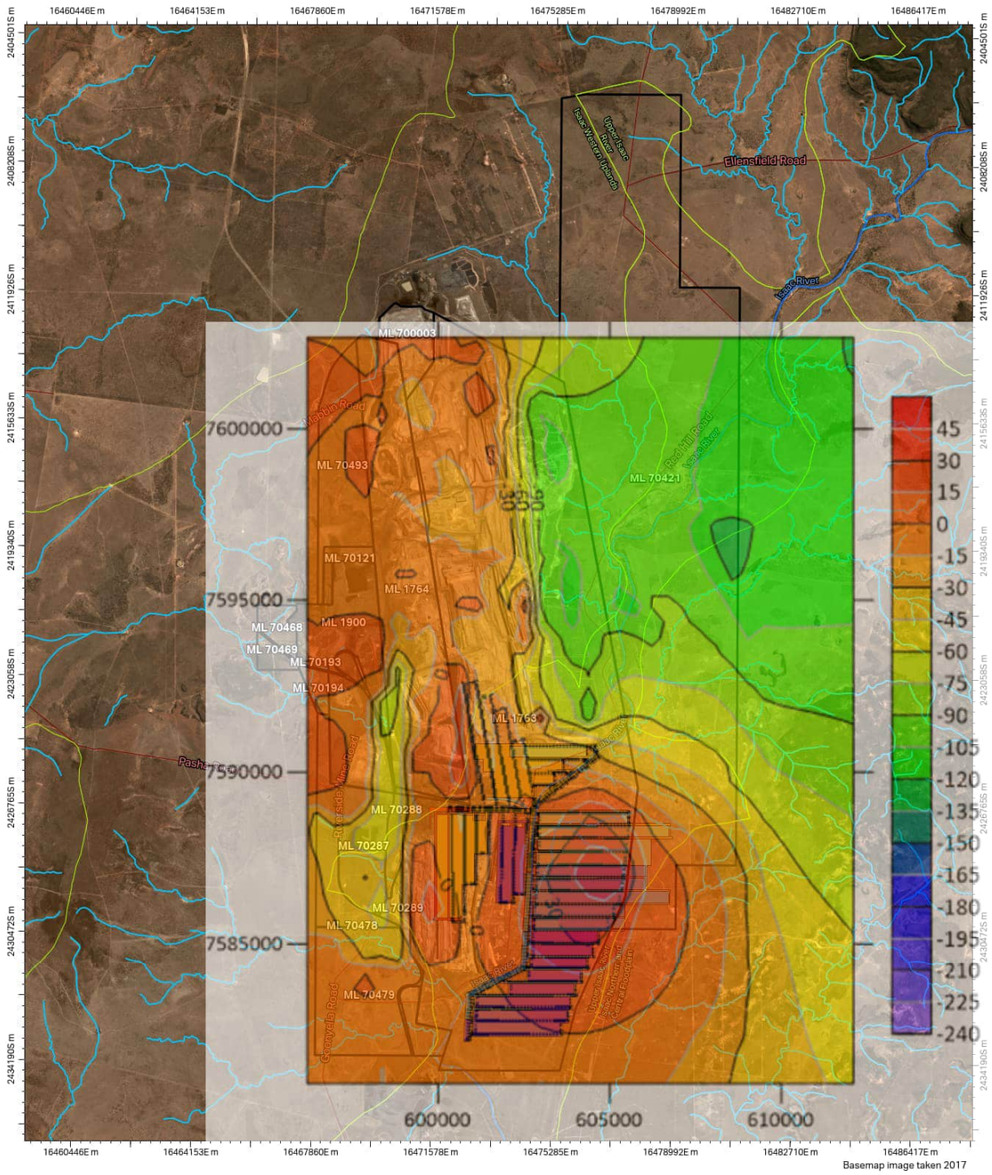


Head Contours at the Start of P1 Layer 12, GLS	Change in water level at the End of P3 Layer 12, GLS	Change in water level at the End of P4 Layer 12, GLS

Green model cells are the Isaac River
Yellow model cells are the Goonyella residual void
RHM and Broadmeadow GMS mine layouts for reference

Plate 41 GLS water level difference from the initial groundwater heads at start of P1 (water level change in m)





Goonyella, Riverside and Broadmeadow Mines
Mining Activities: Broadmeadow Mine (GLS)

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)
- FY2024-2028
- FY2029-2033
- FY2034-2038
- FY2039-2043
- FY2044-2053

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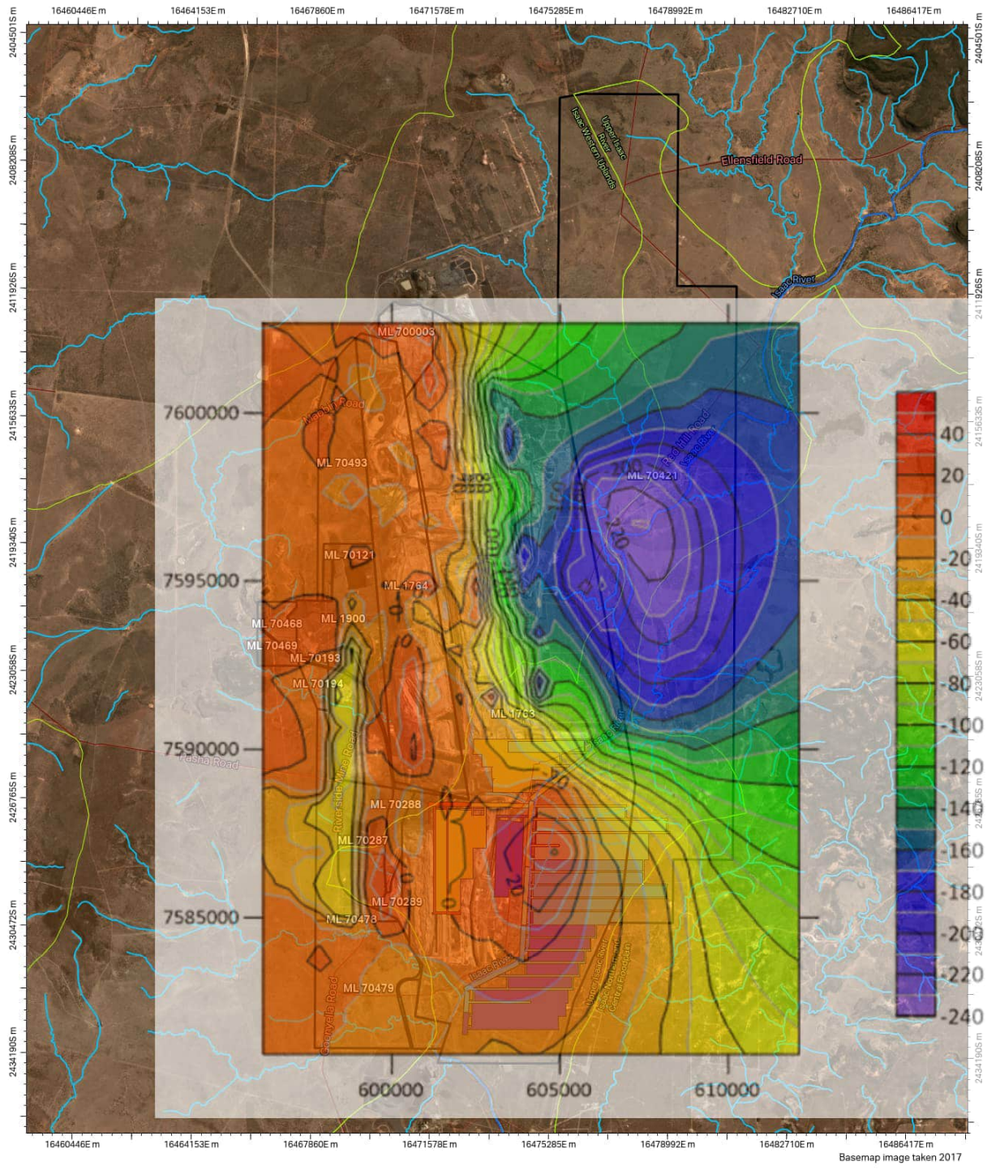

Goonyella, Riverside and Broadmeadow Mines
Mining Activities: Broadmeadow Mine (GLS)

- Mine Lease
- Subcatchment boundary
- Watercourse (Major)
- Watercourse (Minor)
- FY2024-2028
- FY2029-2033
- FY2034-2038
- FY2039-2043
- FY2044-2053

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15.6 Flow Path Simulation

The groundwater model zone budget approach allowed for the evaluation of the groundwater flow either into or out of the residual voids (Section 15.4.2). In addition, the evaluation of the hydrographs generated for hypothetical water level observation points, provided an indication of residual voids acting as sinks or sources within the groundwater system post closure based on relative long term water level predictions (in the residual voids and up and down dip of the residual voids).

The migration of the void water was further assessed using particle tracking, to evaluate flow directions, extent of migration within groundwater, and variation in flow during the post-mining stabilisation of groundwater levels overtime.

Particles were introduced into the saturated model cells at different times during the model prediction phases, to assess migration to or from the residual voids. These data were then considered with groundwater contours (as described in Section 15.4.3), plus the groundwater model zone budget and hydrograph lines of evidence, to assess potential for transport of the void water from the mine leases over time.

The initial particle tracking, based on the large model domain and active cells, was conducted for a 10 year period during prediction periods P3 and P4, to obtain an understanding of groundwater flow patterns and influence of mining activities (mining, rehabilitation, decommissioning, and water introduction during the prediction periods). Long duration post-closure particle tracking were conducted (Section 15.7) based on the 10-year results (i.e., targeted particle tracking was conducted for residual voids were migration from the residual voids were identified to allow for the assessment of potential contaminant migration within the groundwater to be further assessed).

15.6.1 Residual voids (excluding Goonyella Pit)

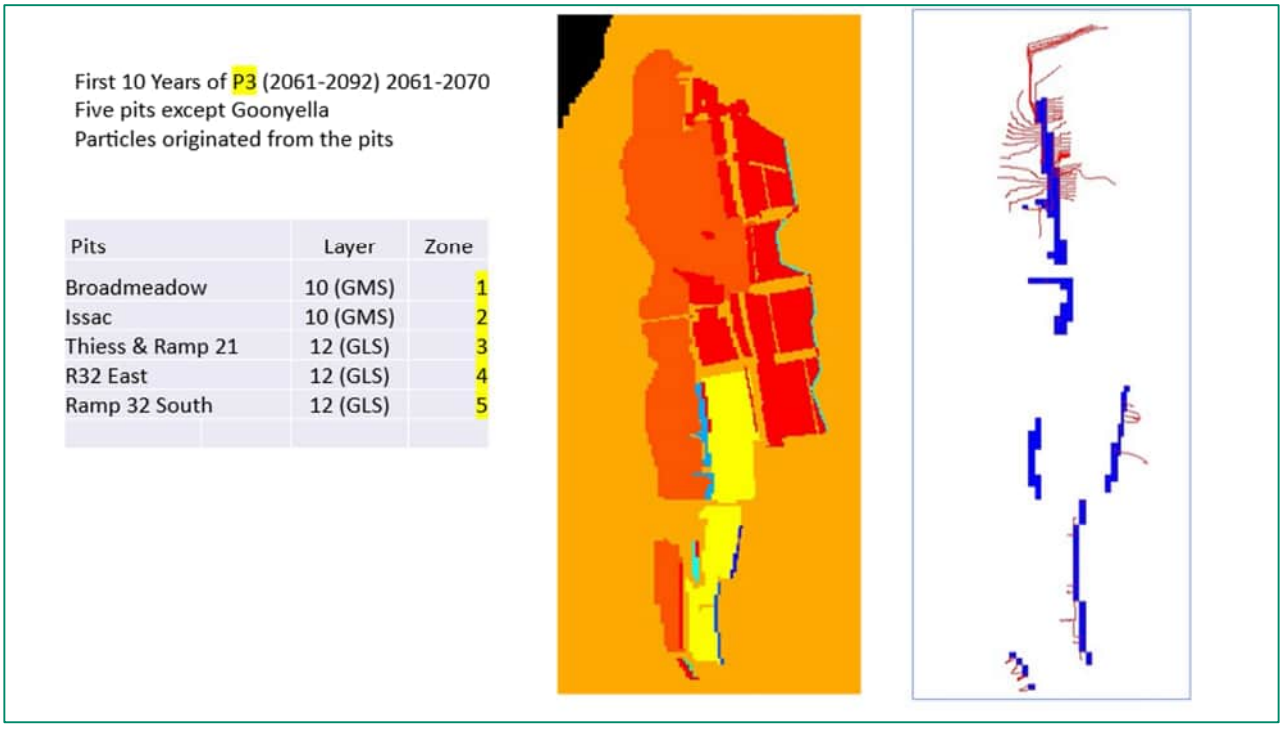
Particle tracking was conducted at the five (5) residual voids to assess possible void water migration within groundwater. The particle tracking was limited to 10 year running times to allow for the evaluation of possible particle movement and to provide validation of the groundwater flow predicted during the post-mining using groundwater contours and flow patterns, model zone budget (in or out) ingress, and pilot hole/s hydrographs.

15.6.1.1 First 10 Years of P3 (2061-2070)

This Prediction Period includes for the residual voids to include CHD, the start of RHM, and Goonyella Pit dewatering (drain cells).

Figure 49 indicates the particle tracking (red lines) where particles originated in the five residual voids. For ease of assessment and to better evaluate the influence of the large deep Goonyella residual void, this residual void was assessed (particles added within and adjacent to Goonyella residual void) separately as presented in Section 15.6.2.

Figure 49 First 10 Years of P3 – 5 residual voids



Blue model cells are the residual voids

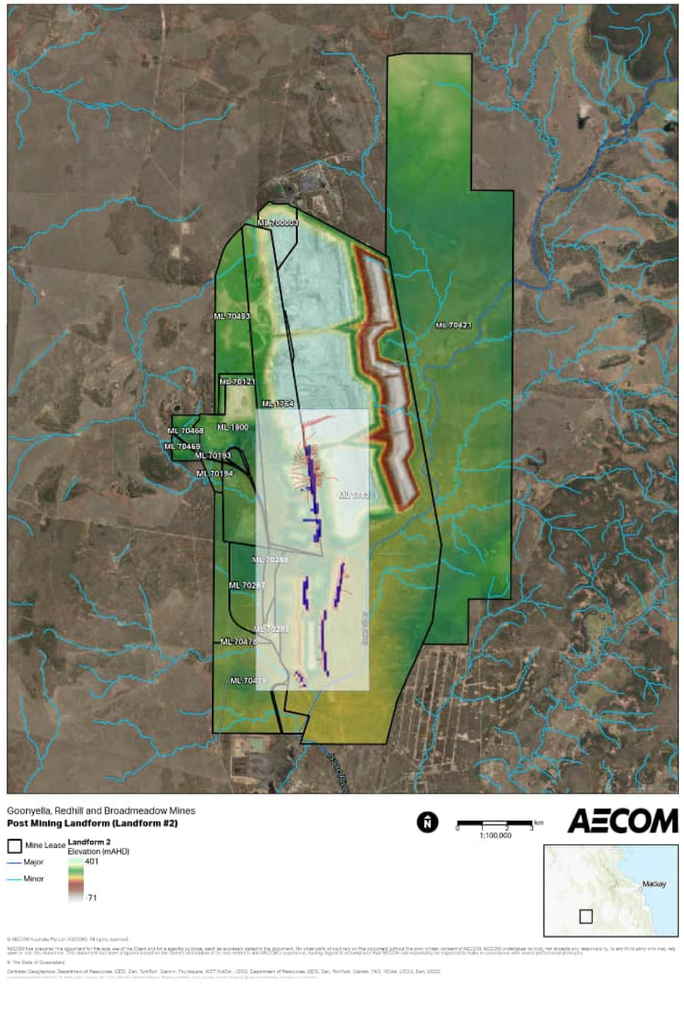
Red lines are particle flow tracks over the 10 year run

The particle pathways, running for 10 years, were included on groundwater head contours for selected years during the particle tracking simulation. These contours for Model Layer 12 (GLS) and Model Layer 10 (GMS) allow for the identification of groundwater flow patterns and gradients in the saturated target coal seams or spoil (backfill) adjacent to the 5 residual voids (Figure 50 to Figure 52).

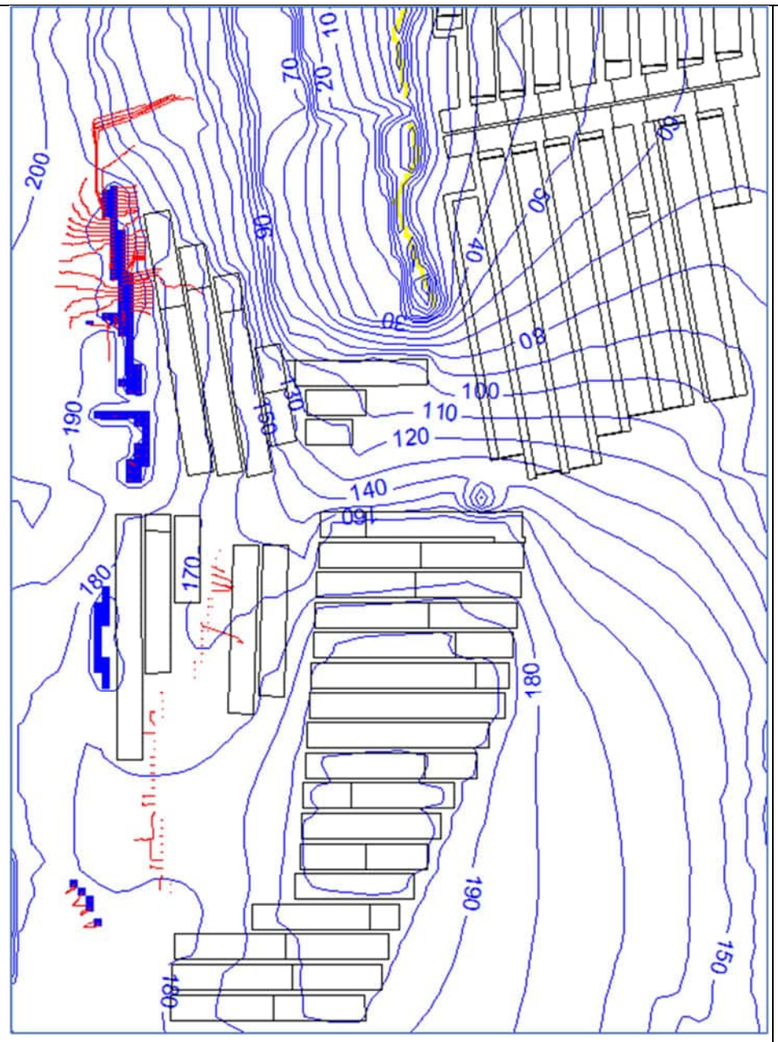
Due to the changing groundwater elevations, in response to mining activities during each prediction period, and the 10 year particle tracking, the groundwater elevation contours at different years were included to illustrate the influence on particle migration.

Note the mining in the five residual voids target different coal seams, as included in Figure 49, this is reflected in the Figure 50 to Figure 52.

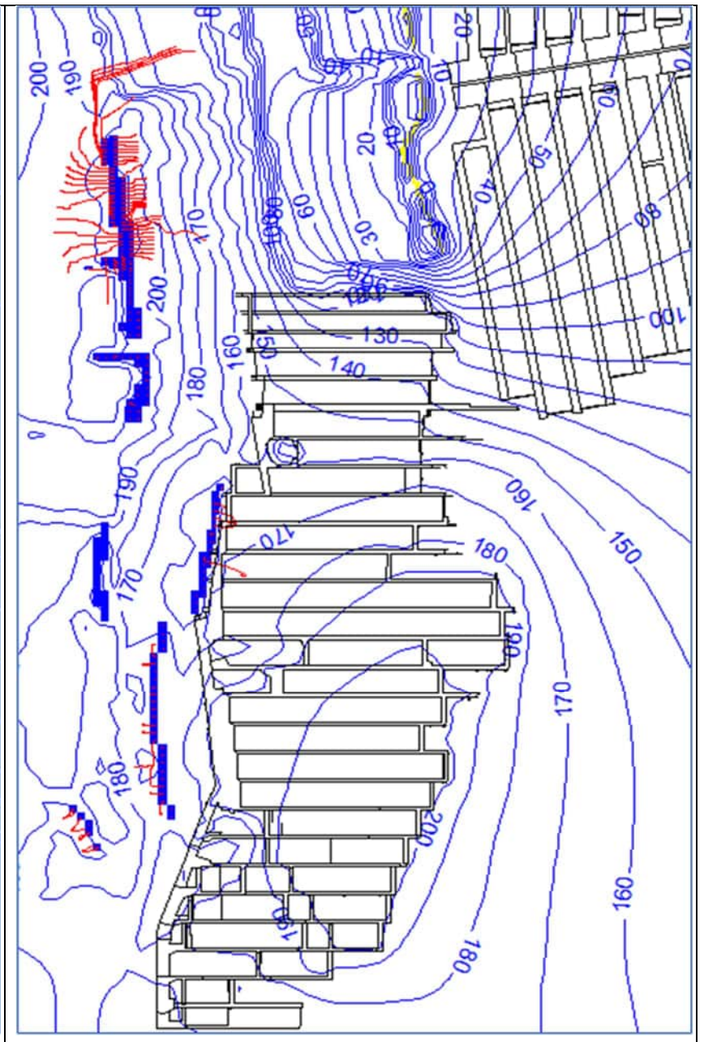
Figure 50 First 10 Years of P3 for 5 residual voids – Year 2061groundwater contours



Particles originating in each of the five residual voids



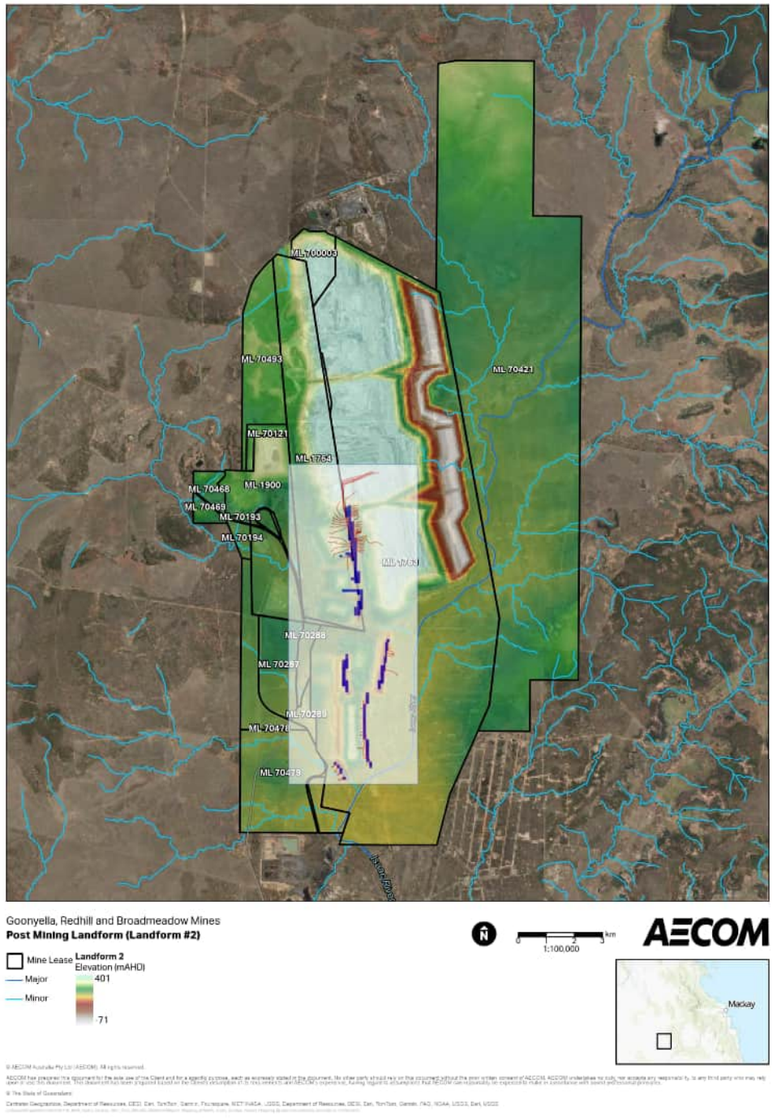
Year 2061 GLS groundwater elevations (mAHD)



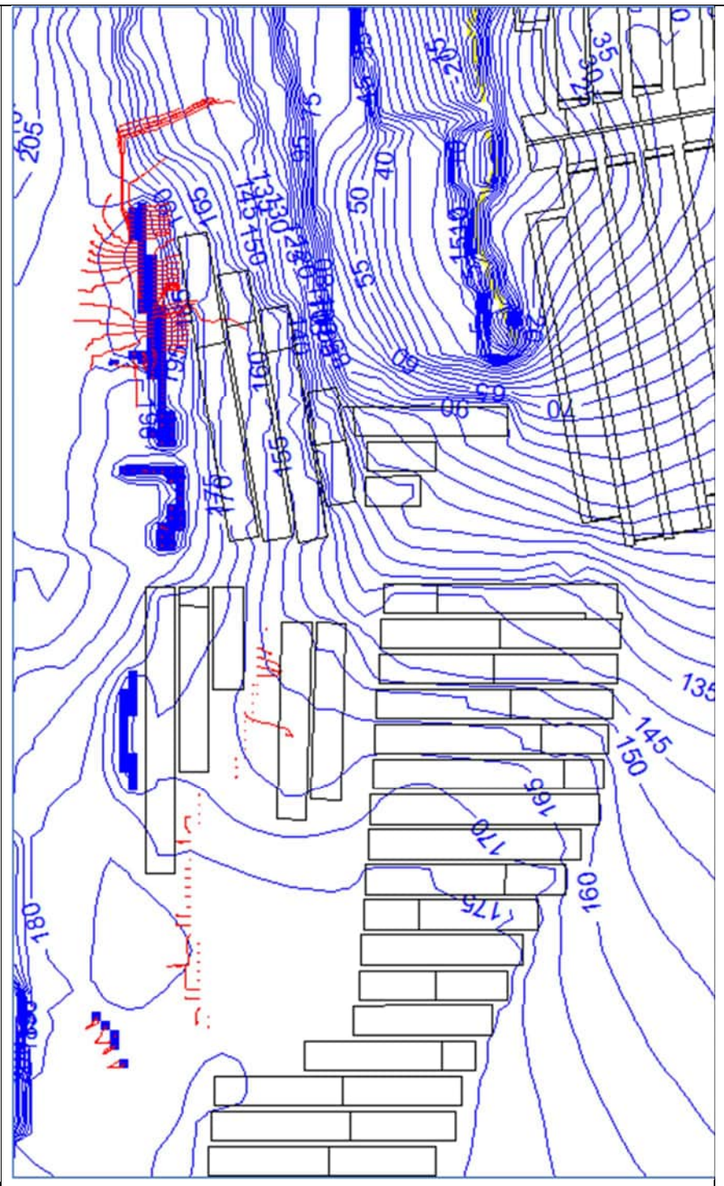
Year 2061 GMS groundwater elevations (mAHD)

Blue model cells are the residual voids
Yellow model cells are the Goonyella residual void
Red paths are the particle tracking migration over a ten year simulation
RHM and GMS and GLS mine footprint s are included as reference locations

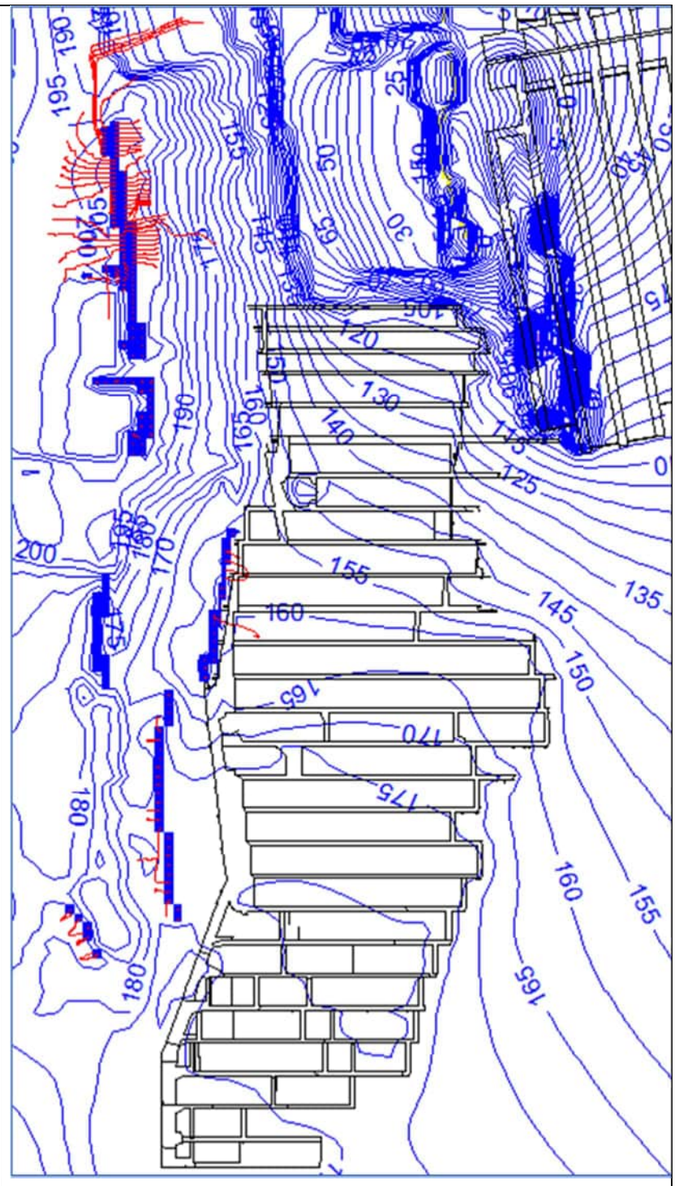
Figure 51 First 10 Years of P3 for 5 residual voids – Year 2063 contours



Particles originating in each of the five residual voids



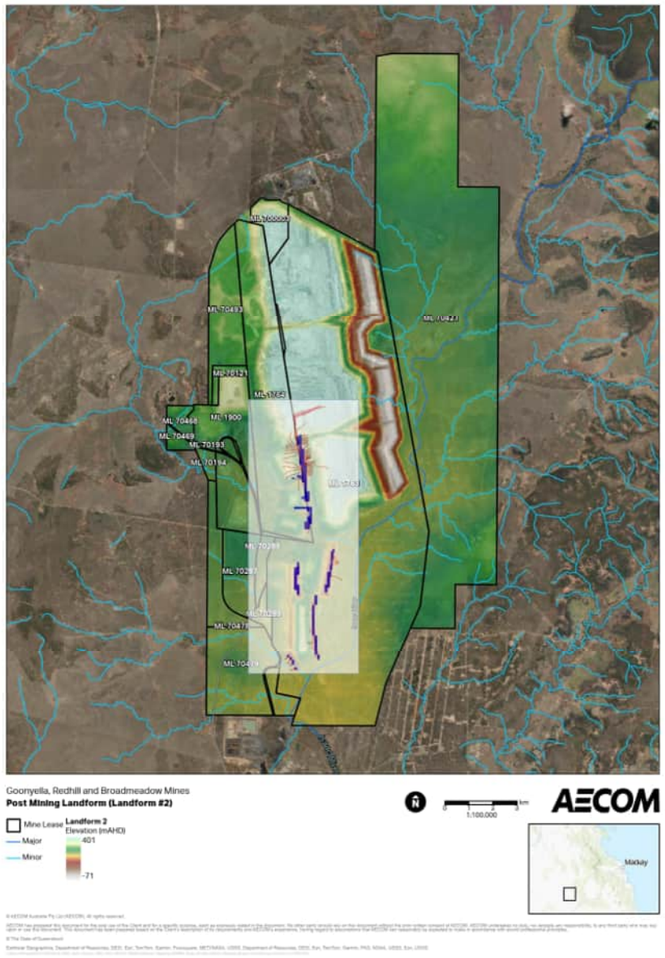
Year 2063 GLS groundwater elevations (mAHD)



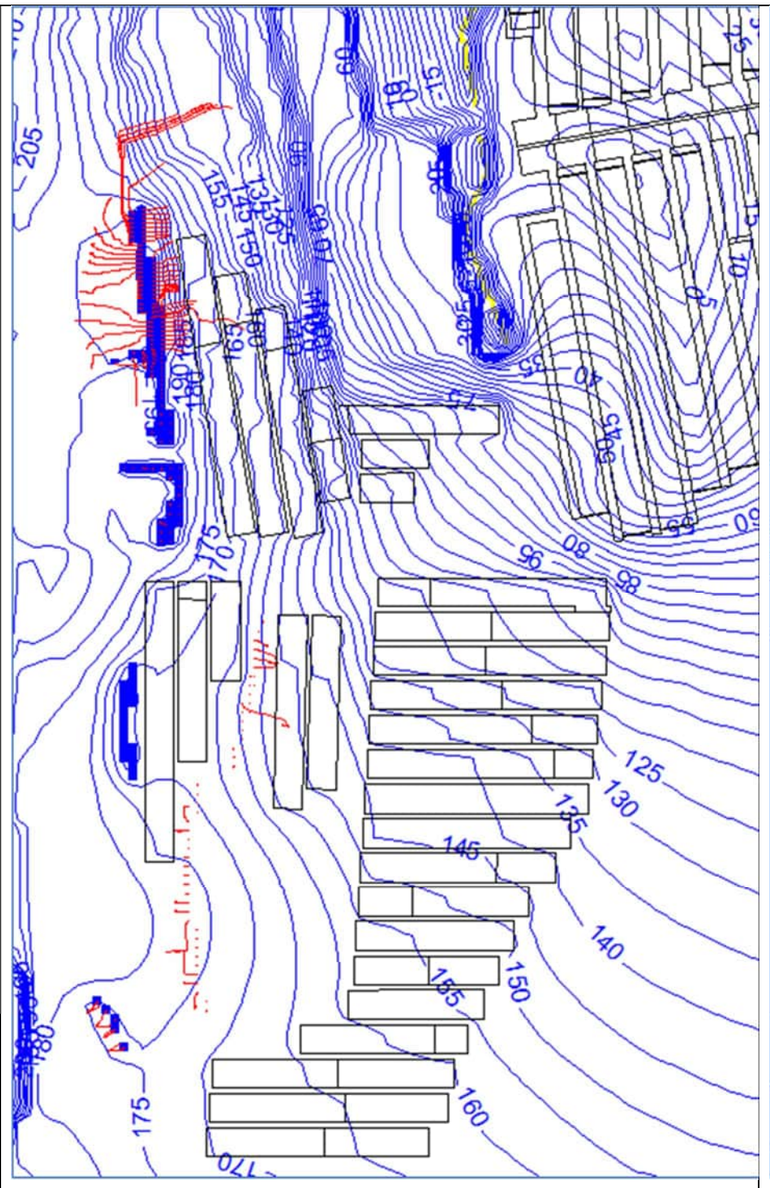
Year 2063 GMS groundwater elevations (mAHD)

Blue model cells are the residual voids
Yellow model cells represent the Goonyella residual void
Red paths are the particle tracking migration over a ten year simulation
RHM and GMS and GLS mine footprint s are included as reference locations

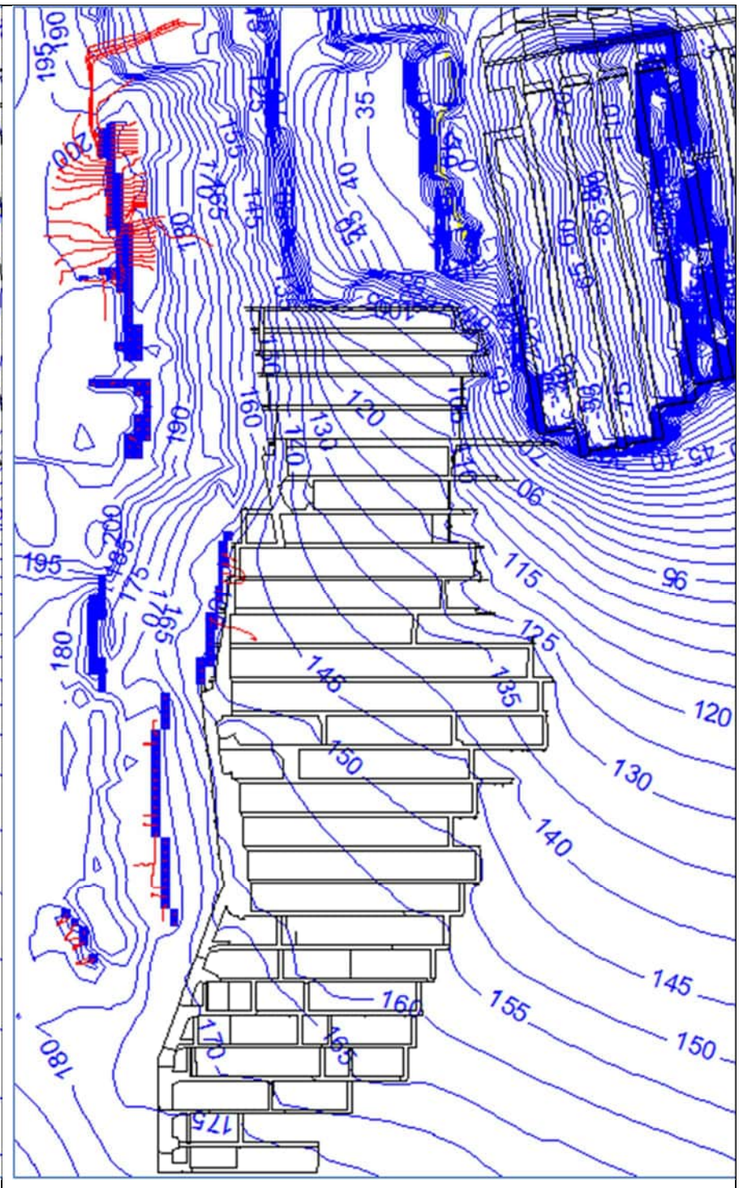
Figure 52 First 10 Years of P3 for 5 residual voids – Year 2070 contours



Particles originating in each of the five residual voids



Year 2070 GLS groundwater elevations (mAHD)



Year 2070 GMS groundwater elevations (mAHD)

Blue model cells are the residual voids
Yellow model cells represent to the Goonyella residual void
Red paths are the particle tracking migration over a ten year simulation
RHM and GMS and GLS mine footprint s are included as reference locations

Figure 50 to Figure 52 indicate the influence of the RHM on the GMS groundwater contours during P3, even with the introduction of water into the Broadmeadow underground (Figure 50).

Residual void water, considering the GLS and GMS groundwater elevation contours and particle tracking, is considered to:

- Migrate within groundwater (saturated groundwater model cells) from Isaac Pit, Ramp 32 South, and Thiess Pit towards the west, into the spoil / backfill areas
- Residual void water migration to the west is limited with particles returning to these residual voids, in response to ongoing mine dewatering at Goonyella Pit and RHM
- Residual void water from Thiess Pit and Broadmeadow Pit is recognised to migrate towards the east (down dip)
- Thiess Pit, which acts as a source (high residual void water level compared to surrounding groundwater), indicates residual void water flow away from the residual void initially then migrating to the north and west in response to mine dewatering (Goonyella Pit and RHM).

15.6.1.2 First 10 Years of P4 (2093-2102)

The prediction period (P4) includes water levels within the residual voids to be represented by CHD (including Goonyella Pit), the end of RHM mining, introduction of water into RHM, and recovery (no mining activities from 2097).

Figure 53 indicates the particle tracking (red lines) where particles originated in the five residual voids. Due to the fluctuation in the residual void water levels, particles were also included immediately adjacent to Broadmeadow Pit and Isaac Pit to further assess possible pit water migration (Figure 54).

The particle tracking during this P4 10 year simulation indicates continued residual void water loss from Thiess Pit, which is migrating within groundwater towards the drawdown caused by the deep Goonyella Pit residual void water levels.

Residual void water migration from Broadmeadow Pit can occur where the particles are predicted to migrate towards RHM GMS dewatering even though water has been introduced into RHM GMS mine workings.

Particles immediately adjacent to Broadmeadow Pit indicate potential for residual void water migration. This is not predicted for the Issac Pit residual void.

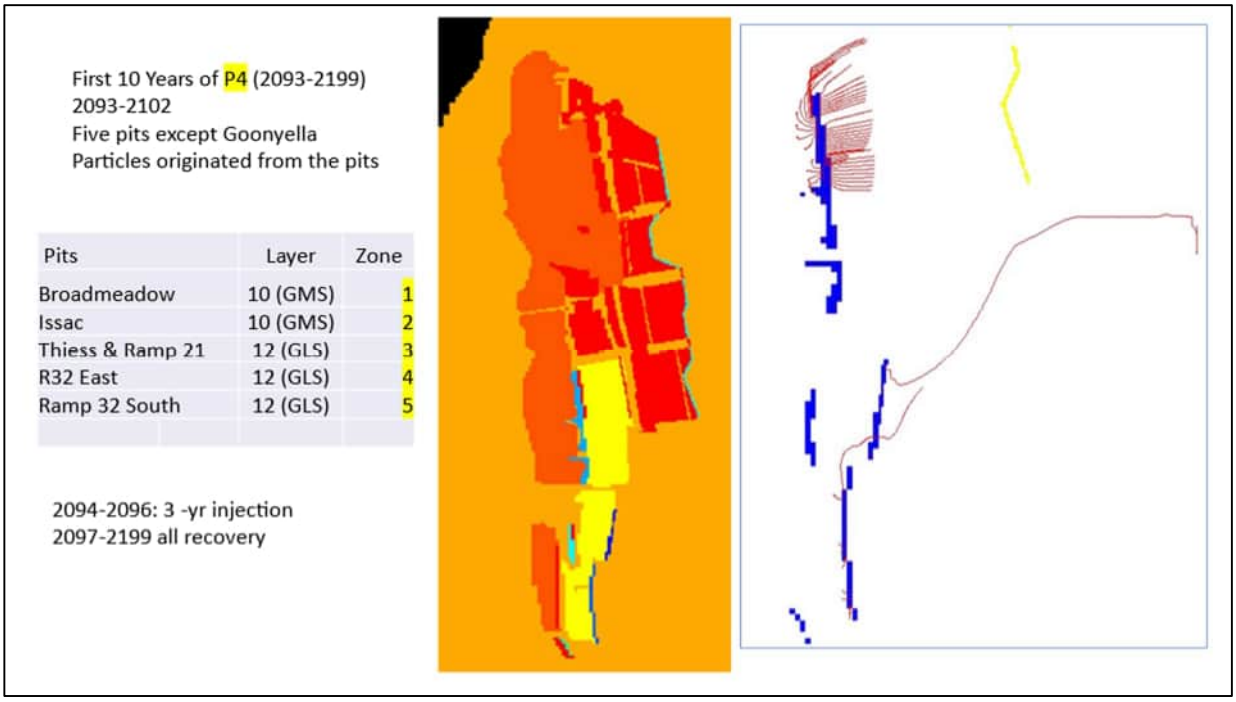
The particle pathways, running for 10 years at the start of P4, were included on groundwater elevation contours for selected years during the particle tracking simulation. These contours for Model Layer 12 (GLS) and Model Layer 10 (GMS) allowed for the identification of groundwater flow patterns and gradients in the saturated target coal seams or spoil (backfill) adjacent to the 5 residual voids.

Figure 55 to Figure 57 indicate flow from Broadmeadow Pit towards the dewatered RHM flooded underground (Figure 56), as the underground workings do not flood entirely when adopting the volumes supplied by BMA (Section 14.2.1).

The long particle travel path from Broadmeadow is recognised to reach the RHM and then change direction to the northeast, towards Goonyella Pit.

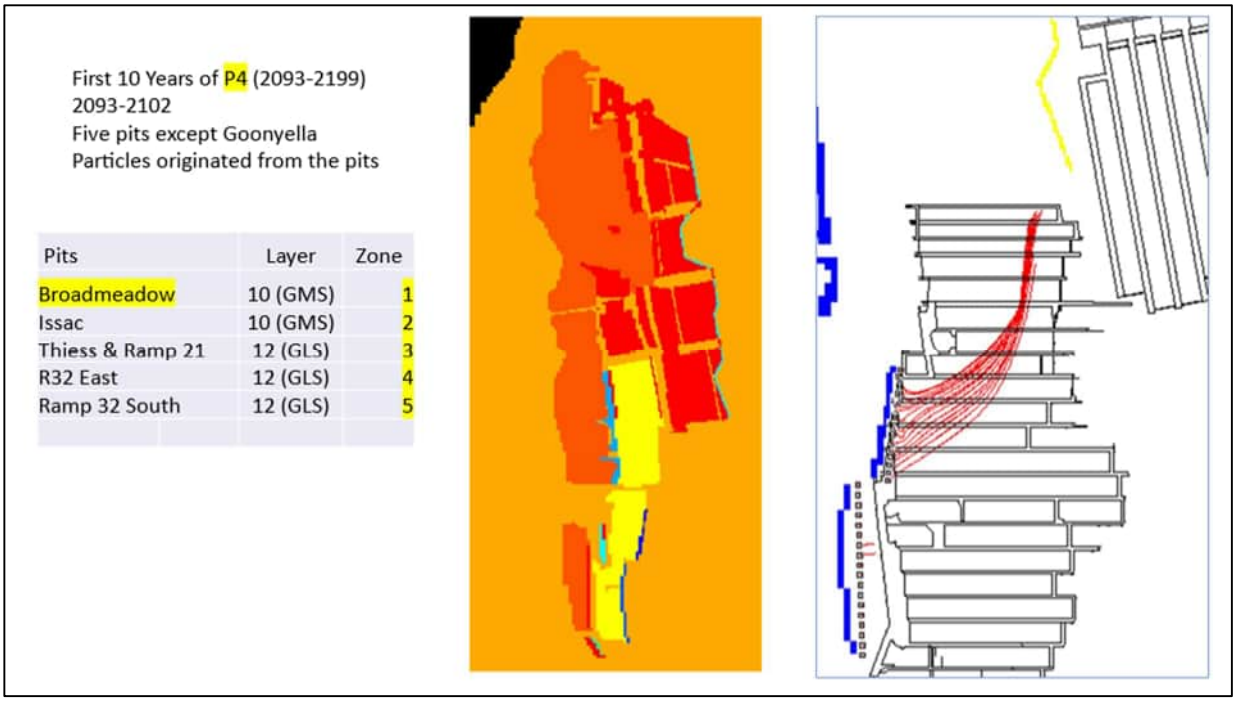
Note: The particles migrate for a period of 10-years, the groundwater elevations change over time based on mining activities which vary over time (as detailed in the prediction periods, Section 15.2), hence the need to illustrate the groundwater contours in and adjacent to the residual voids (including Goonyella Pit) to aid with evaluating the particle tracking.

Figure 53 First 10 Years of P4 – 5 residual voids



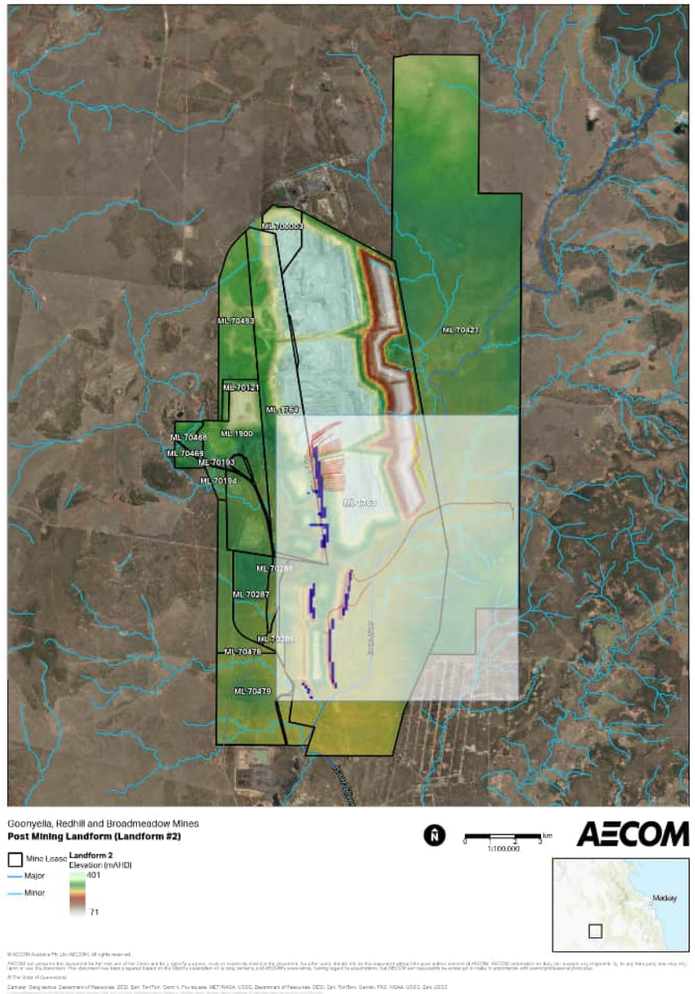
Blue model cells are the residual voids
Red lines are particle flow tracks over the 10 year run

Figure 54 First 10 Years of P4 – 5 residual voids (particles outside Broadmeadow and Isaac Pits)

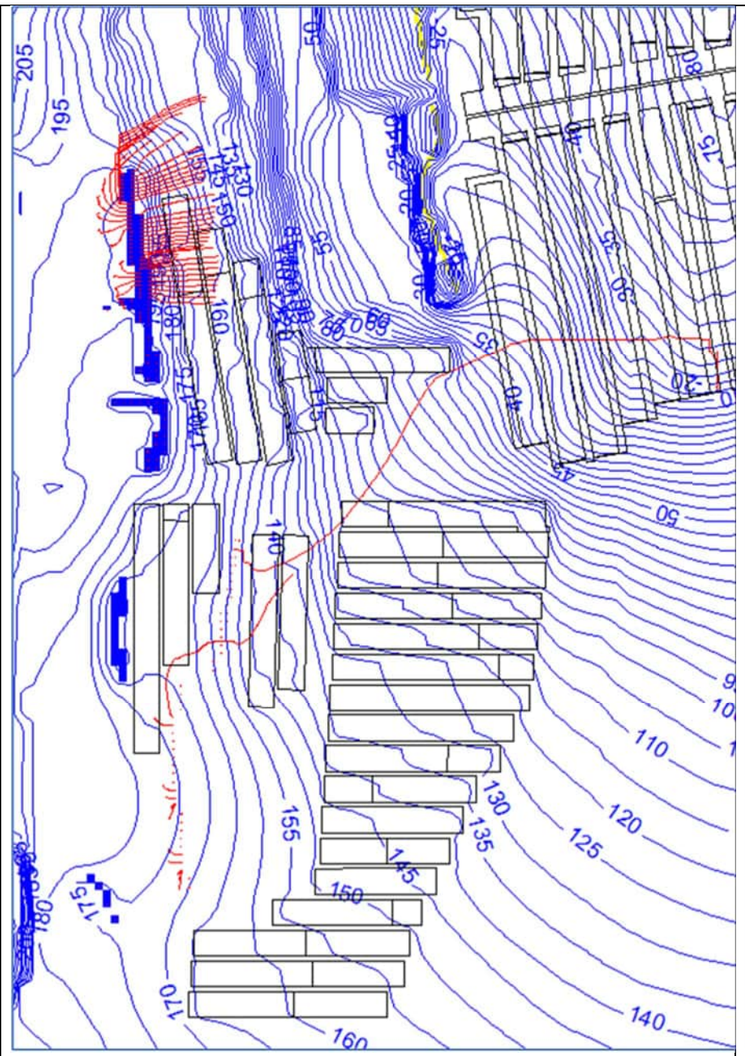


Blue model cells are the residual voids
Red lines are particle flow tracks over the 10 year run

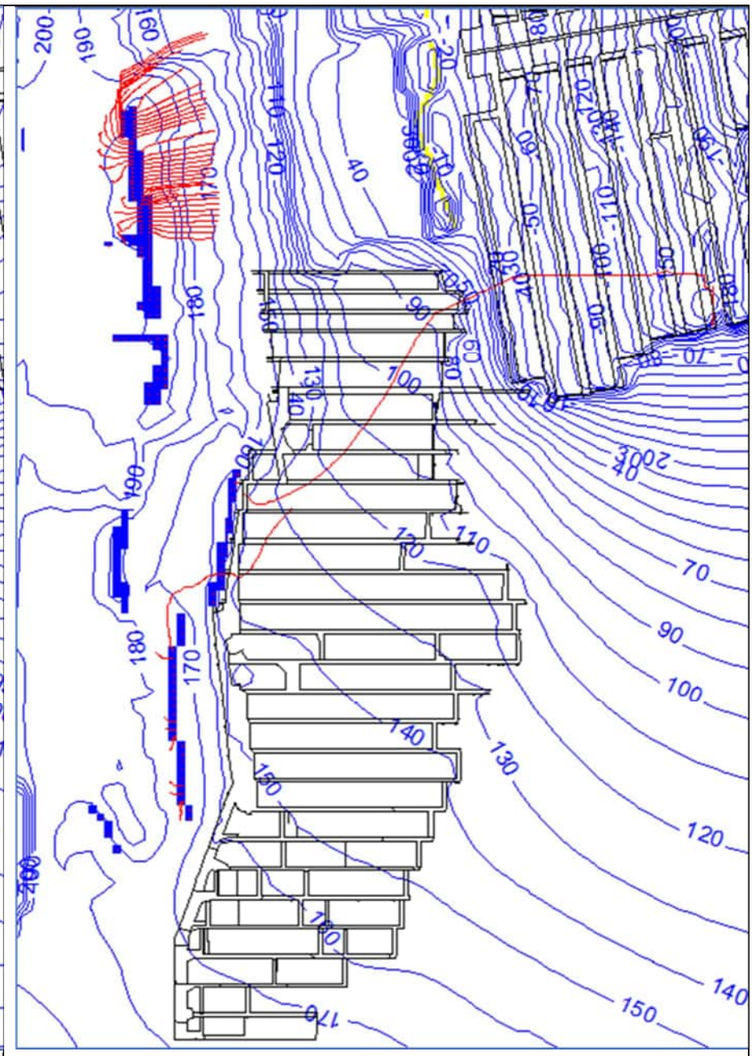
Figure 55 First 10 Years of P4 for 5 residual voids – Year 2093 contours



Particles originating in each of the five residual voids



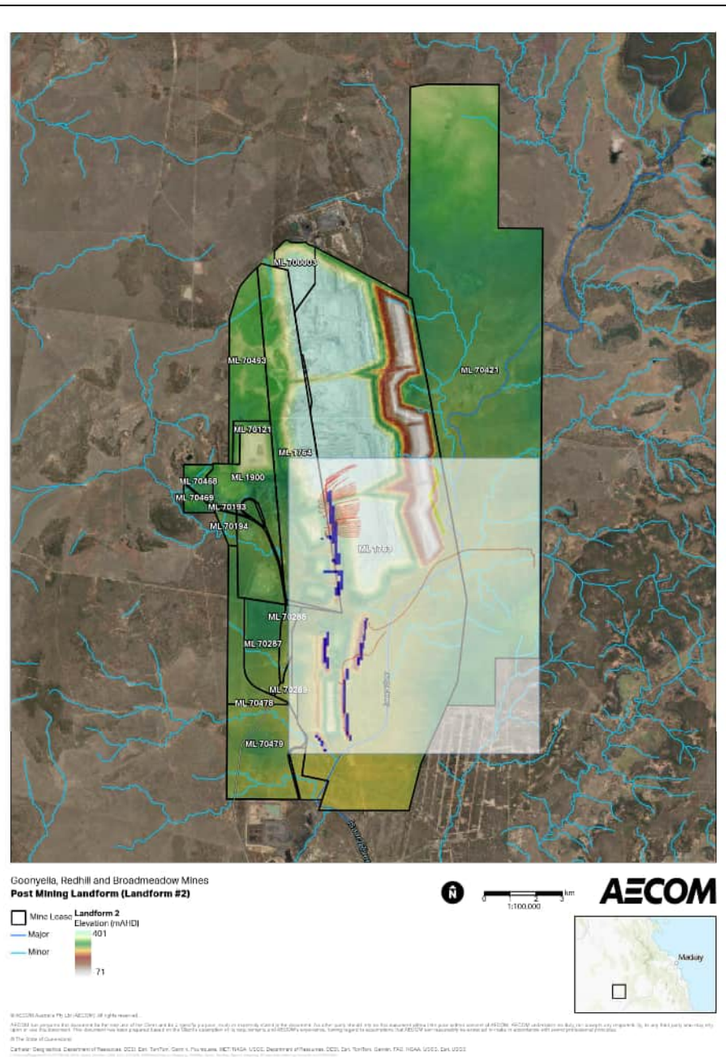
Year 2093 GLS groundwater elevations (mAHD)

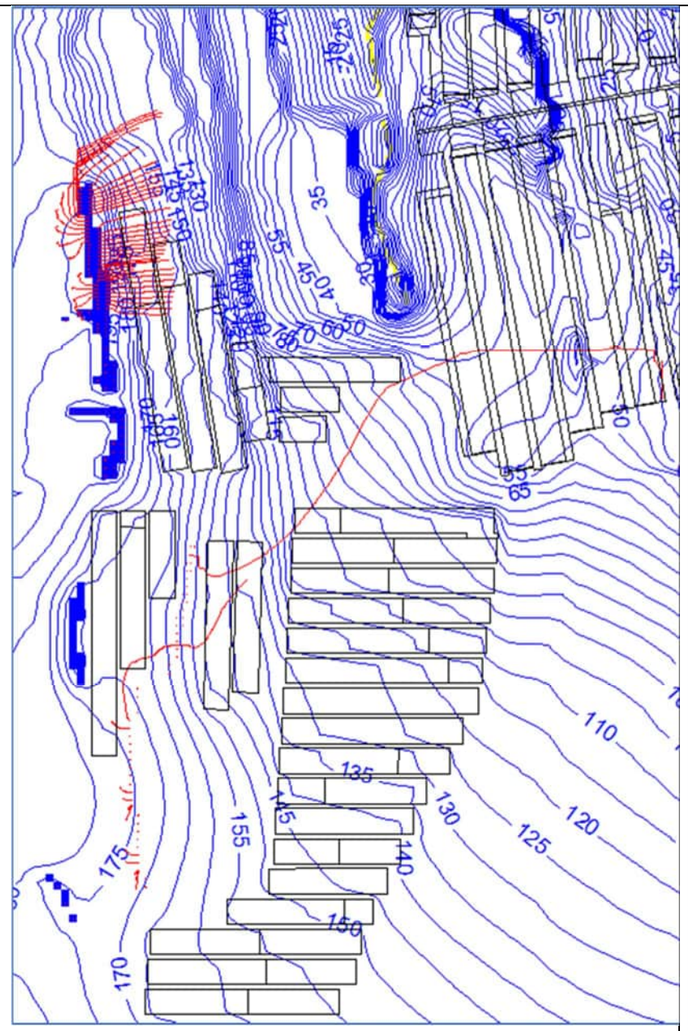


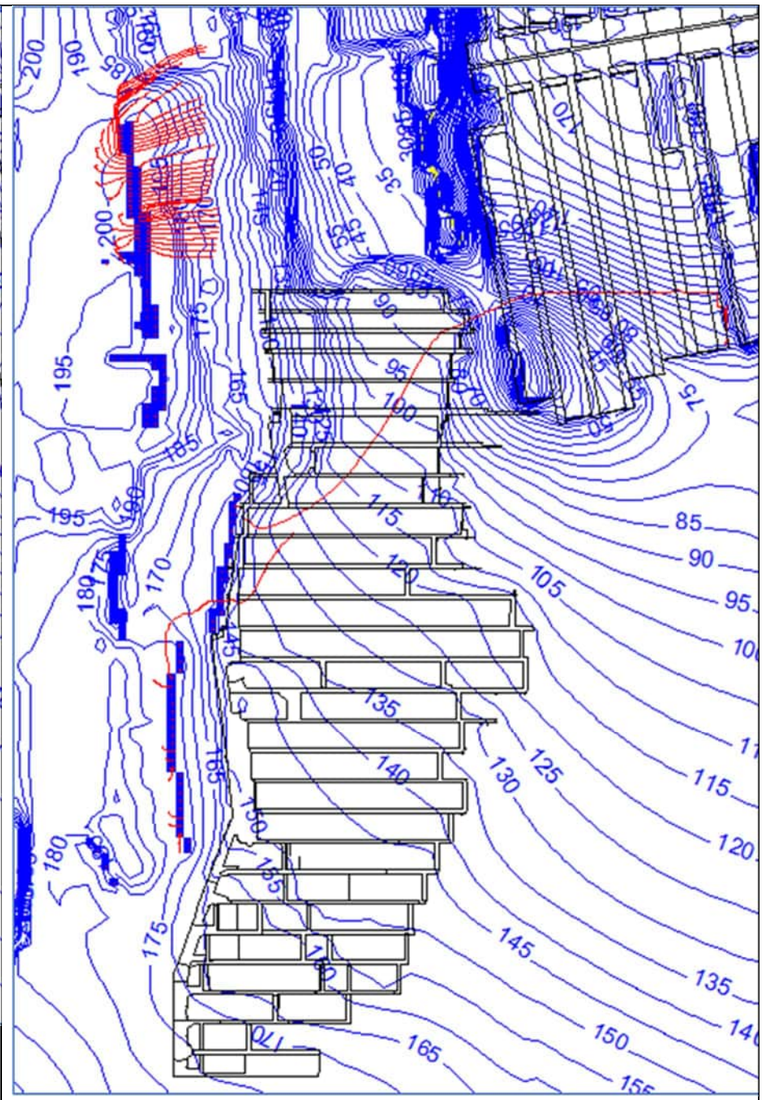
Year 2093 GMS groundwater elevations (mAHD)

Blue model cells are the residual voids
Yellow model cells represent to the Goonyella residual void
Red paths are the particle tracking migration over a ten year simulation
RHM and GMS and GLS mine footprint s are included as reference locations

Figure 56 First 10 Years of P4 for 5 residual voids – Year 2096 contours



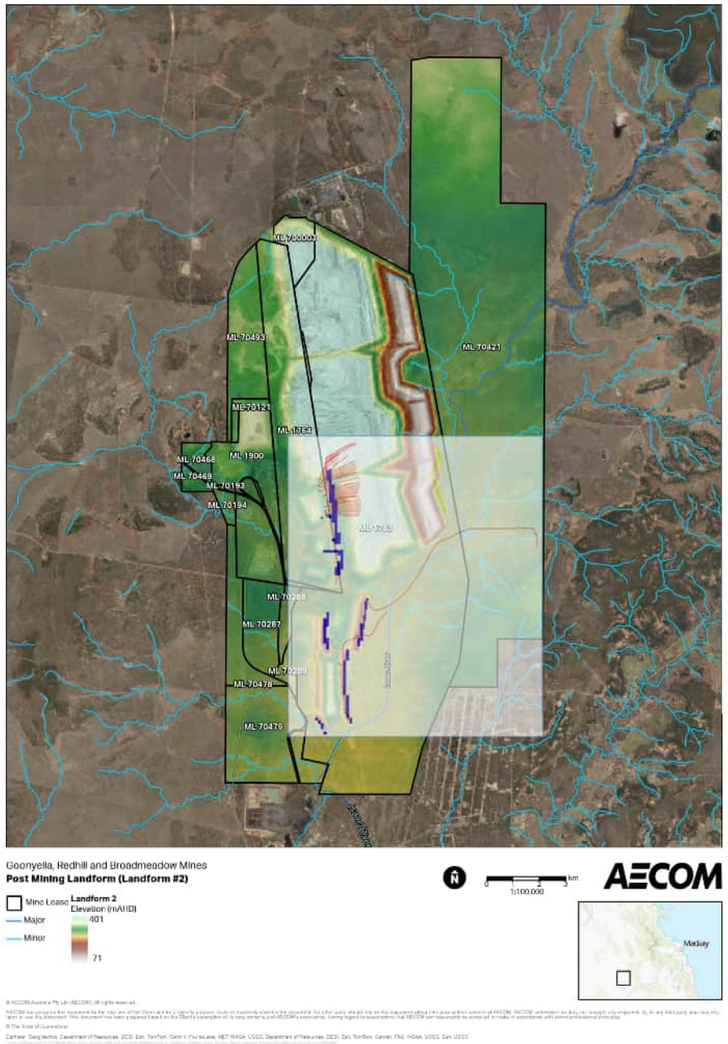




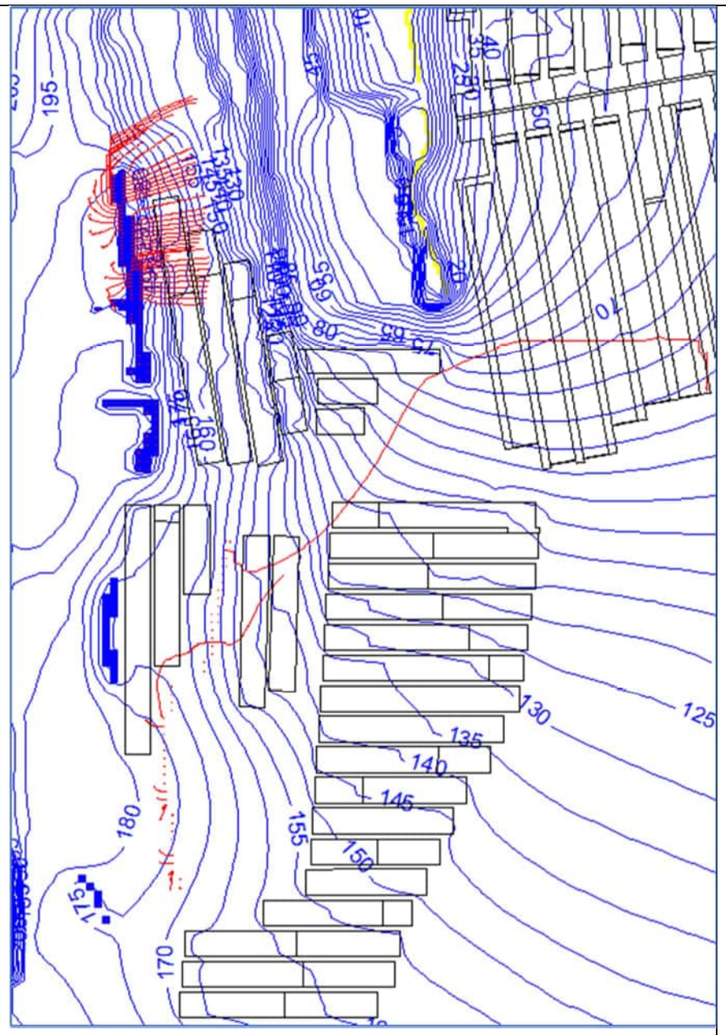
Particles originating in each of the five residual voids	Year 2096 GLS groundwater elevations (mAHD)	Year 2096 GMS groundwater elevations (mAHD)

Blue model cells are the residual voids
Yellow model cells represent to the Goonyella residual void
Red paths are the particle tracking migration over a ten year simulation
RHM and GMS and GLS mine footprint s are included as reference locations

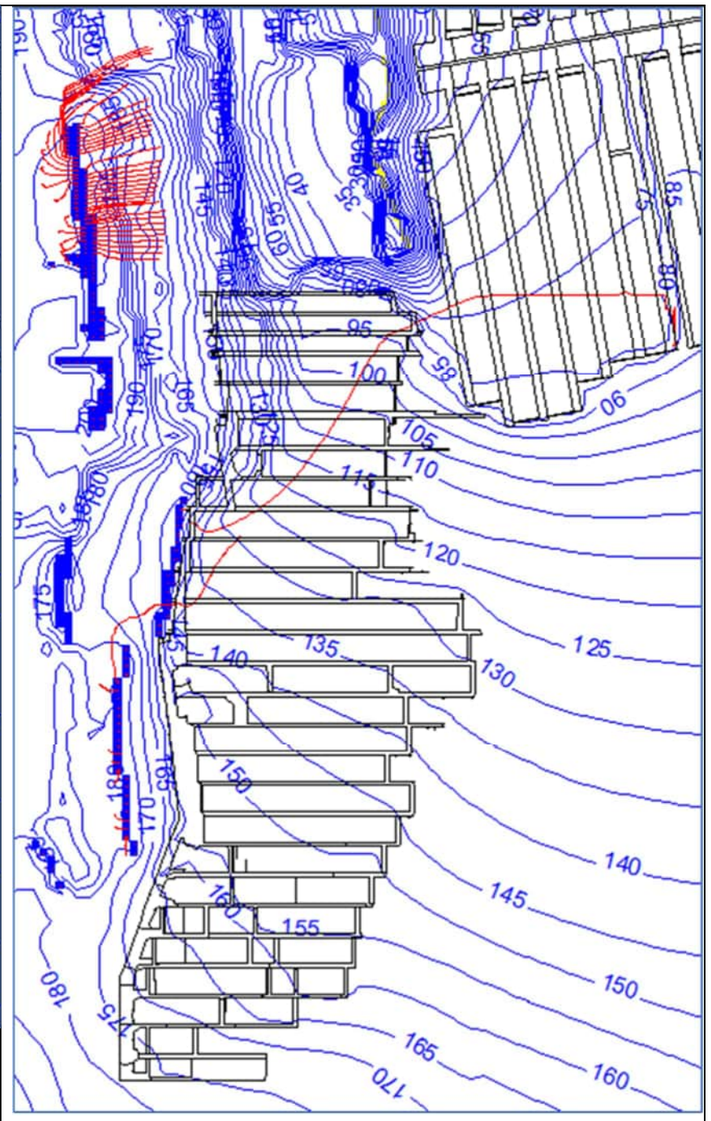
Figure 57 First 10 Years of P4 for 5 residual voids – Year 2102 contours



Particles originating in each of the five residual voids



Year 2102 GLS groundwater elevations (mAHD)

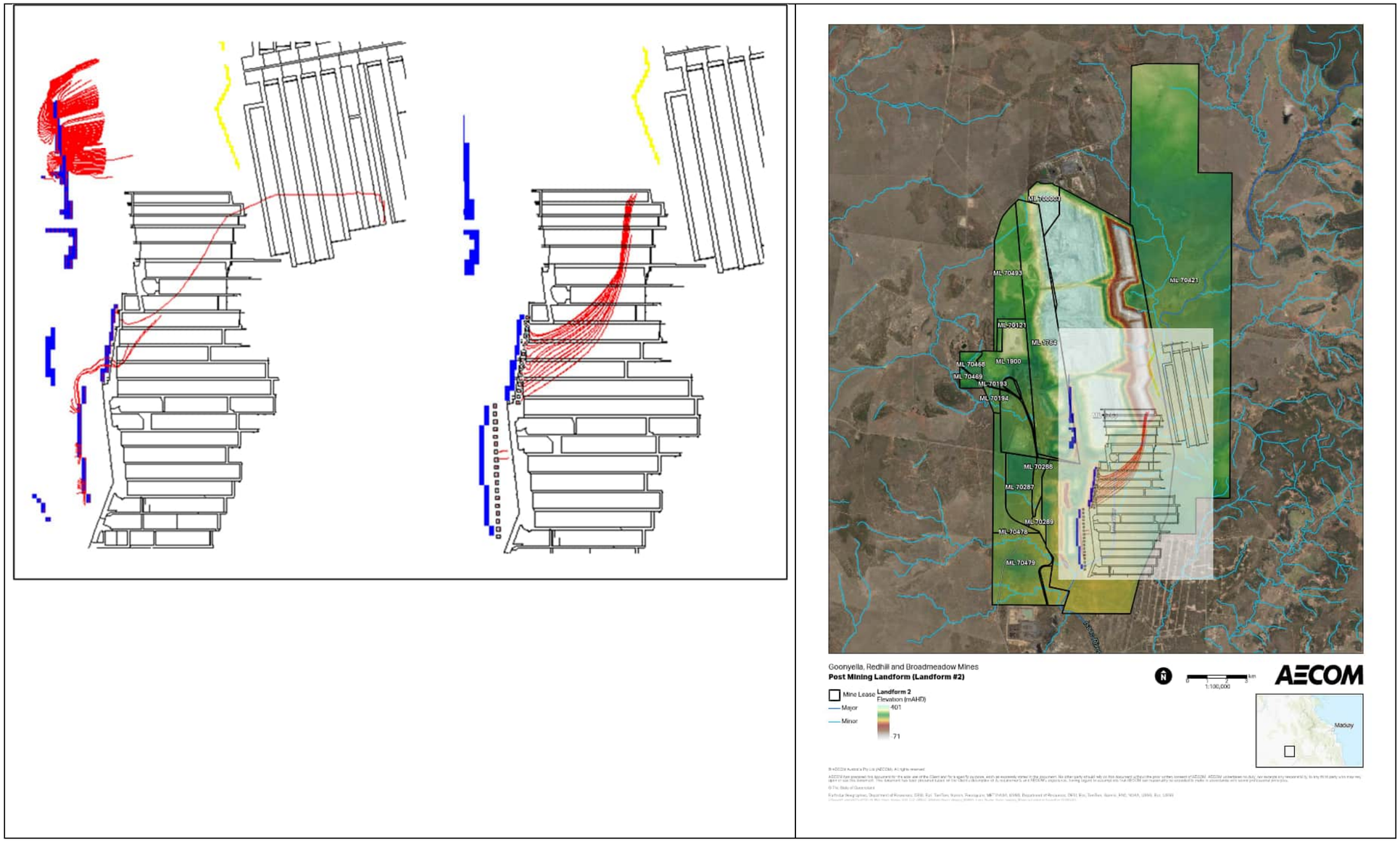


Year 2102 GMS groundwater elevations (mAHD)

Blue model cells are the residual voids
Yellow model cells represent to the Goonyella residual void
Red paths are the particle tracking migration over a ten year simulation
RHM and GMS and GLS mine footprint s are included as reference locations

Figure 58 presents the particle tracking from inside and outside the residual voids at a higher resolution. Migration away from the residual voids is recognised to be influenced by the Goonyella Pit dewatering, such that particles move away and then return to the voids or change direction towards the north, due to the drawdown at Goonyella Pit.

Figure 58 First 10 Years of P4 for 5 residual voids – higher resolution particle tracking



Blue model cells are the residual voids
Yellow model cells represent to the Goonyella residual void
Red paths are the particle tracking migration over a ten year simulation
RHM and GMS mine footprint s are included as reference locations

15.6.2 Goonyella Pit residual void

To aid with the assessment of each residual void and to allow for ease of evaluation and discussion, the particle tracking for the five residual voids (Section 15.6.1) included the mining activities associated with Goonyella Pit (mine dewatering and residual void water levels) but did not include particles for particle tracking around the Goonyella residual void.

Particle tracking for the Goonyella Pit required the inclusion of particles adjacent to the residual void, to allow for evaluation of pit water migration. This was done as any particle included within the residual void, based on the depth and surrounding groundwater levels (Section 15.4.2.6), would not migrate within groundwater.

The particle tracking, similar to the five residual voids, included 10 year simulations for prediction periods P3 and P4.

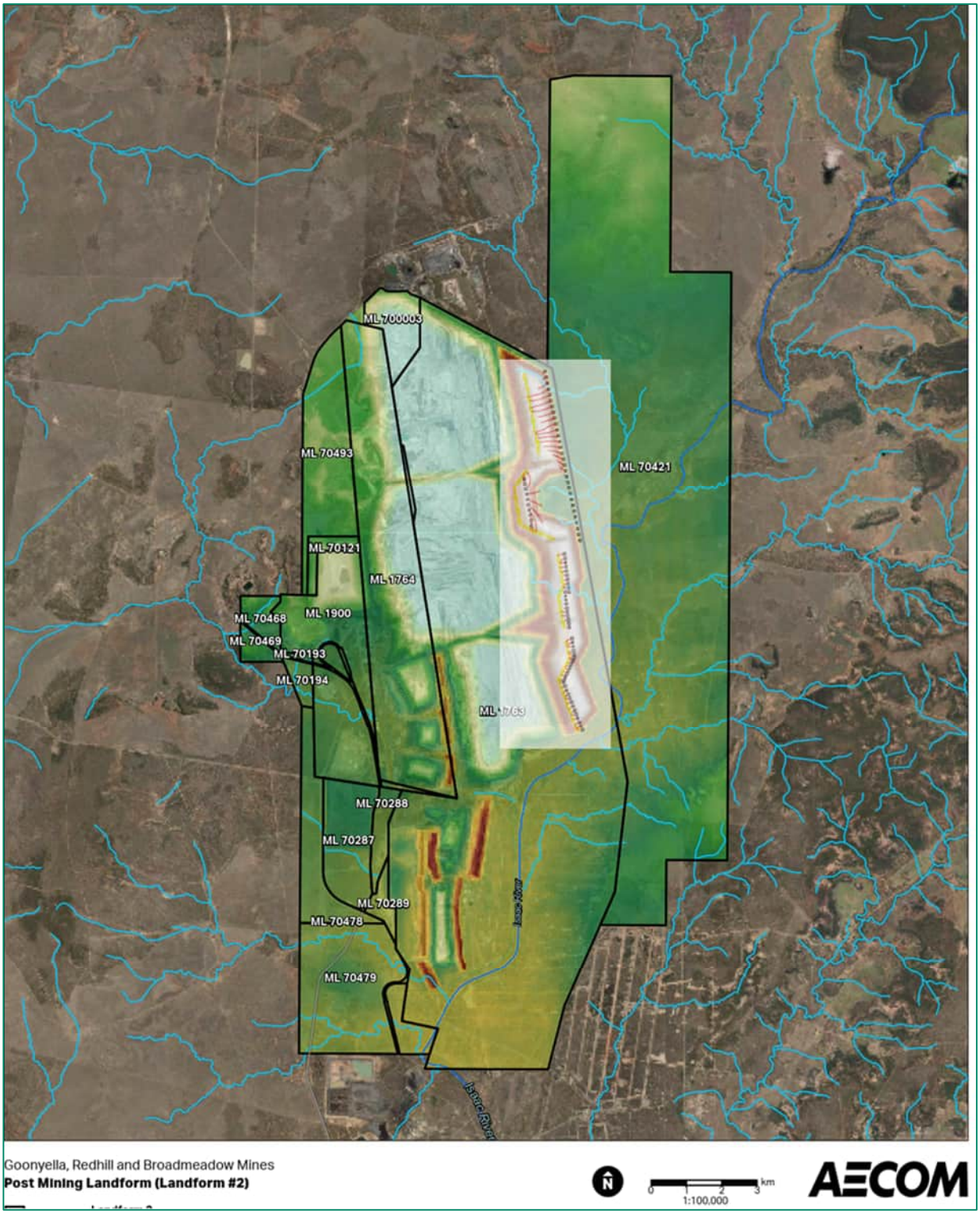
15.6.2.1 First 10 years of P3 (2061 – 2070)

The particle tracking during this time period is included in Plate 42, and indicate flow into the deepest Goonyella Pit locations.

The particles adjacent to the shallowest central portion of Goonyella Pit, as detailed in Section 15.4.2.6, are at higher groundwater elevations than the surrounding dewatered (deeper groundwater elevations) areas associated with the Goonyella Pit and RHM. Particles are recognised to initially migrate from this section of the Goonyella Pit during P3 and then migrate towards the Goonyella Pit dewatering as evident in Plate 42.

Groundwater flow contours for the P3 years 2061, 2063, and 2070, spilt into a northern and southern portion (to accommodate the long pit length), are included in Figure 59.

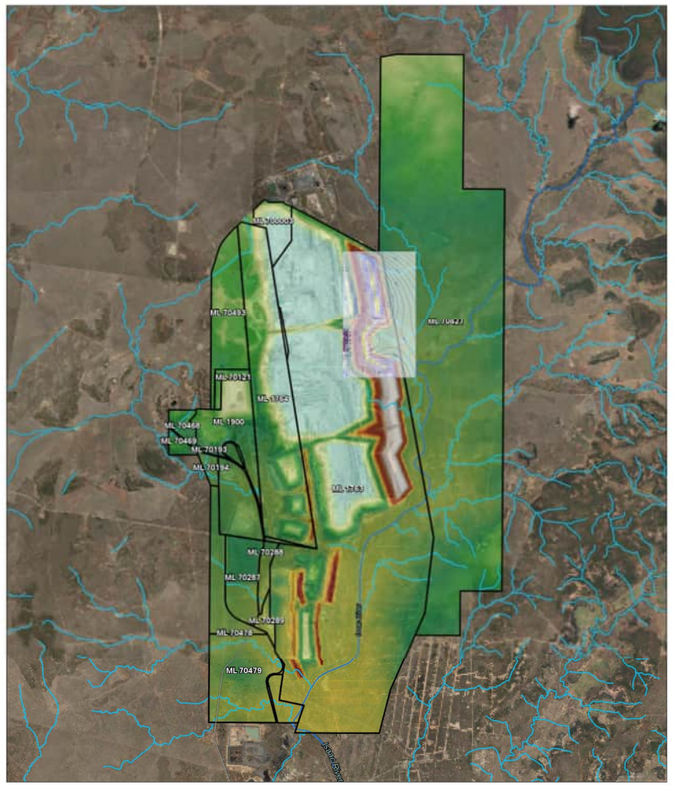
Plate 42 Goonyella residual void particle placement and tracking first 10 years of P3



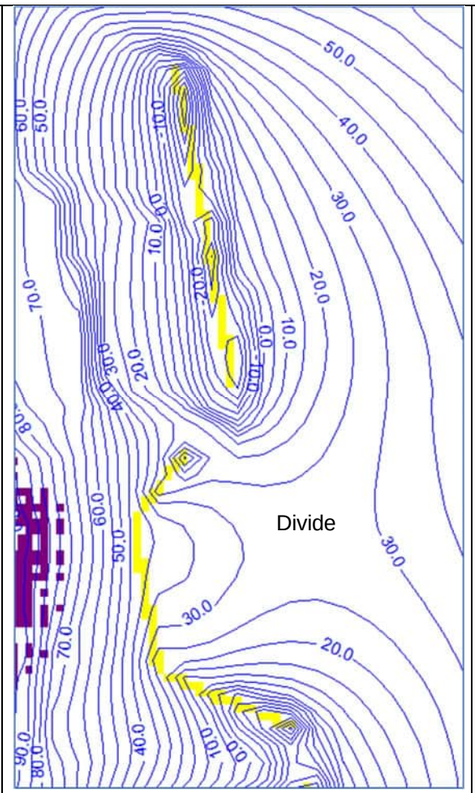
Yellow model cells are the Goonyella residual void

Grey model cells are cells used for the Goonyella residual void particle tracking

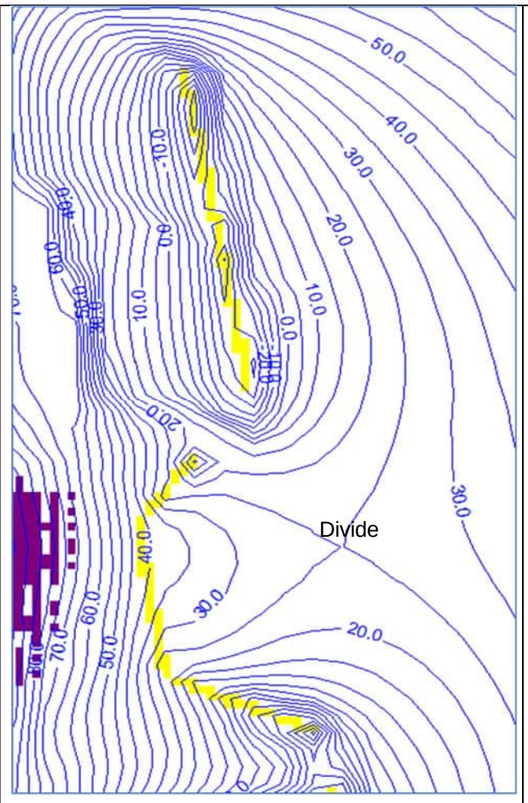
Figure 59 Groundwater flow contours for P3 years 2061, 2063, and 2070 – Goonyella Pit (GLS contours)



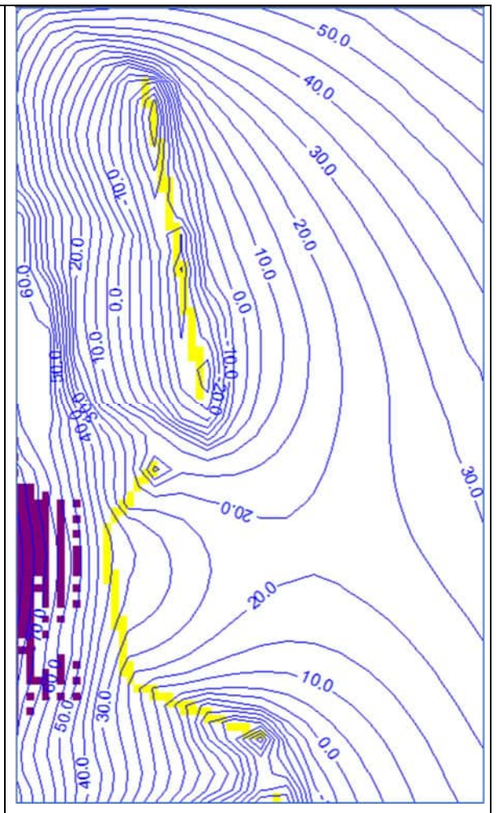
Location



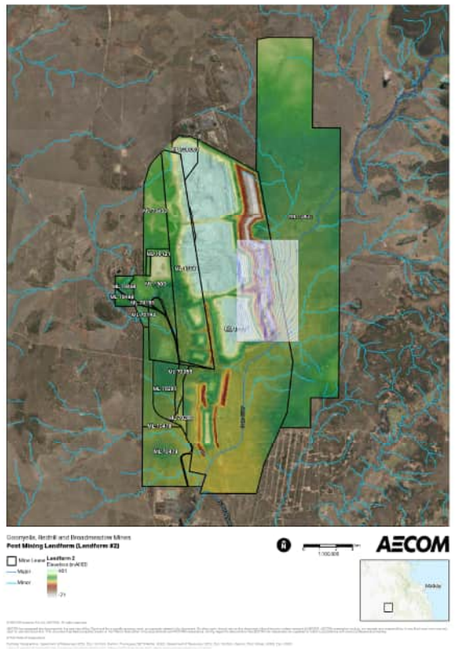
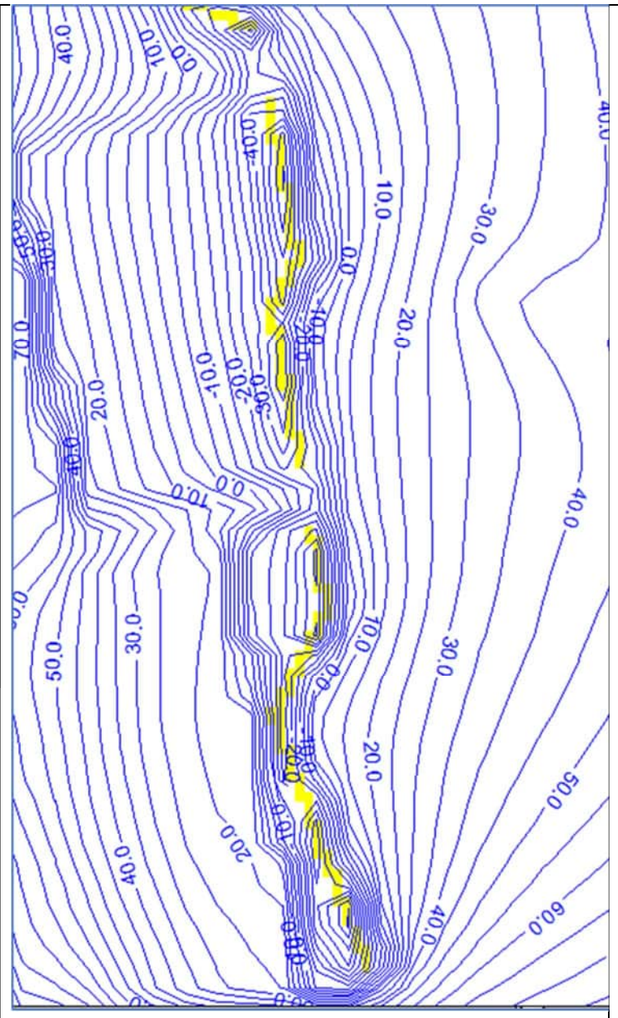
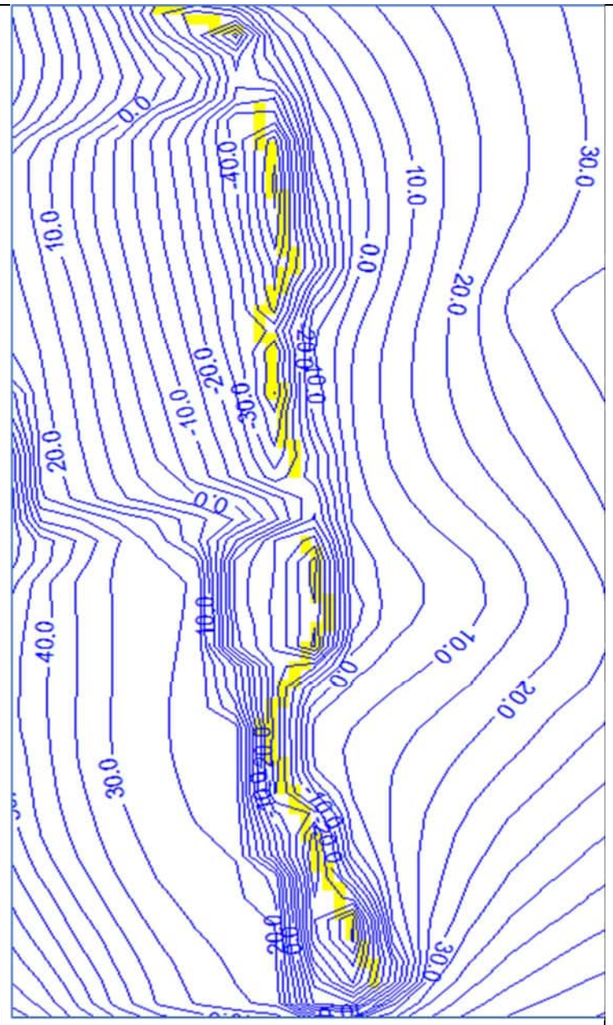
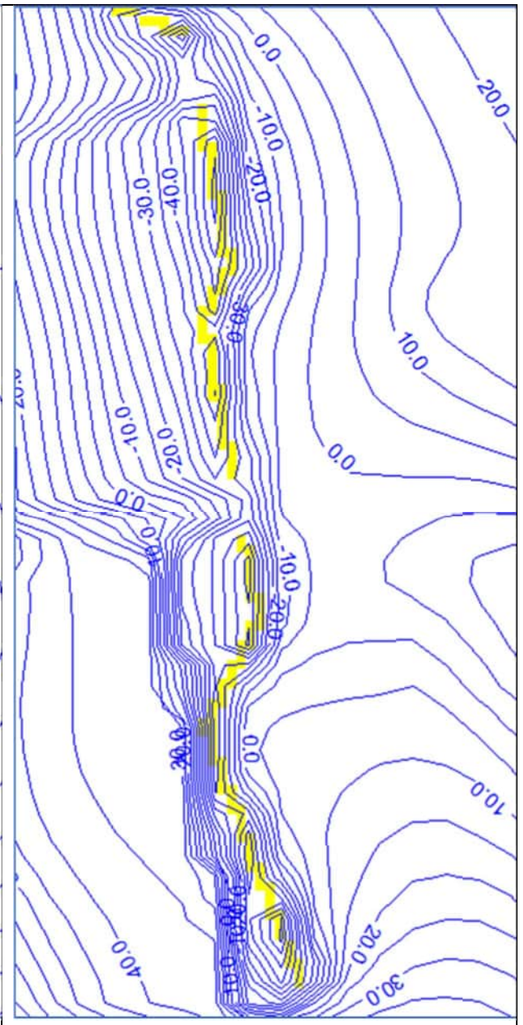
2061 (North)



2063 (North)



2070 (North)

			
Location	**2061 (South)**	**2063 (South)**	**2070 (South)**

Yellow model cells depict the Goonyella residual void
Purple model cells are dry (unsaturated)

The GLS groundwater flow pattern shows the groundwater contours in 2061 and 2063 facilitate flow towards a groundwater depression along the East-West direction, as well as form a groundwater divide in the North-South direction, east of the shallow central portion of Goonyella Pit (divide on Figure 59). This explains how particles are predicted to move away from the portion of the Goonyella Pit and then turn north and south, due to the influence of the groundwater divide.

Groundwater contours in 2070 indicates the developed groundwater divide adjacent to Goonyella Pit in response to RHM mining.

15.6.2.2 First 10 years of P4 (2093 – 2102)

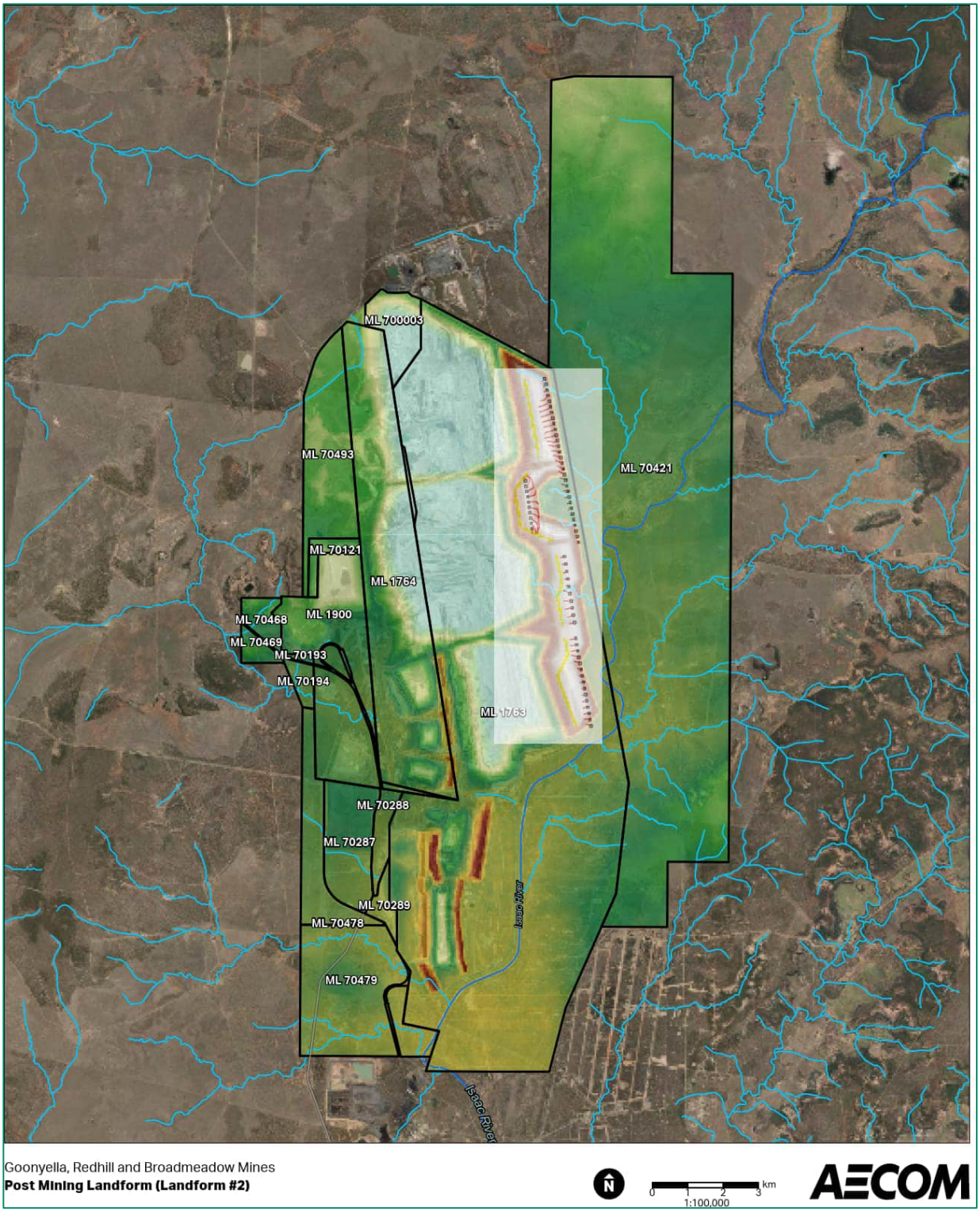
The particle tracking during this time period is included in Plate 43, and indicate flow into the deepest Goonyella Pit locations.

The particles adjacent to the shallow central portion of Goonyella Pit, are recognised to migrate back towards the Goonyella Pit during this phase of prediction. This relates to the reinjection of RHM and the stabilisation of flow patterns around Goonyella Pit, which dominates the groundwater flow pattern, as included in Figure 60.

The groundwater flow pattern indicates steep groundwater gradients around Goonyella Pit in 2102. The purple model cells are dry in Figure 60, including immediately west (up dip) of the central shallow section of the Goonyella Pit, indicating the particles from this section of the pit can only flow east due the dry conditions to the west.

These varying groundwater flow patterns, saturated and unsaturated model cells, plus predicted long term pseudo-steady water levels across the Project was assessed to allow for the evaluation of all residual voids post-closure (i.e., particle tracking for all residual voids was conducted from 2199 (post P4 prediction period) to 2299, a 100-year particle tracking simulation in Section 15.7.

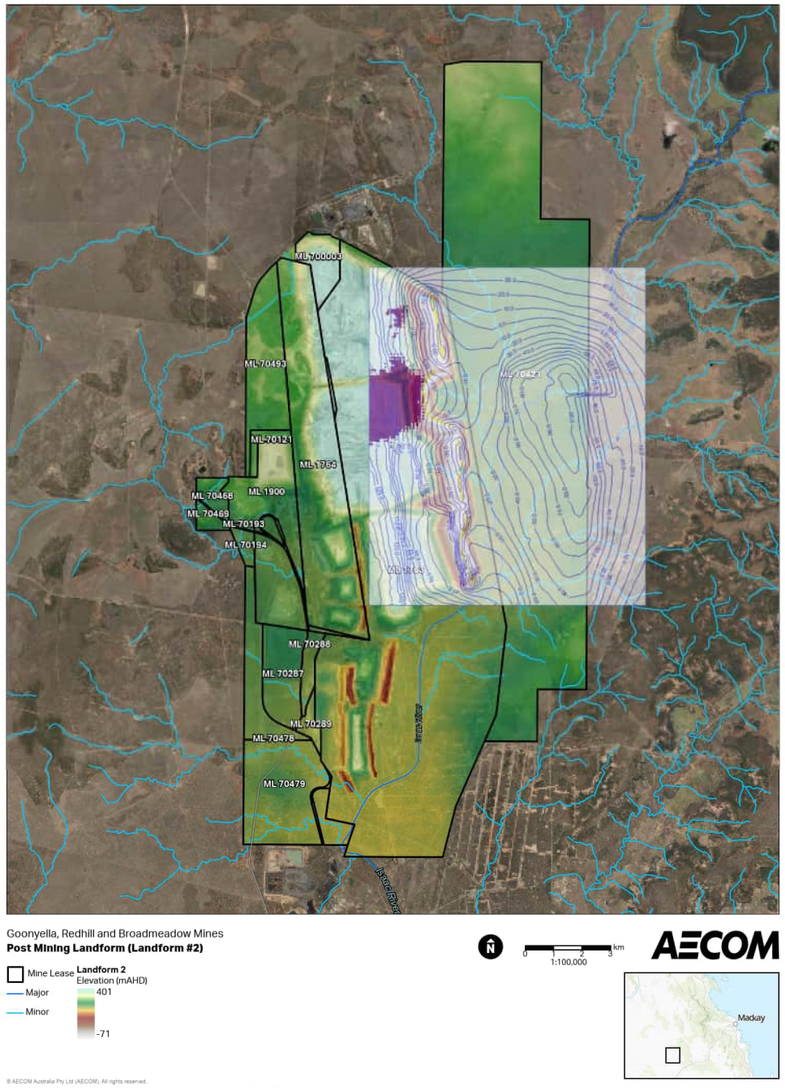
Plate 43 Goonyella Pit particle tracking first 10 years of P4



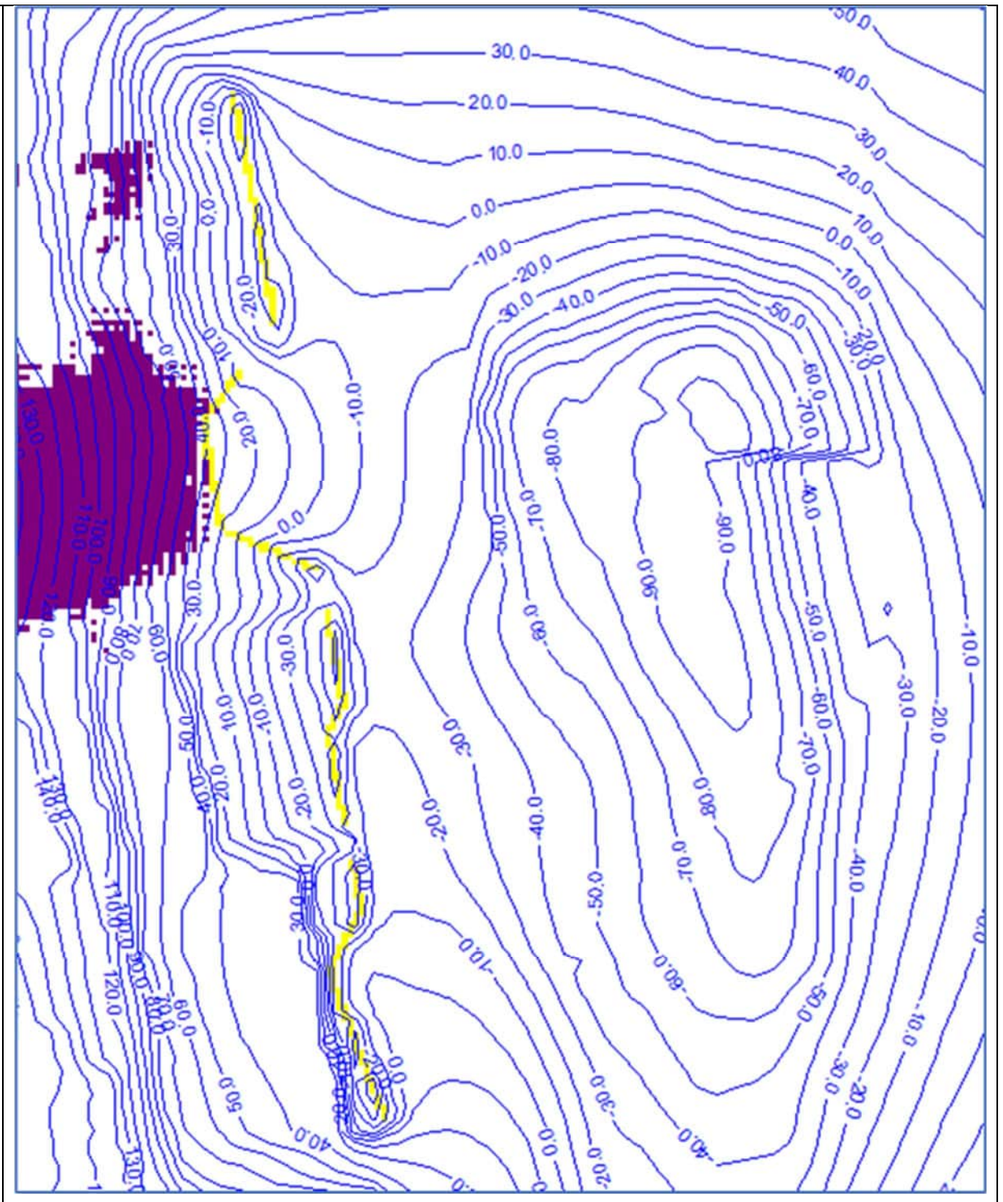
Yellow model cells are the Goonyella residual void

Grey model cells are cells used for the Goonyella residual void particle tracking

Figure 60 Groundwater flow contours for P4 years 2093, 2096, and 2102 – Goonyella Pit (GLS contours)

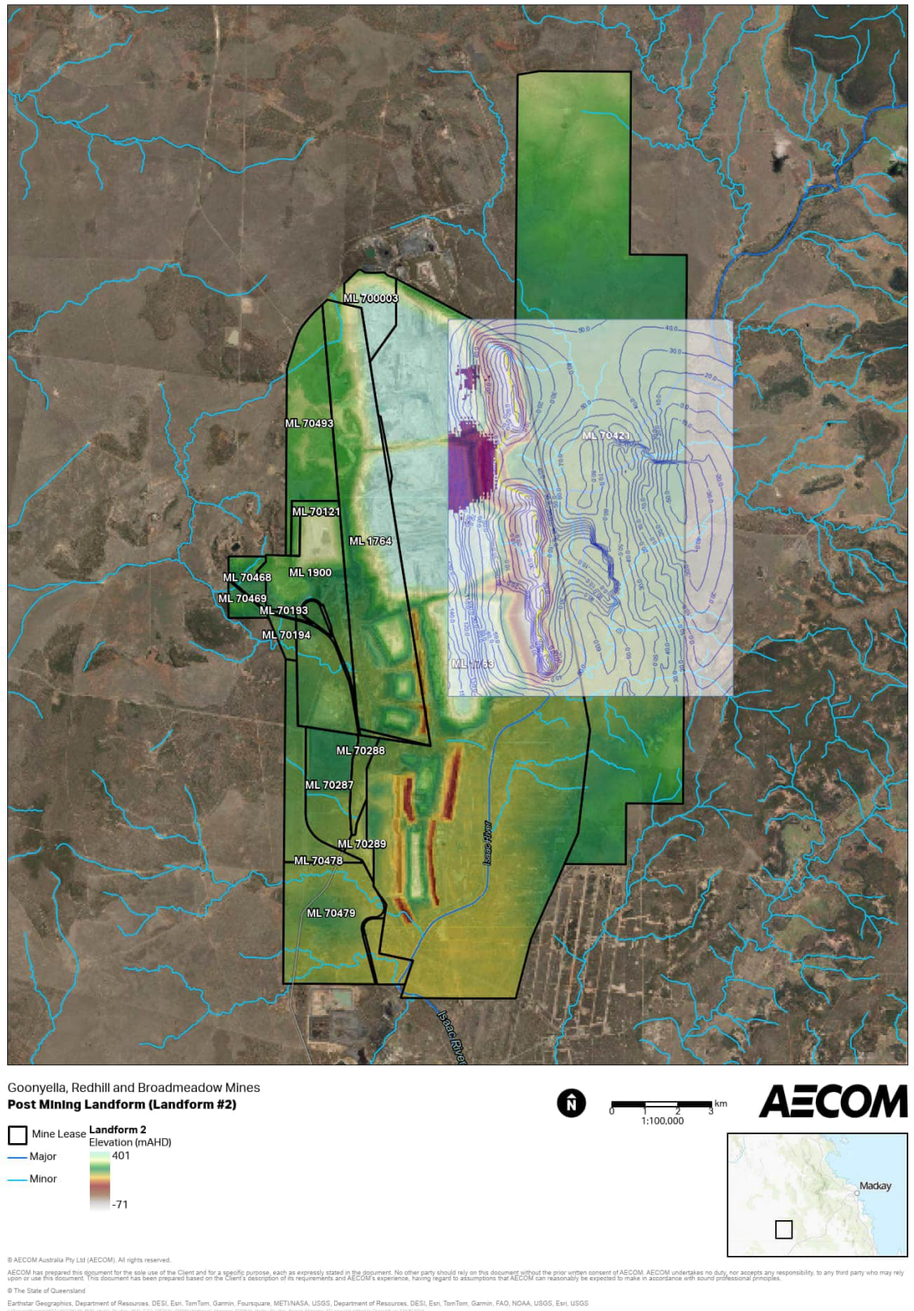


Location

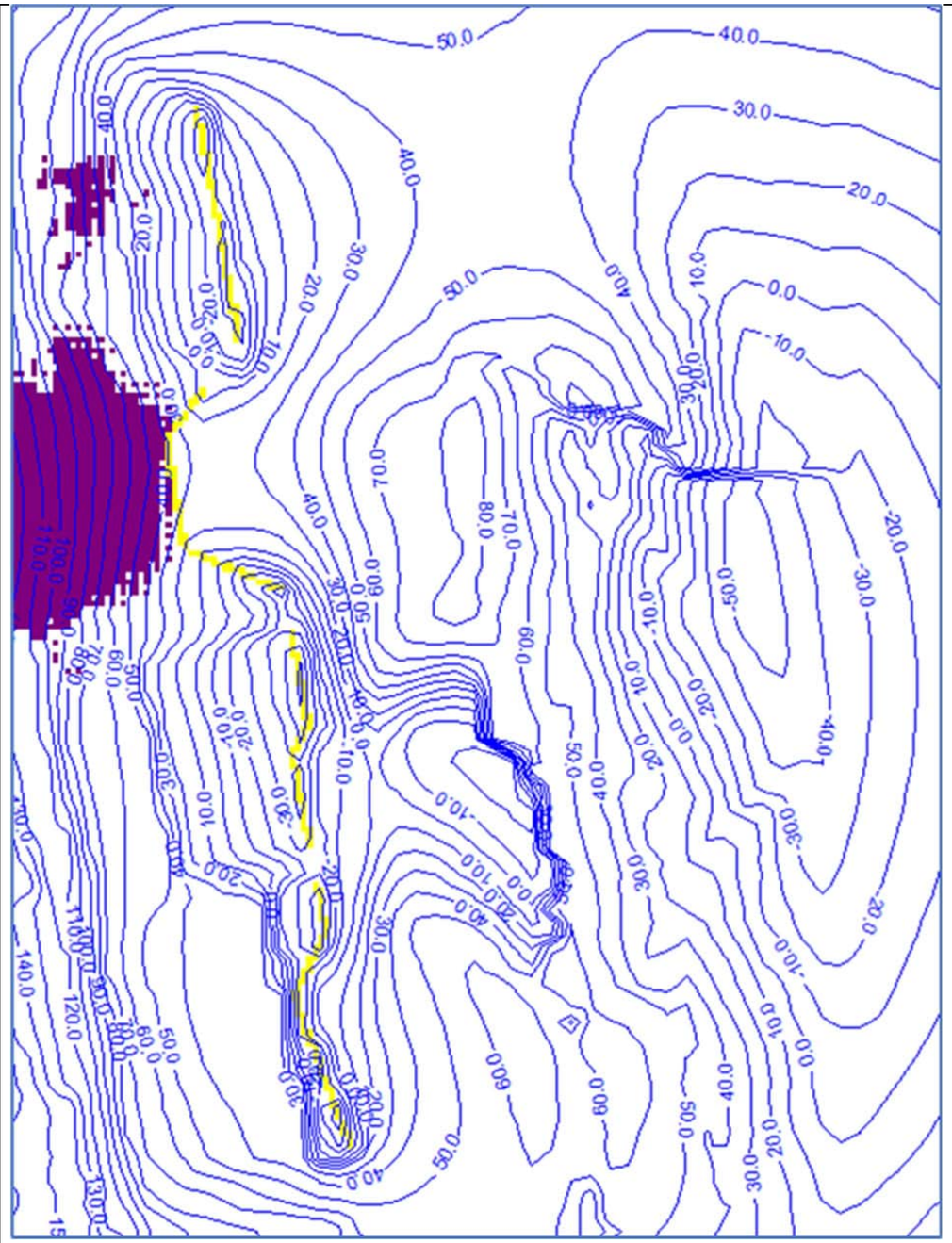


2093

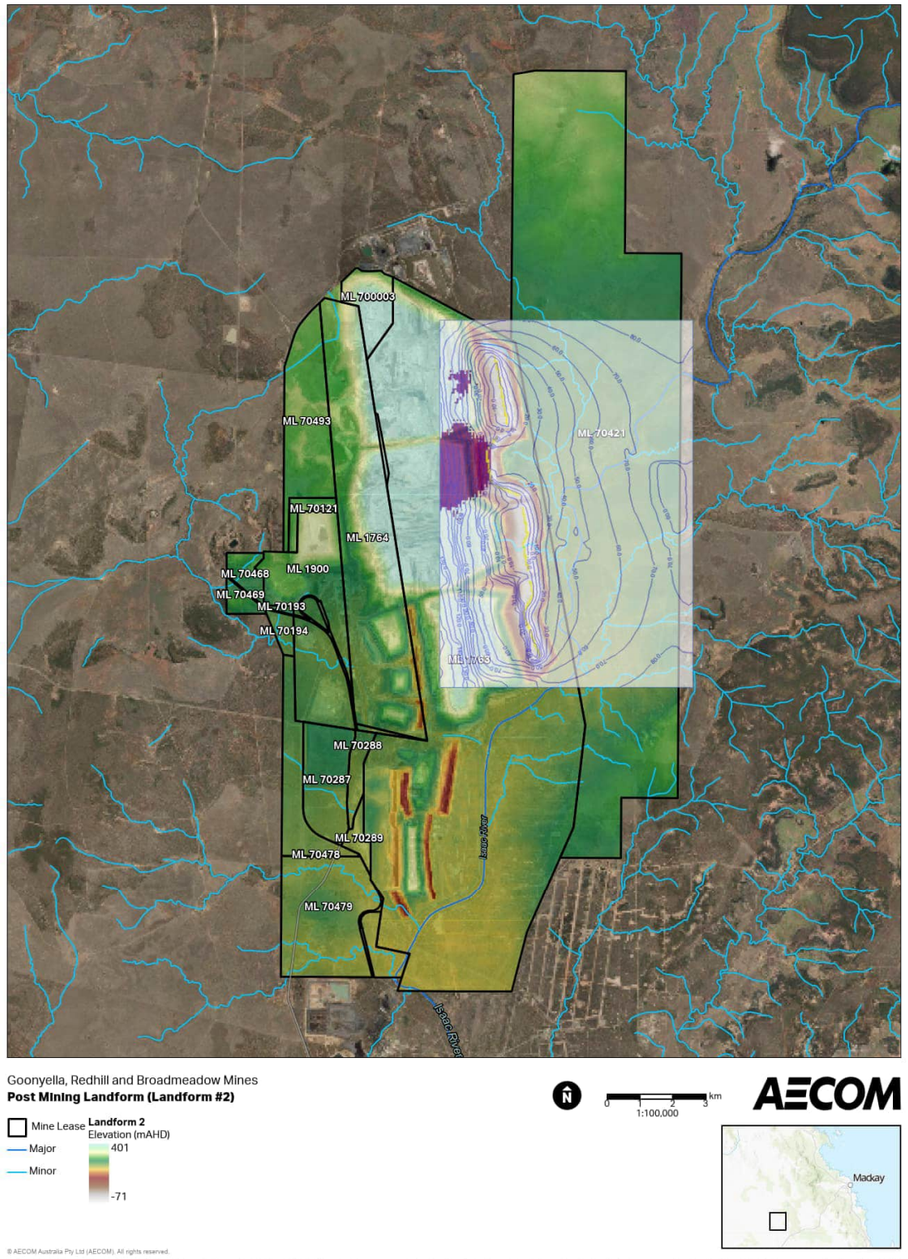
Yellow model cells depict the Goonyella residual void
Purple model cells are dry (unsaturated)

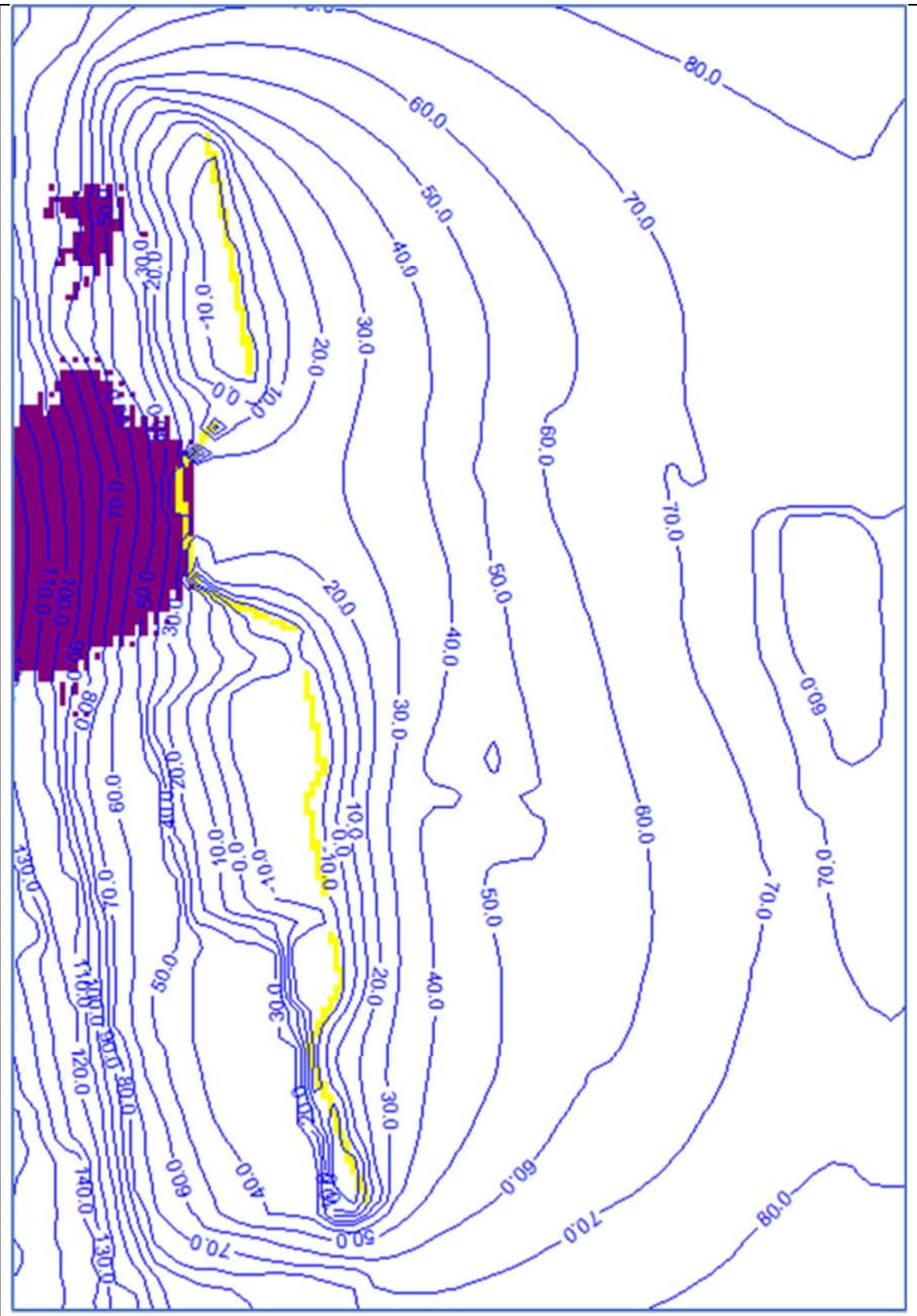


Location



2096 (3-year water introduced 2094 to 2096)





Location | **2102**

15.7 Long-term assessment

Utilising particle tracking and the predicted groundwater elevations in the long-term, after 2199, the assessment of potential pit water migration within groundwater was conducted. The long-term assessment also considered potential migration from rehabilitated mine waste storage areas located across the model domain.

15.7.1 Particle tracking 2199 to 2299

As per Section 15.6 particles were included both within and immediately next to the residual voids as included in Figure 61. The particles, per year, were simulated within the predictive groundwater model to provide an indication of post-closure flow patterns.

The long term stabilised groundwater flow patterns in the GMS coal seam (in 2299) are included in Figure 61, which shows the Goonyella Pit (yellow model cells) acts as a groundwater “sink” in the long term. Particles included in and immediately adjacent to the Broadmeadow and Isaac pits plus particles within the Thiess, Ramp 32 East, and Ramp 32 South, were predicted to migrate over time. The travel times, in days, indicates that all particles will reach the Goonyella Pit within the 100 year (36500 days) particle tracking timeframe.

The Goonyella Pit influences localised flow within the Project area.

Particle tracking for the Goonyella Pit plus the predicted 2299 GLS groundwater elevation contours are included in Figure 62. Particles included in the model cells immediately adjacent to the Goonyella Pit final void indicate flow into the residual void.

The Goonyella Pit influences localised flow within the GLS at the Project.

15.7.2 Particle tracking for mine waste storage areas

To further assess the potential for water, associated with mine waste storage facilities, to migrate post-closure, particle tracking simulations were conducted.

The mine waste storage facilities and Goonyella and Riverside Mine Industrial Areas, which can act as potential sources of artificial recharge post closure, were included in the predictive groundwater model. The potential sources (identified to have been included in the final landform and will be rehabilitated) are included in Plate 44 (below),and include (refer to Figure 2) RS1 North and South tailings storage facility (TSF)

- GS1 North and South TSF
- Thiess TSF
- Riverside Rejects dump
- R32/Airstrip TSF
- Goonyella Mine Industrial Area (MIA)
- Riverside MIA.

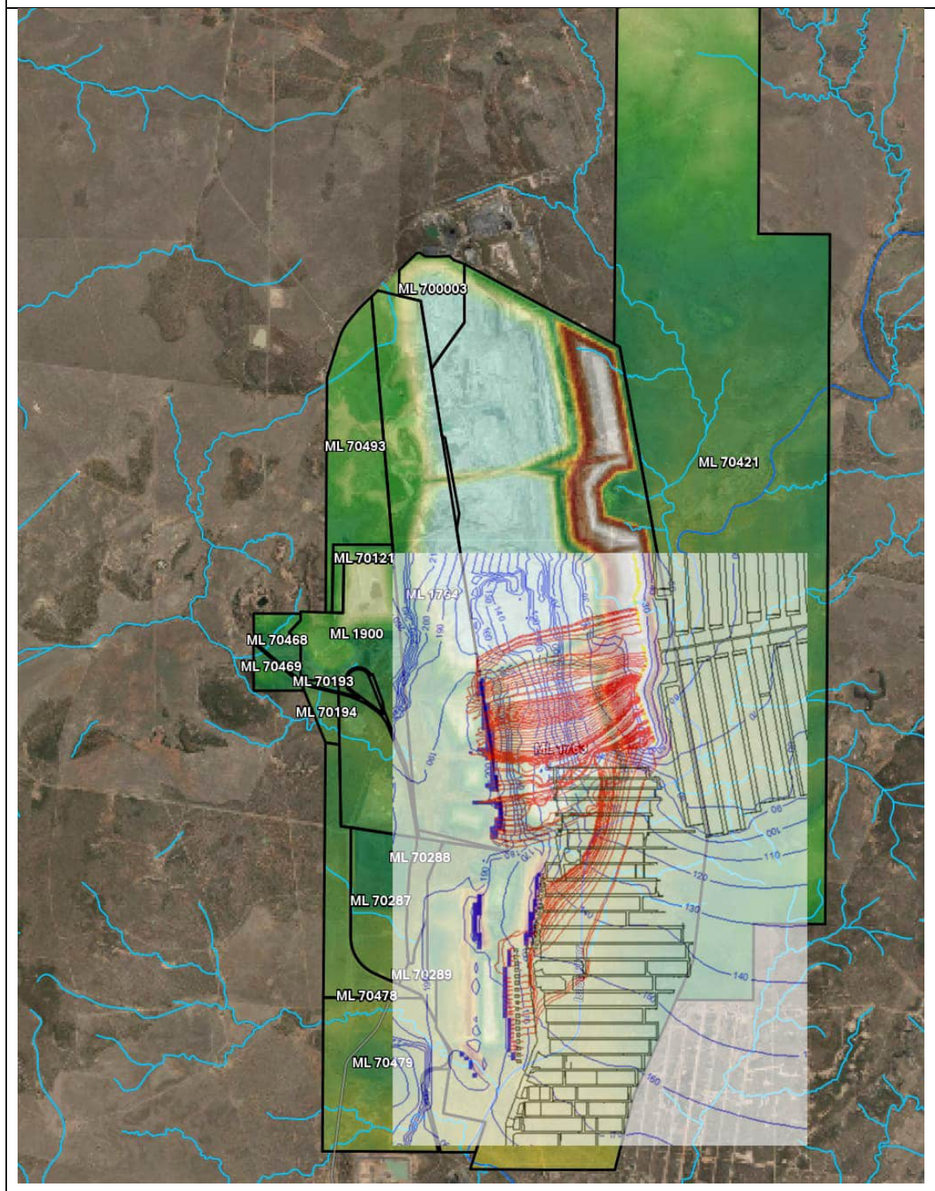
Particles were included within each of these mine waste source areas in model layer 1, simulating possible seepage from these locations post-closure, for 100 years from 2199 to 2299. The resultant particle tracking indicates limited saturation in model layer 1 (purple model cells in Figure 63 are dry during the 2199 to 2299 simulation) resulting in migration from only the southern portion of GS1 TSF, the Riverside MIA, and the Riverside Rejects.

The 100 year particle migration is influenced by the Goonyella Pit; however, the possible migration will take over 100 years to reach the residual void.

Due to the limited saturation in model layer 1, which limits migration assessment, an evaluation of the depth-to-water below these mine waste storage facilities was conducted to evaluate the risk of artificial recharge from these facilities to the groundwater post-closure.

Figure 61 Long-term particle tracking for the residual voids except Goonyella Pit

Particle tracking for 100 years (2199 to 2299) for the five residual void except Goonyella Pit, particles include in the 5 pits plus outside of Broadmeadow and Issac pits



GMS groundwater elevation contours in 2299

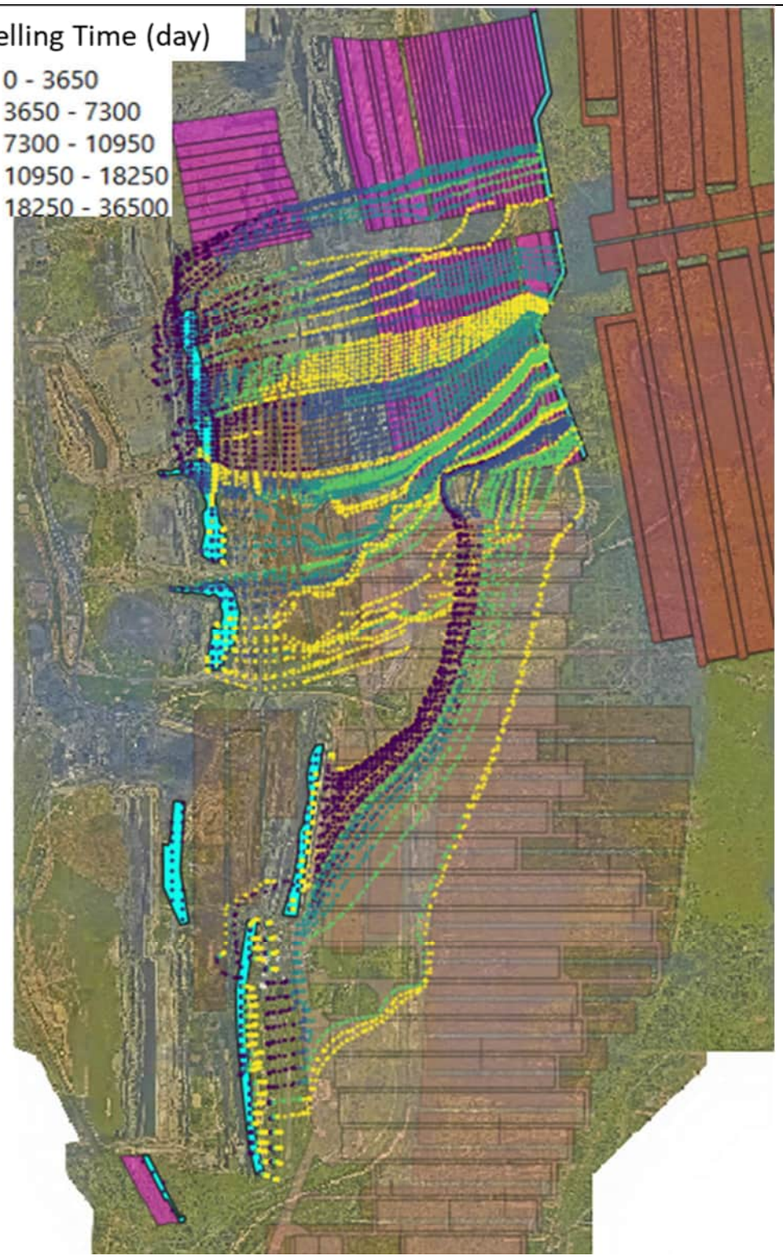


Figure 62 Long-term particle tracking for the Goonyella Pit residual void

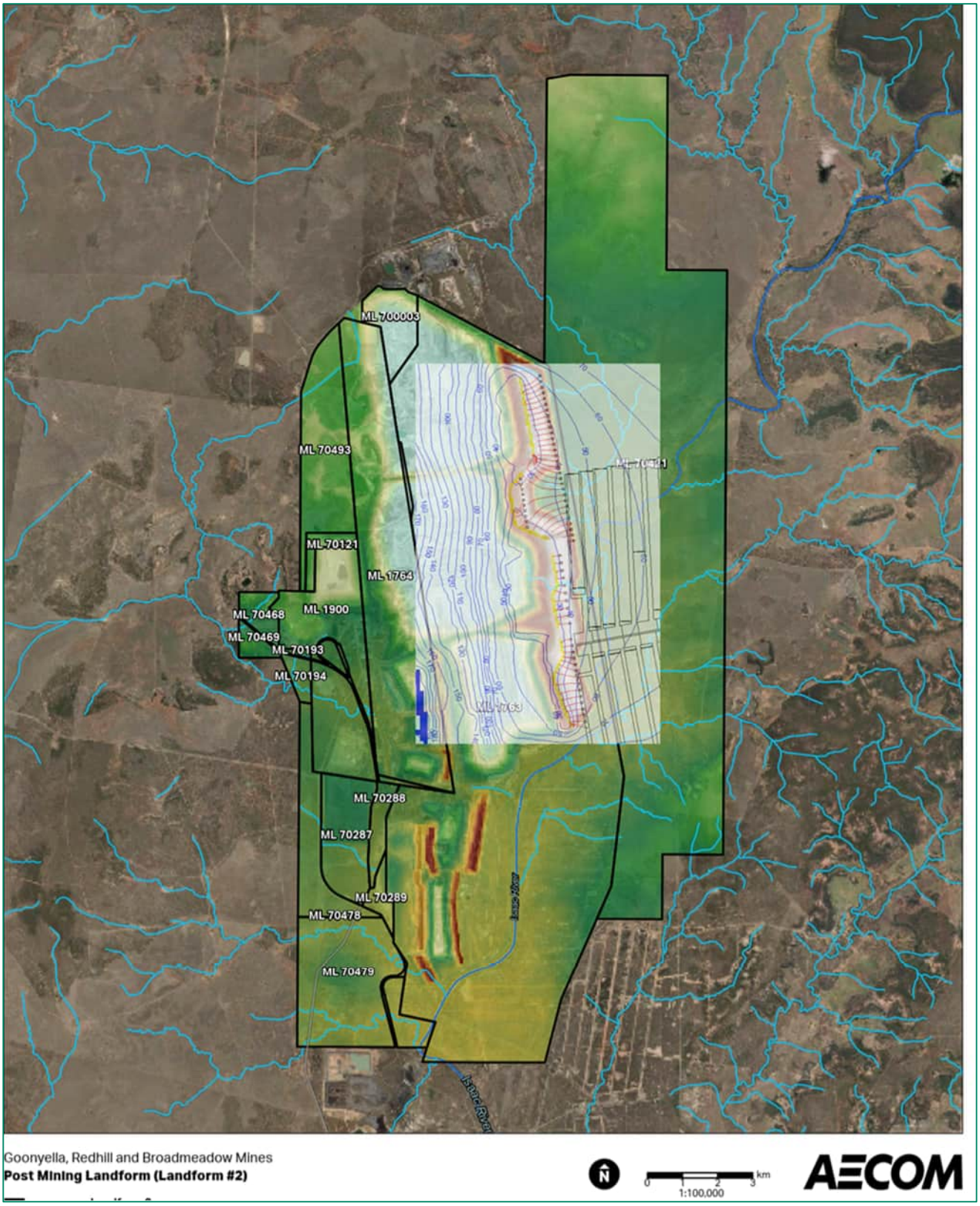


Plate 44 TSFs, MIAs, and the Riverside Rejects locations

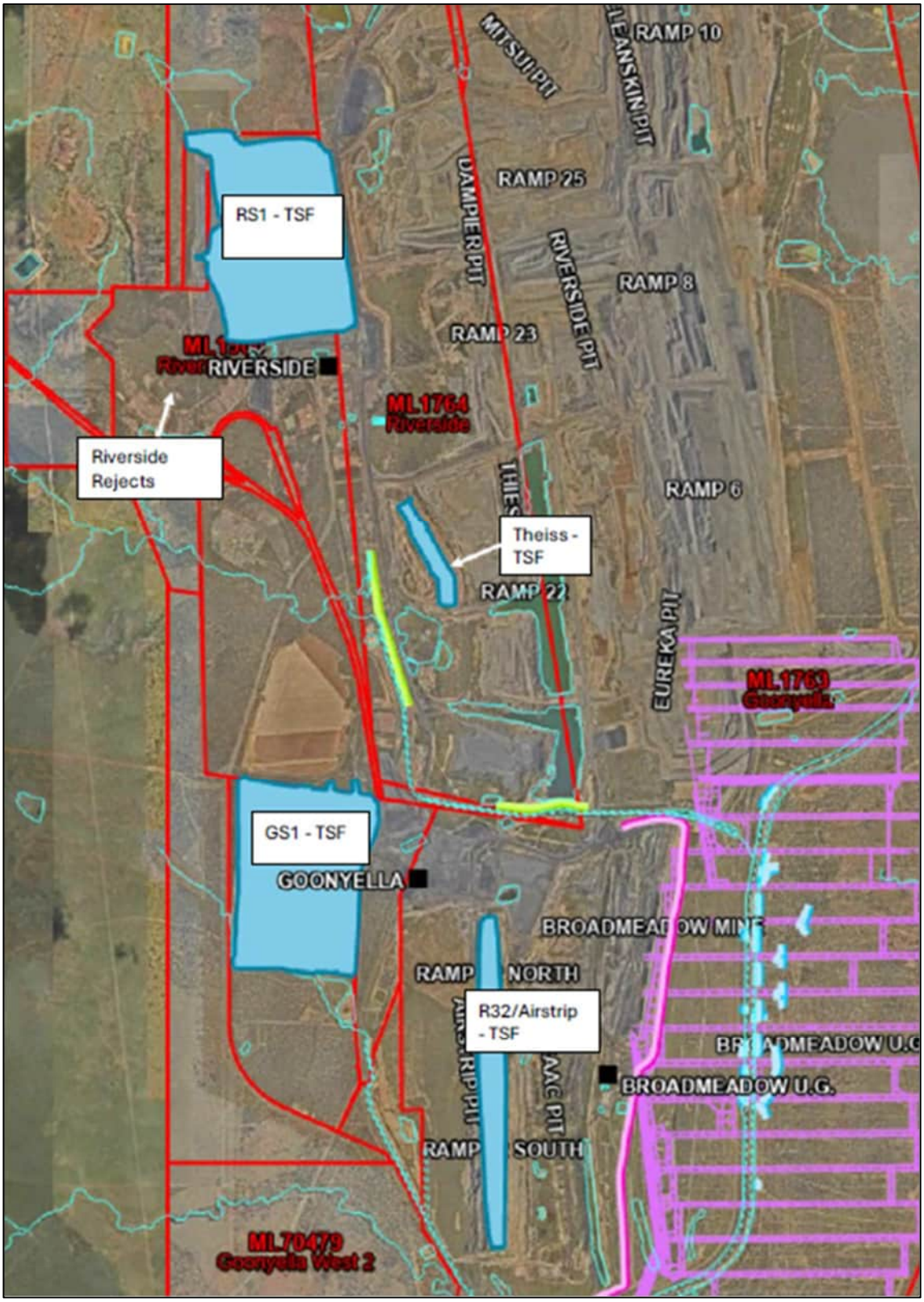
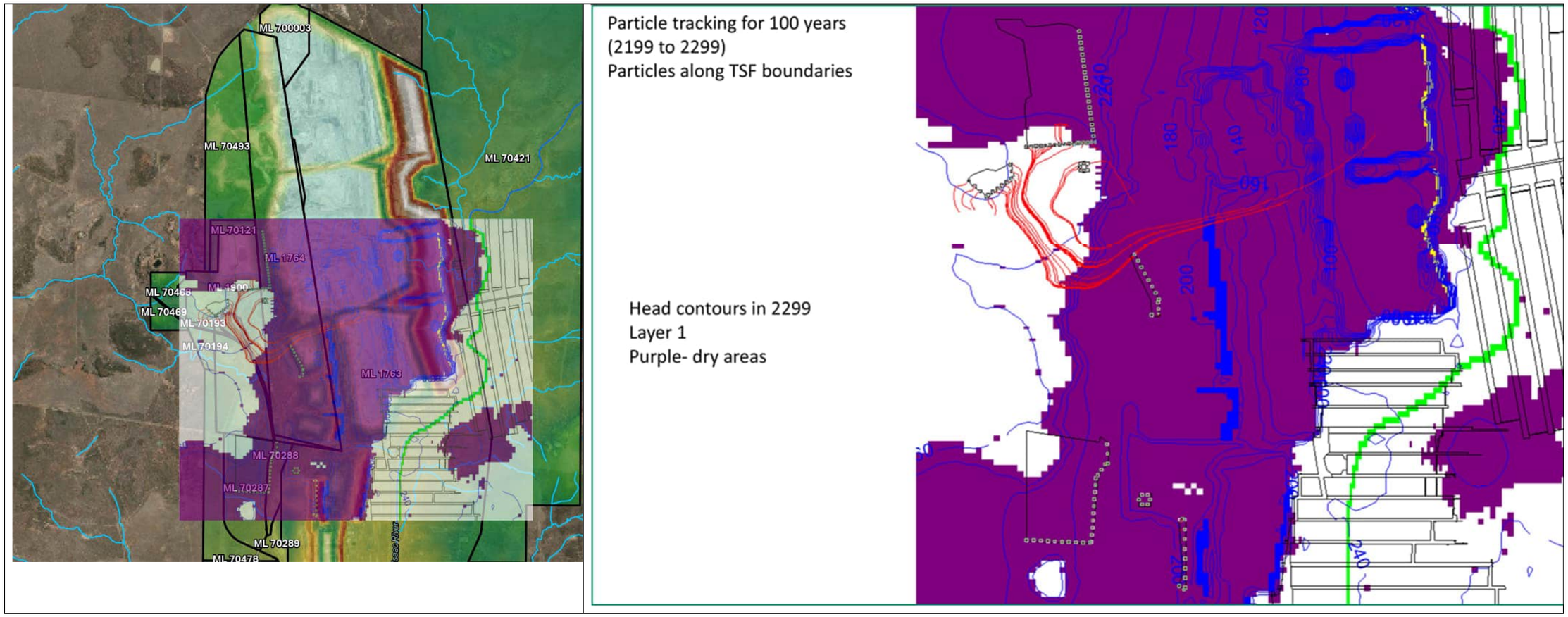


Figure 63 Particle tracking from mine waste storage facilities

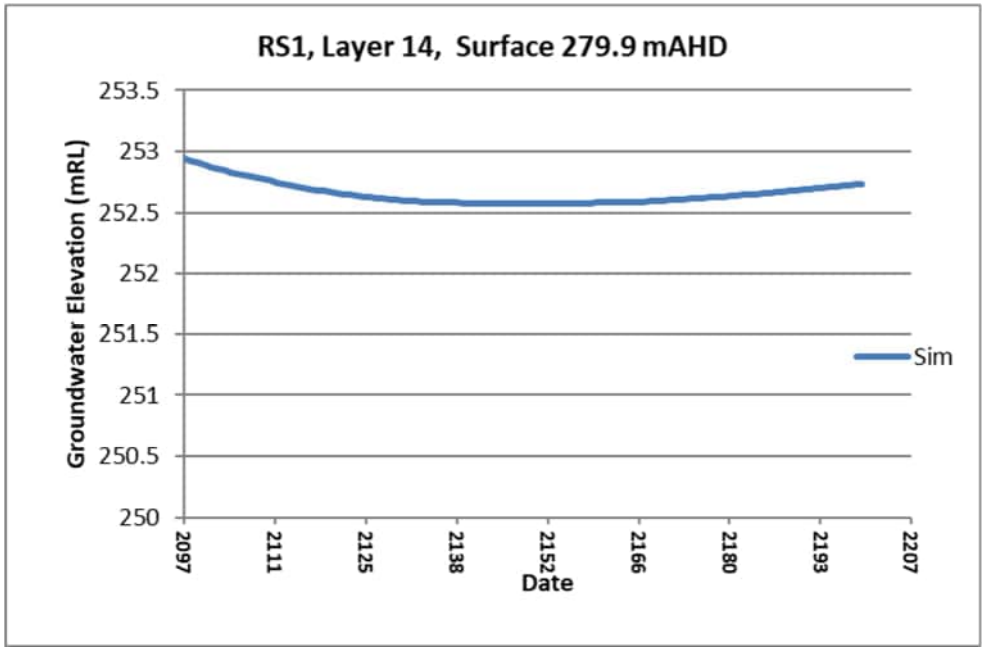


Purple model cells in the surficial sediments (model layer 1) are dry
White model cells are saturated
Green model cells represent the Isaac River

Mine closure when all mining and decommissioning activities have ceased is recognised to be 2097. This is considered to include the rehabilitation of all mine waste storage facilities, included in the particle tracking simulation above. Hypothetical water level observation points were included within the predictive groundwater model within the footprints of these mine waste storage areas, MIAs, and rejects dump. The water level hydrographs allowed for the assessment of groundwater elevations (depth-to-water) at these locations from 2097 to 2199.

The resultant water level hydrographs provided the depth-to-water at each site at the start of the post-closure particle tracking simulation 2199 to 2299 (Figure 63). The hypothetical observation points water level hydrographs indicate:

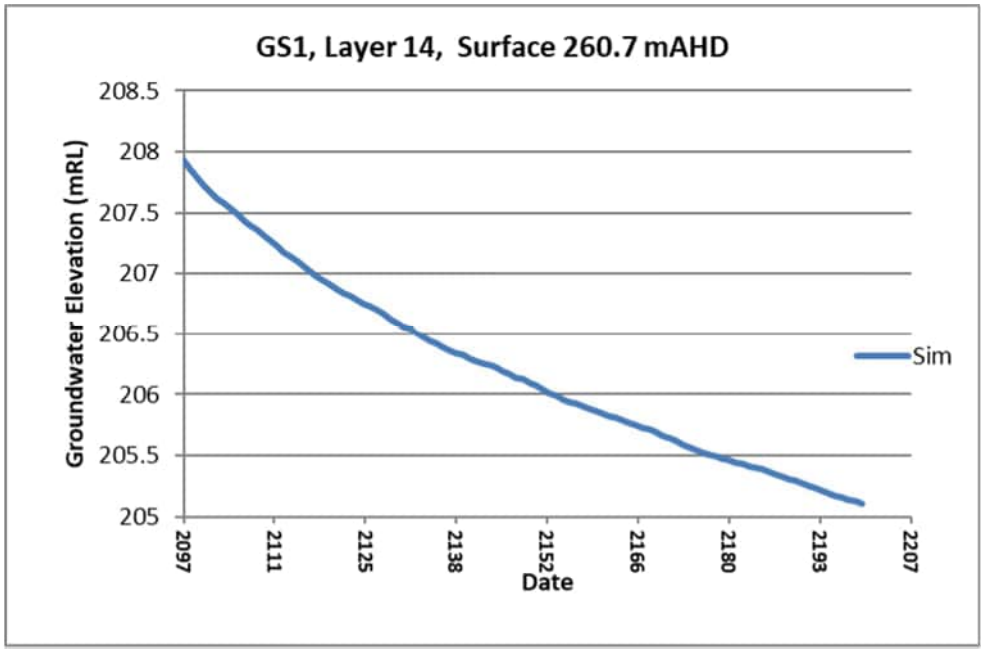
- RS1 North and South TSF



Sim – simulated groundwater elevation in mAHD

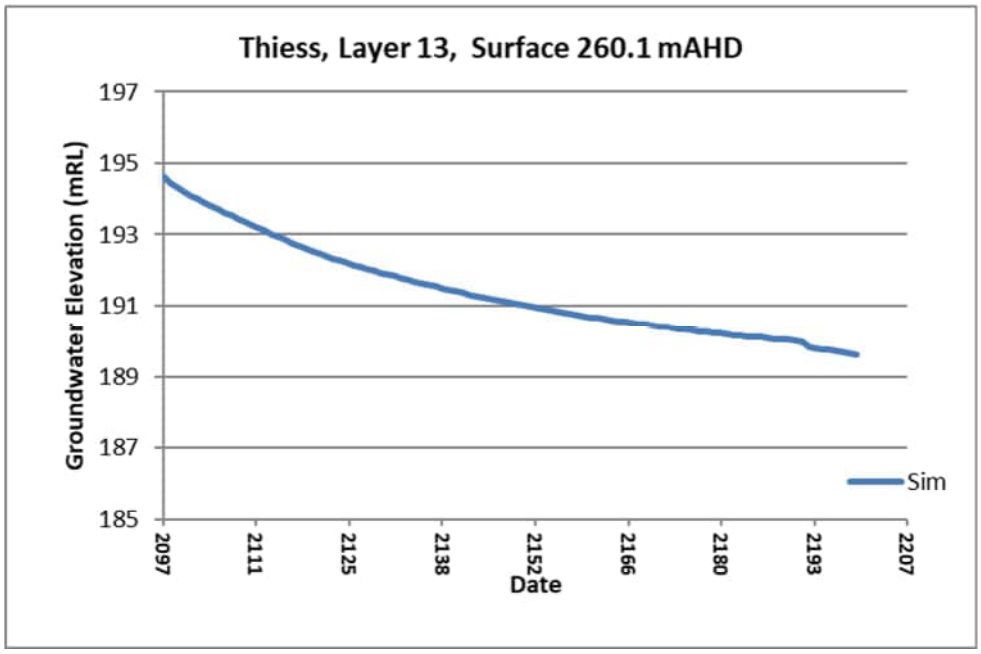
- The saturated model layer below the RS1 TSF is the Back Creek Group, and the depth-to-water at the centre of the TSF is some 27 m below surface.
- The aquitard nature of the Back Creek Group (Table 20) indicates limited vertical seepage migration potential below the TSF.
- Particles were included in the south of the TSF were the surficial cover (model layer 1) is predicted to be saturated.

- GS1 North and South TSF



  - The saturated model layer below the GS1 TSF is the Back Creek Group, and the depth-to-water is some 55 m below surface in 2199.
  - The aquitard nature of the Back Creek Group negates the risk of vertical migration from surface to the saturated Back Creek Group in this location.

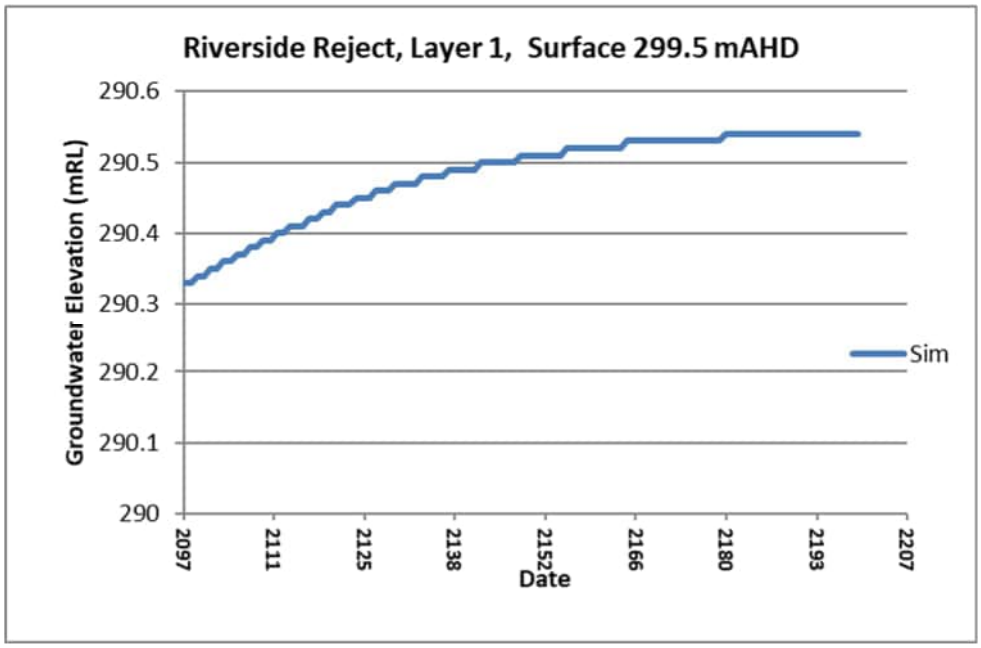
- Thiess TSF



  - The saturated layer below the Thiess TSF is model layer 13, the underburden below the GLS coal seam.
  - The depth to the groundwater in 2199 at this TSF is 70 m.
  - The thick unsaturated zone reduces potential for artificial recharge (if possible after rehabilitation) to enter the saturated hydrostratigraphic units and migrate within the

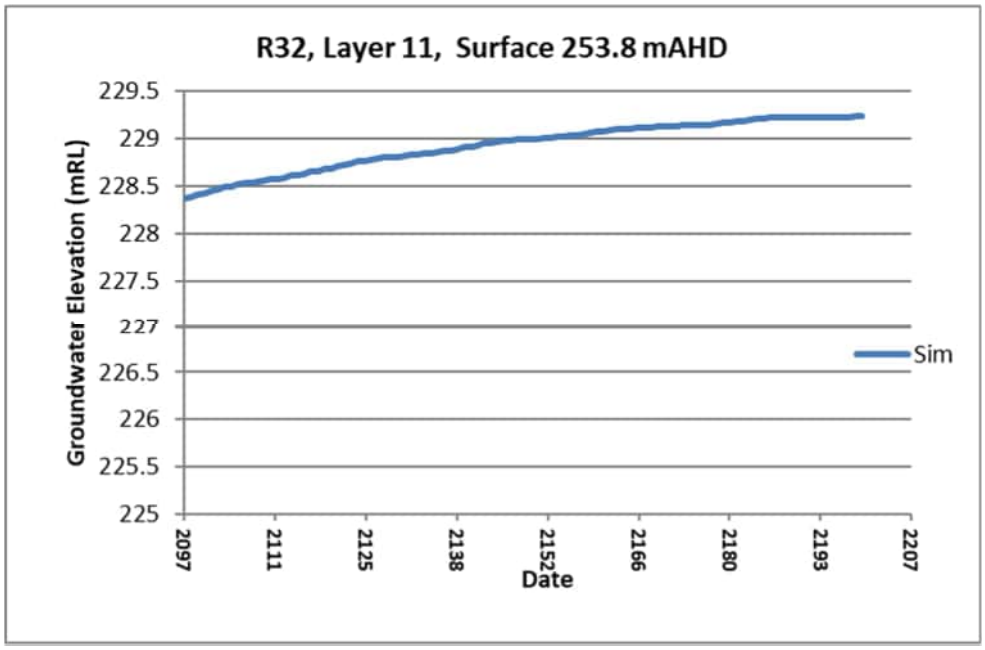
groundwater. Noting that any possible artificial recharge migration would ultimately end at the Goonyella Pit.

- Riverside Rejects dump



- The surficial cover is saturated within the Riverside Reject area, with groundwater approximately 9 m below surface.
- Particle tracking for this waste storage facility is included in Figure 63.

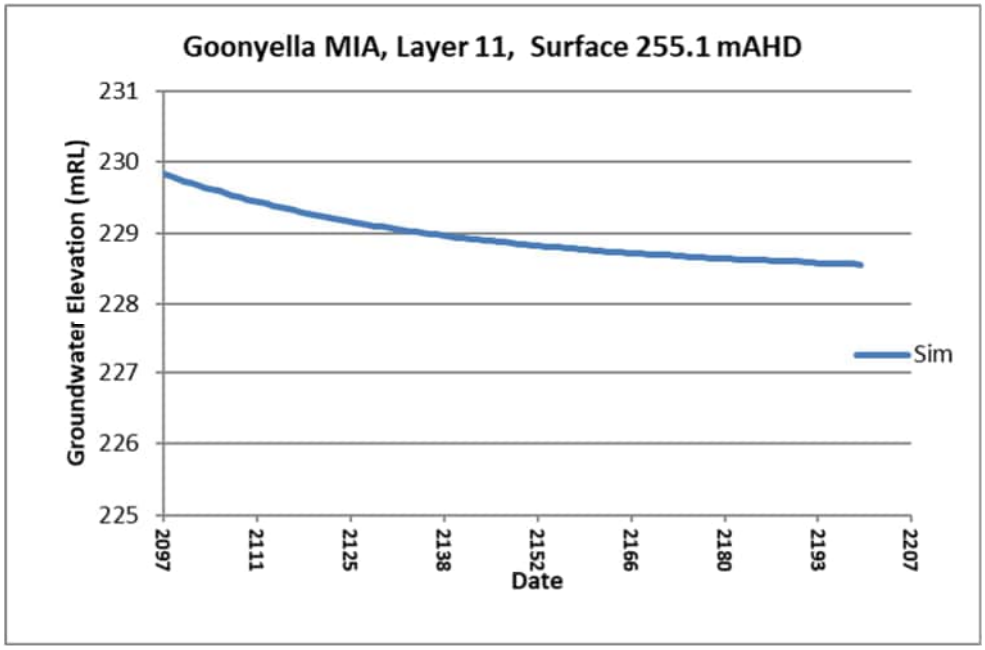
- R32/Airstrip TSF



- The saturated layer below the Airstrip TSF is model layer 11, the interburden between GMS and the GLS coal seams. Note: The GMS subcrop is predicted to be dry post-closure (Section 15.7.3).
- The depth to groundwater in 2199 in this location is 25 m.

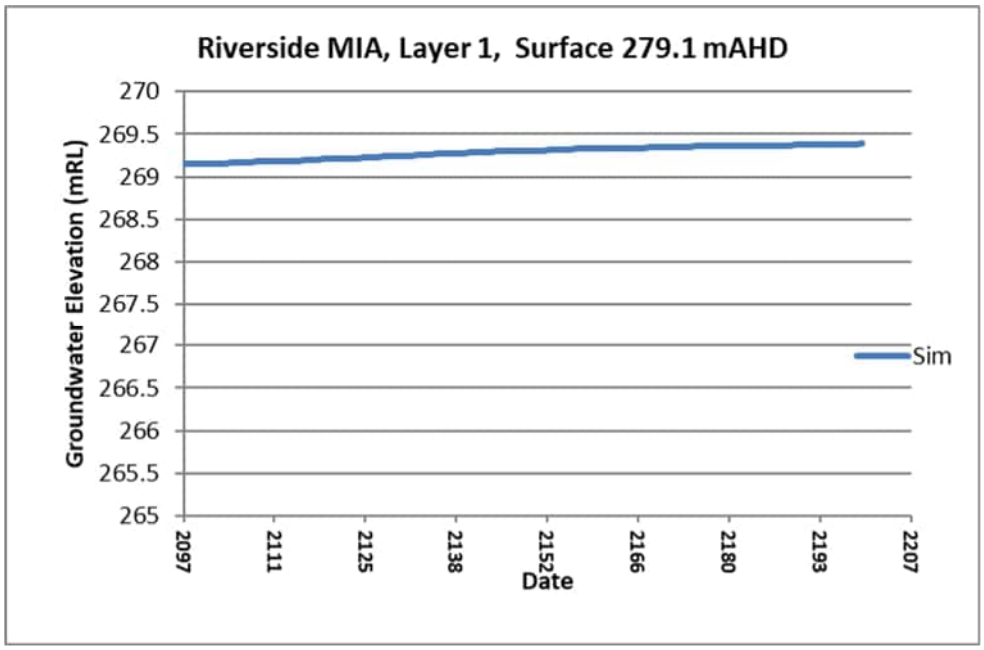
- Possible artificial recharge (if possible after rehabilitation) resulting in vertical migration to the saturated hydrostratigraphic units and migration within the groundwater is limited in this area. Noting that any such migration would report to the Goonyella Pit.

- Goonyella Mine Industrial Area (MIA)



- The saturated layer below the Goonyella MIA is model layer 11, the interburden between GMS and the GLS coal seams. Note: The Goonyella MIA is located to the west of the GMS outcrop.
- The depth to groundwater in 2199 in this location is some 25 m.
- Possible artificial recharge (if possible after rehabilitation) resulting in vertical migration to the saturated hydrostratigraphic units and migrate within the groundwater is limited in this area. Noting that any such migration would end at the Goonyella Pit

- Riverside MIA.
  - The depth-to-water at the Riverside MIA is some 9 m below surface in the surficial cover (Model Layer 1).
  - Particle tracking from this facility is included in Figure 63



The depth-to-water at these facilities indicate the limited risk to groundwater post-closure, based on:

- The thickness of the unsaturated zone below each site
- The limited aquifer hydraulic properties, particularly the vertical hydraulic conductivity, of the underlying units
- The resultant long-term groundwater flow patterns all locally influenced by the deep Goonyella Pit water level (possible water migration from mine storage facilities would end at the Goonyella Pit).

15.7.3 GMS long term saturation

The assessment of particle tracking and predictive groundwater elevations for the GMS indicate that the GMS would remain unsaturated in sections of the Project area post-closure. Groundwater elevations for the GMS after calibration (at the start of prediction phase P1), Figure 39, indicates the influence of historic Broadmeadow GMS underground mining. Water is introduced into the Broadmeadow underground workings between 2057 and 2060 (Section 15.2). An evaluation of groundwater contours for the GMS over time is included in Figure 64.

Figure 64 indicates the influence of Red Hill Mine, the introduction of water into Red Hill Mine, and the Goonyella Pit on the groundwater elevations and flow patterns in the GMS. The groundwater elevations and depth of GMS (bottom of coal seam elevations) allowed for the identification of saturated and unsaturated conditions of the GMS in the model. The purple model cells in Figure 64 indicate dry cells.

The northwest portion of the Broadmeadow GMS underground workings are identified to be unsaturated, after the introduction of water into the underground, over time due to the influence of the Goonyella Pit in this area.

The underground workings are planned to be filled with water to facilitate geotechnical stability. It is noted that mitigation and management of this portion of the GMS workings may be required in the future subject to further geotechnical assessment.

The portion of the Project area presented in Figure 64 is as included below.

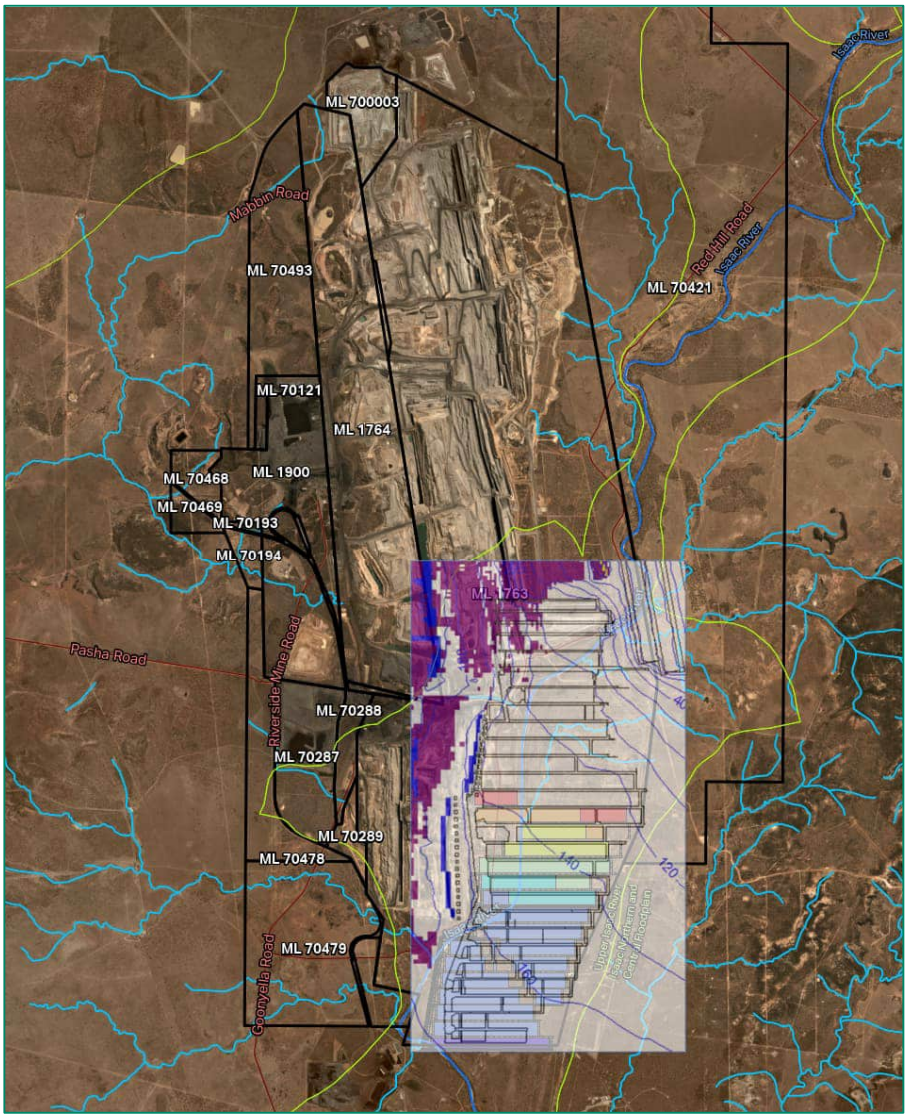
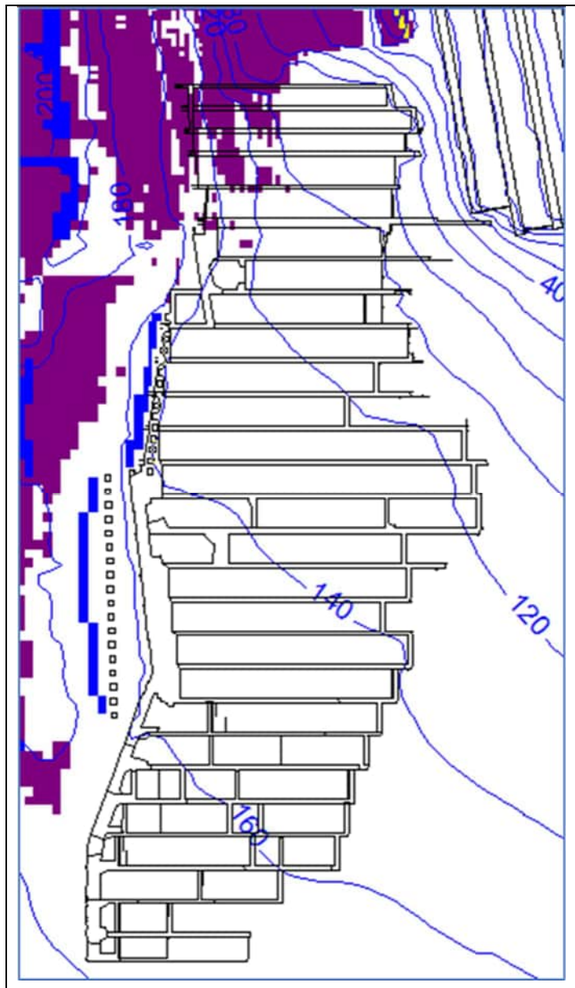
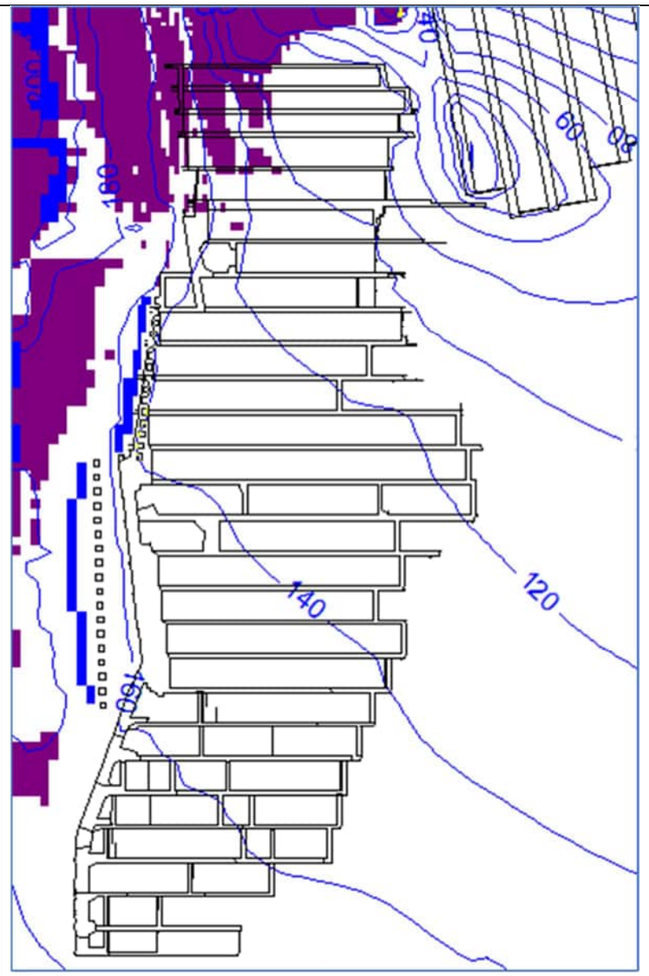


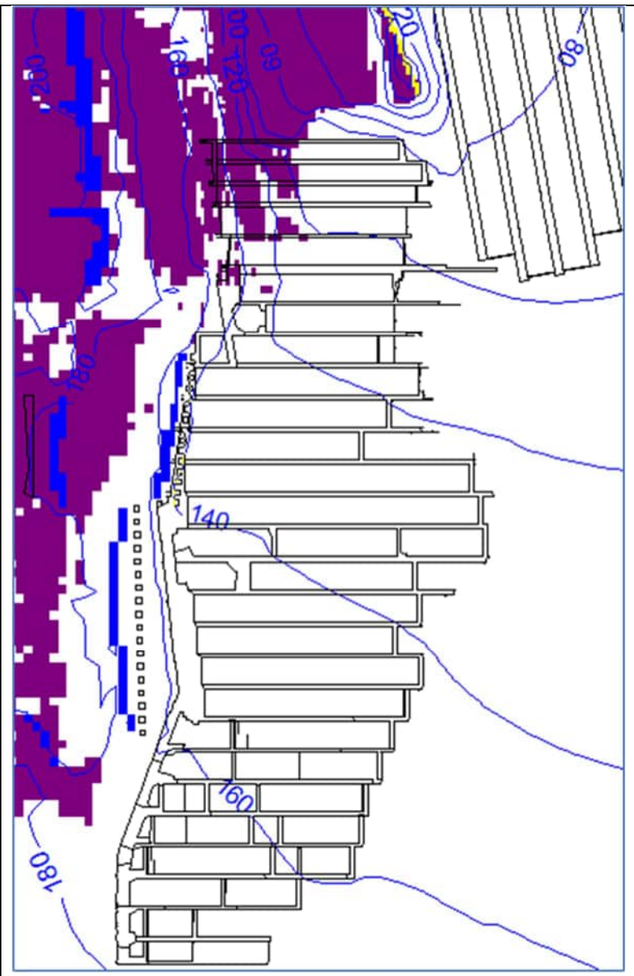
Figure 64 GMS saturated and unsaturated conditions over time



2093

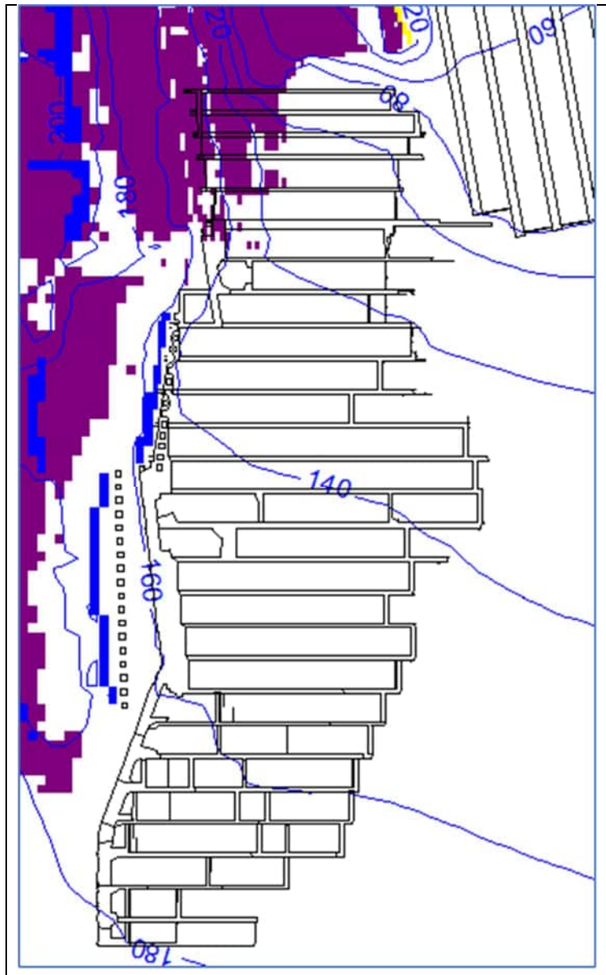
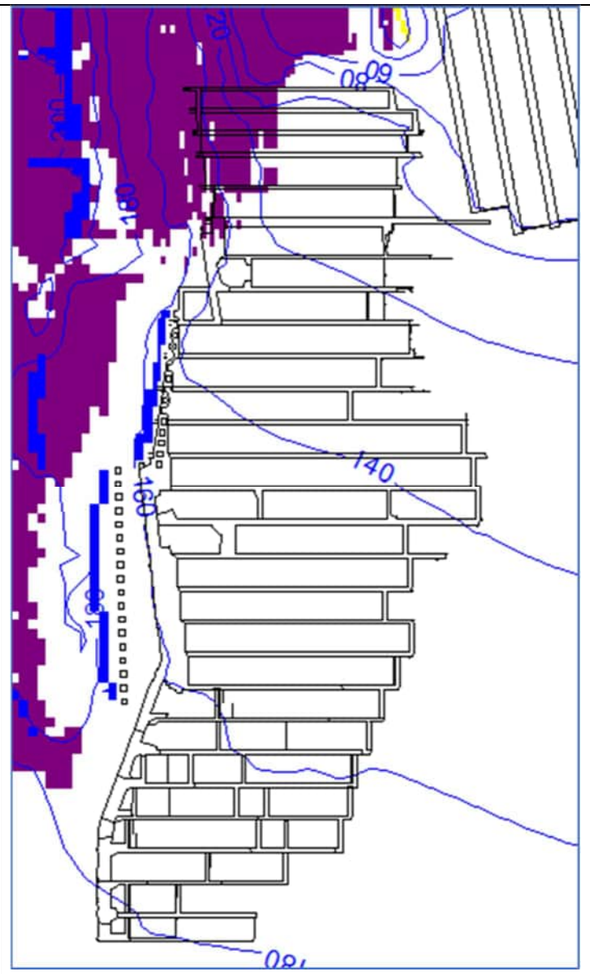
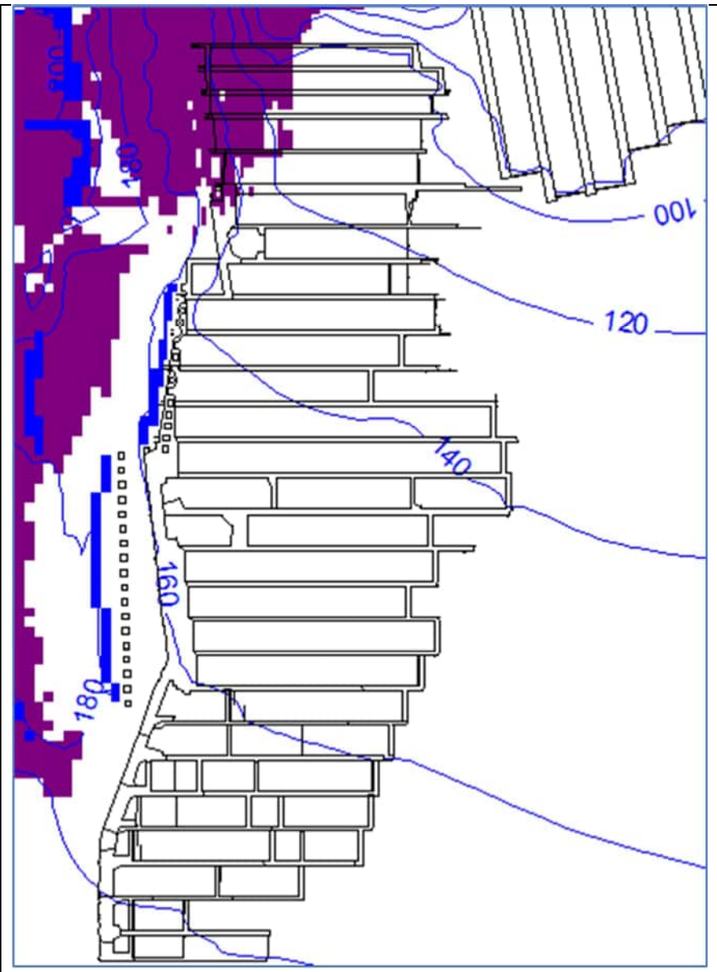


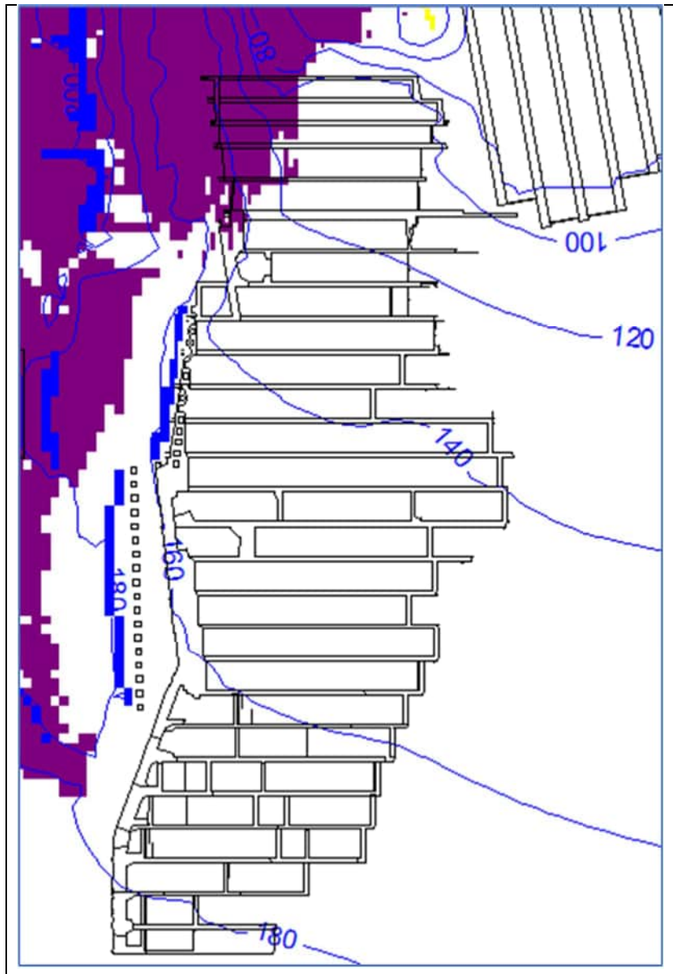
2096 (after RHM water introduced)



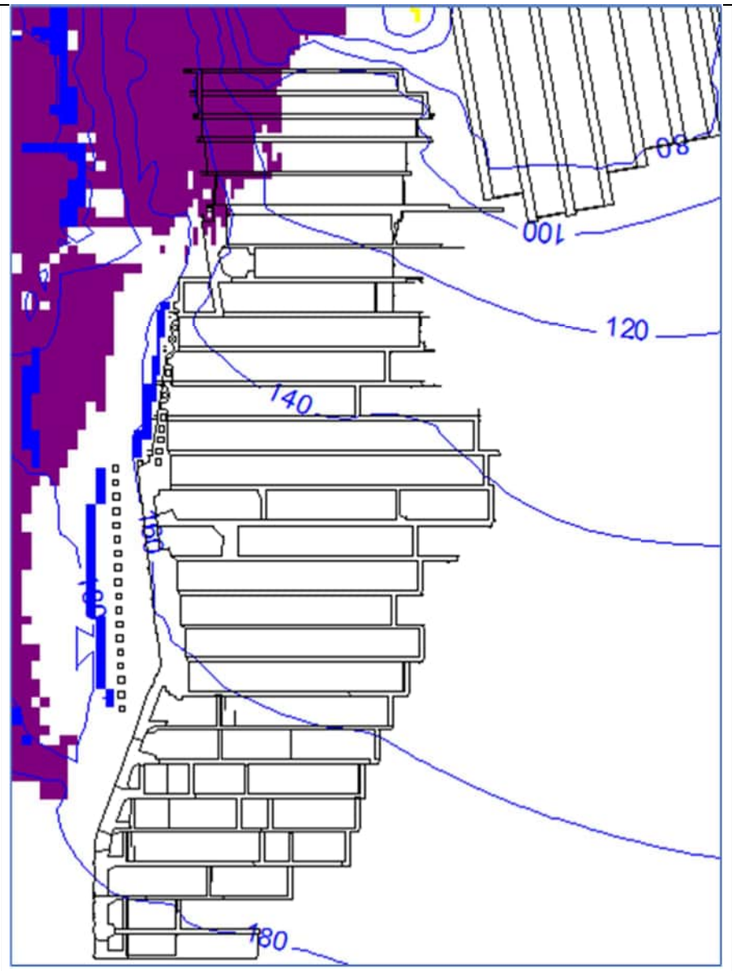
2100

Purple model cells are dry
Yellow model cells are Goonyella residual void
Blue model cells are the other five residual voids

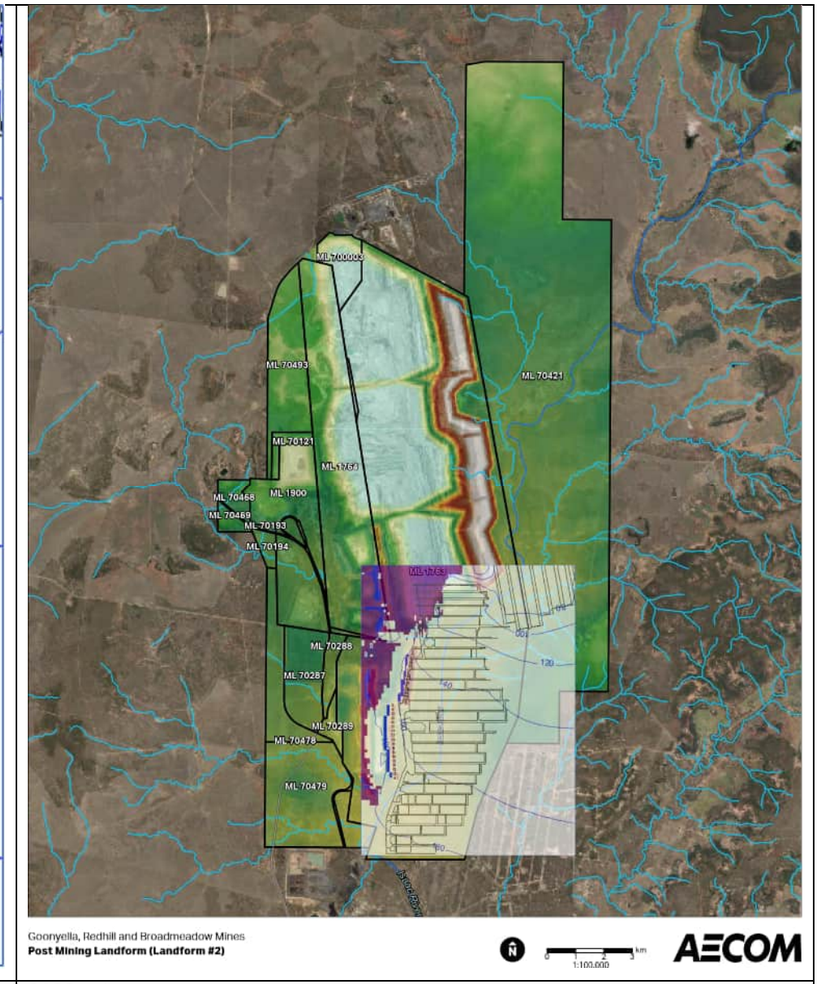
		
2120	**2140**	**2160**



2180



2199



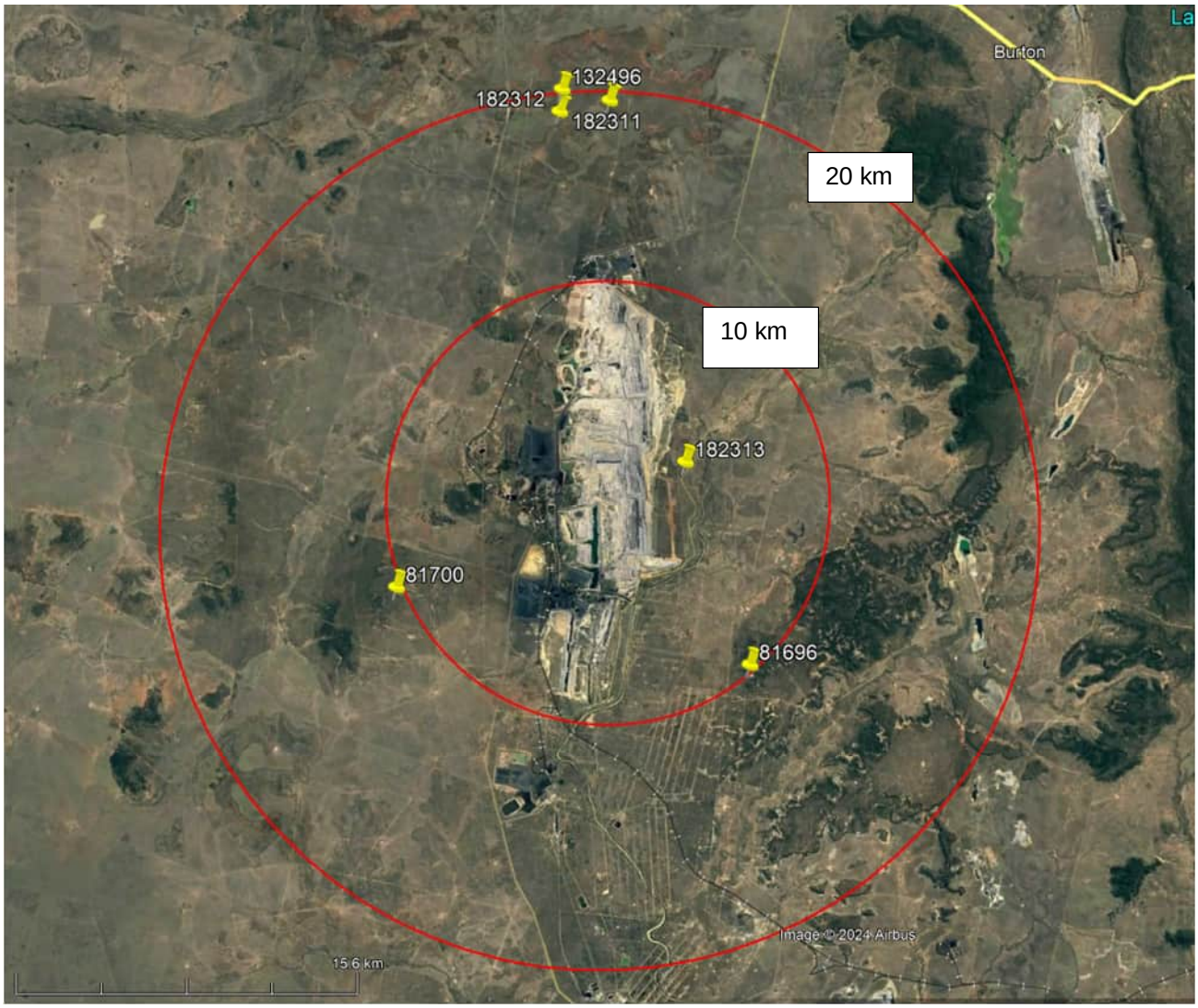
2199 reference

15.8 Potential Groundwater Level Impact to Receptors

15.8.1 Water supply bores

Six water supply bores were identified within the assessment of registered bores, as discussed in Section 9.1. The six water supply bores, as included in Table 14, were located up to 20 km from the GRB mining area, as shown in Figure 65.

Figure 65 Water supply bores identified adjacent to GRB



Groundwater level hydrographs were compiled for each of these registered bores to assist in assessing the potential change in groundwater levels, due to approved mining and post-closure, overtime.

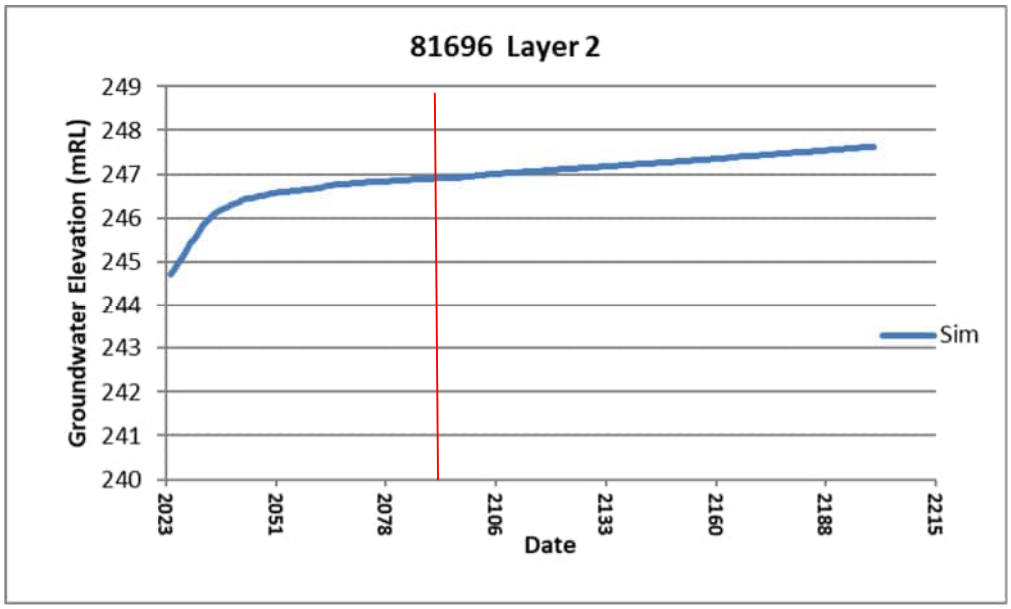
Three water supply bores, at or within 10 km from the current GRB footprint include:

- RN182313, Cleanskin Gully bore, which was drilled to 25.34 m, and based on depth intersects FCCM (model layer 2)
- RN81696, Skeleton Bore, which was drilled to 63.7 m in model layer 2
- RN81700, Harvey's Bore, has no data but assumed to be in model layer 2 (same as the other two water supply bores).

The water supply bores were included in the groundwater model domain and the groundwater levels were simulated during all four prediction phases (Section 15.2), from 2024 to 2199. The resultant hydrographs are discussed below.

The hydrographs include 2097 the date when mine closure is recognised, when all mining and decommissioning activities are complete.

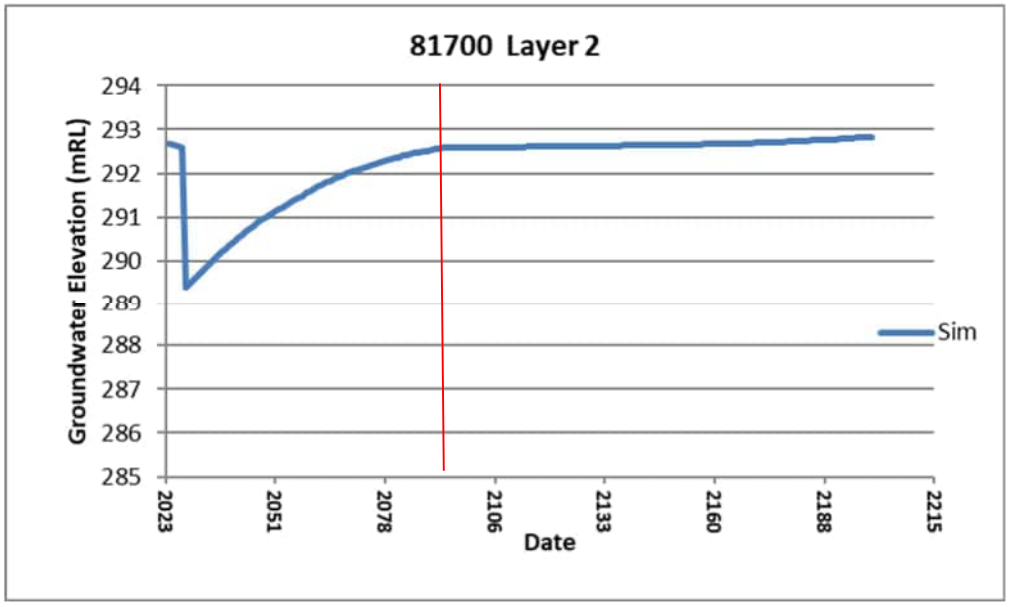
RN81696 Skeleton Bore



Sim – simulated groundwater level within the water supply bore
Red line – 2097 closure date

The bore, located some 10 km to the south west of GRB is recognised to recover over time, indicating no predicted alteration due to GRB during and post-closure in this location.

RN81700 Harvey's Bore

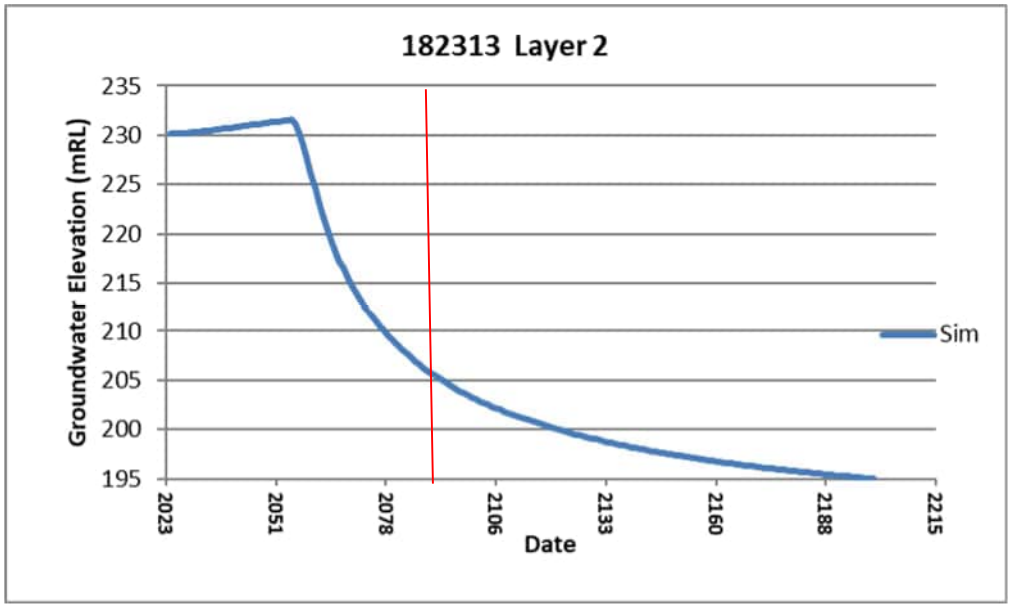


Sim – simulated groundwater level within the water supply bore
Red line – 2097 closure date

Note: Harvey's Bore is located to the west of the GRB mining, on Back Creek Group sediments. The Model Layer 2 to 13 in this area are dummy layers as required in the MODFLOW model. The surficial sediments, alluvium and Tertiary, are 10 m thick in the model to the west of the Permian coal bearing units. This bore is assumed, based on the other water supply bores, to be deeper than 10 m and thus included in the underlying model layer.

The groundwater drawdown for RN81700 is predicted at the start of the prediction period P1 (2024 – 2056), which includes the Broadmeadow underground mining. This change in groundwater level possibly relates to matching calibration levels for the Back Creek Group rather than mine related drawdown (i.e., the mine dewatering activities are not predicted to impact on Back Creek Group sediments to the west). The groundwater level then recovers back to 2024 (start of P1) groundwater elevations.

RN182313 Cleanskin Gully Bore



Sim – simulated groundwater level within the water supply bore
Red line – 2097 closure date

This bore, down dip and in proximity to the residual Goonyella Pit void, is predicted to be dewatered overtime and remain dewatered post-closure. This bore is located in proximity to the Goonyella residual void high wall on BMA operated area. Therefore, it is reasonably assumed not to be used for supply purposes.

A drawdown of some 35 m will, based on the bore depth of 25.34 m, become dry with time. It is considered that the approved mining activities will result in the dewatering of the bore and has been assessed and managed under approval conditions.

15.8.1.1 Remaining water supply bores

Based on the limited impact of the mining post-closure at 10 km from the Project, the three registered bores, 182311, 182312, and 132496, are located some 20 km from GRB and thus are sufficiently far from the mining activities to not be impacted. These water supply bores are located outside the active model domain (Plate 16) (i.e., these bores are beyond the northern model boundary, which is based on the Isaac River catchment).

15.8.2 GDEs

The mapped potential GDEs (aquatic and terrestrial) are included in Figure 20. The mapping indicates low potential terrestrial GDEs adjacent to the Isaac River with the river channel itself identified as having high potential aquatic GDEs. Mine water storages across the GRB are mapped as high and moderate potential GDEs. It is noted that these storages, including the RS and GS TSFs (Plate 44) will be rehabilitated at closure. As per Section 9.2 it was noted that the potential aquatic GDEs, mapped in Figure 20, included areas containing tailings dams, mine water storages, and mining voids. Thus, the mapping is recognised to identify potential GDEs only.

Groundwater elevations derived during the groundwater model at the end of 2023 (Q1 2024) are included in Figure 66. These groundwater levels and flow patterns were representative of the influence of approved mining activities within the Project area. The modelling identified where saturated sediments, which can provide groundwater for GDEs, have been dewatered due to approved mining activities.

The extent of groundwater drawdown in the surficial sediments (Model Layer 1) as discussed in Section 15.5.1, is identified to be limited to the proximity of the mine workings. This is due to:

- The discontinuous nature of the surficial sediments
- The thin saturated thickness of the surficial cover
- The discontinuous nature of saturated sediments
- The restricted aquifer hydraulic properties.

Groundwater elevation contours from north (upstream) to south (downstream) along the Isaac River (green model cells) do not indicate any drawdown influence in 2024 (start of prediction periods in the groundwater model).

The mapped potential GDEs, a portion of Figure 20, is included in Figure 67. This figure includes the mapped GDEs within the mine footprint. Groundwater drawdown, compared to the initial groundwater elevations in Model Layer 1 in 2023/2024, is included in Figure 66.

The post-closure change in groundwater compared to current (2024) conditions resultant from approved mining, indicates:

- Zero (0) change along the Isaac River (green model cells)
- Drawdown immediately adjacent to the Goonyella residual void post-closure is not predicted to extend to the Isaac River
- Marked reduction in extent of drawdown around the closed mine workings due to decommissioning activities, introduction of water, and recovery of groundwater levels, which reduce the extent of drawdown.

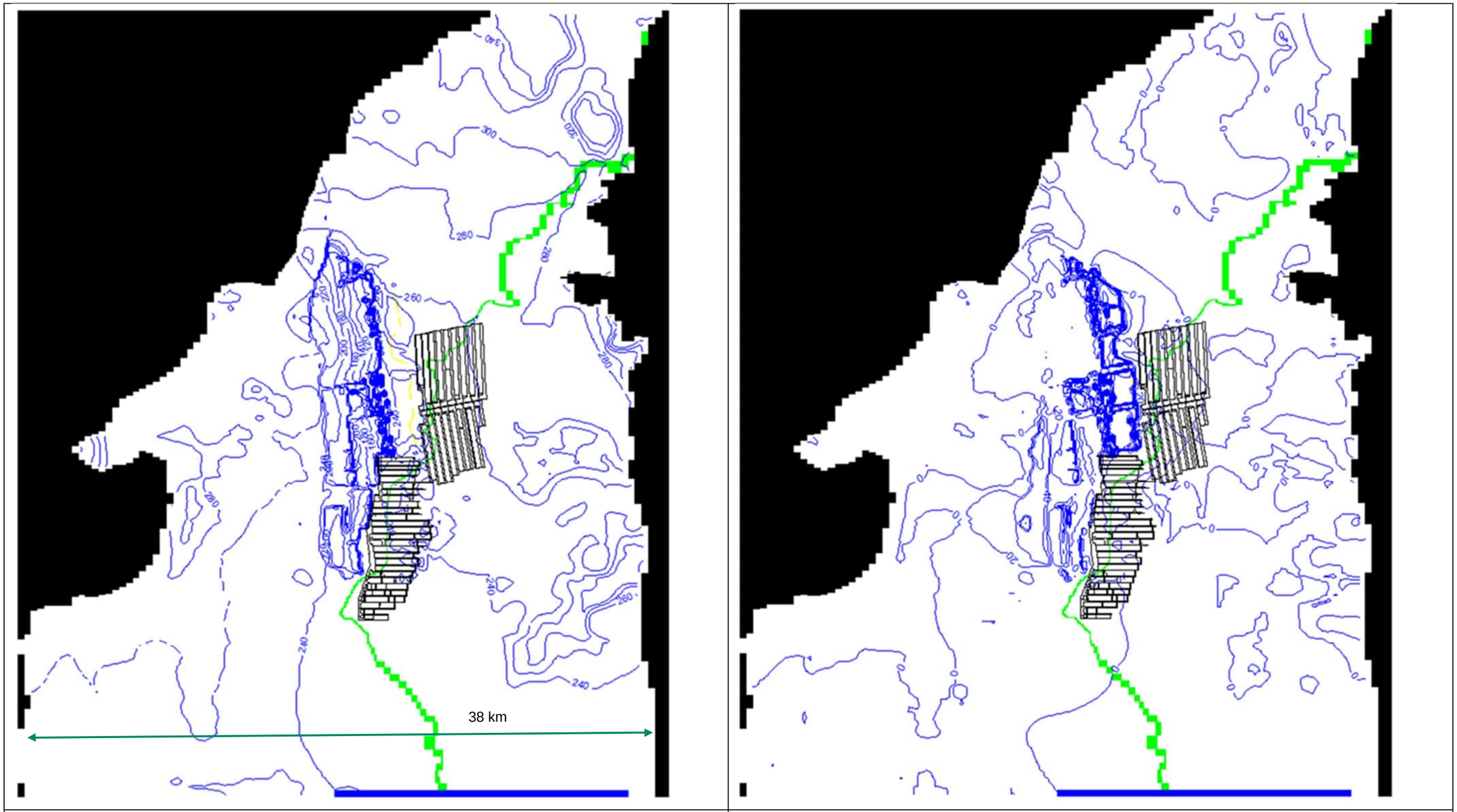
The post-closure groundwater conditions are not predicted to impact on the Isaac River GDEs and have reduced impact to potential GDEs compared to mining operations

Hypothetical water level observation points were included in the predictive model, model layer 1, along the Isaac River and at potential high potential aquatic GDEs, to aid in the assessment of water level change. The hypothetic observation points, GDE1 to GDE4, are included on Figure 67.

The hydrographs included in Plate 45 indicate:

- Stable or increasing groundwater elevation at these locations post-closure indicate no predicted impacts to the potential aquatic GDEs
- Limited natural fluctuation in groundwater levels over time (narrow range of groundwater levels)
- Water level recovery at GDE3 relates to initial water level derived during 2024 calibration correcting during the prediction periods in response to mining activities.

Figure 66 Water level change from the 2024 groundwater elevations post-closure



Initial groundwater level contours in the surficial sediments in 2024	Change in water level from the initial 2024 levels in 2199 (in m)

Green model cells are the Isaac River
Yellow model cells are the Goonyella residual void

Figure 67 Mapped GDEs within the groundwater drawdown extent Model Layer 1

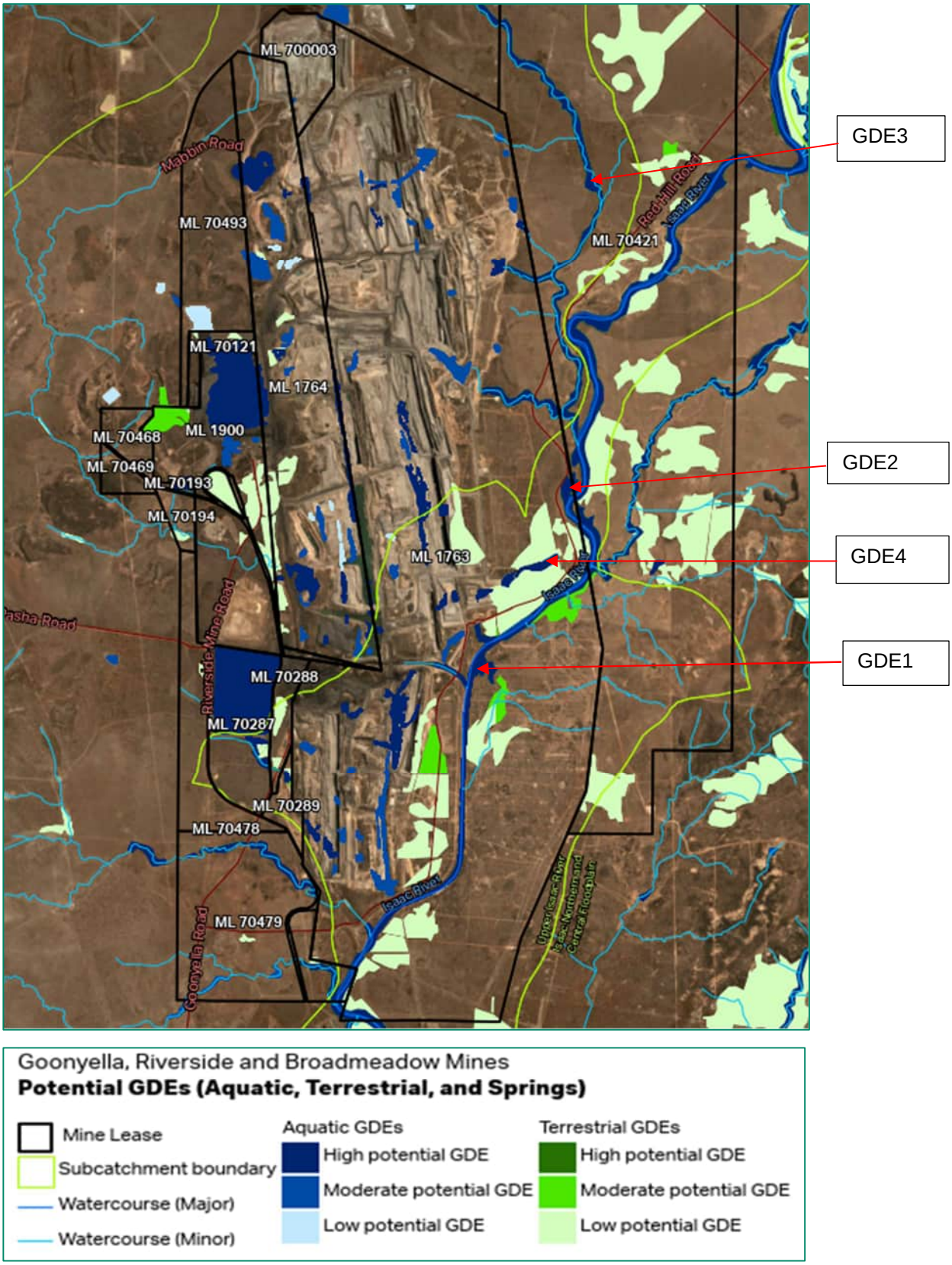
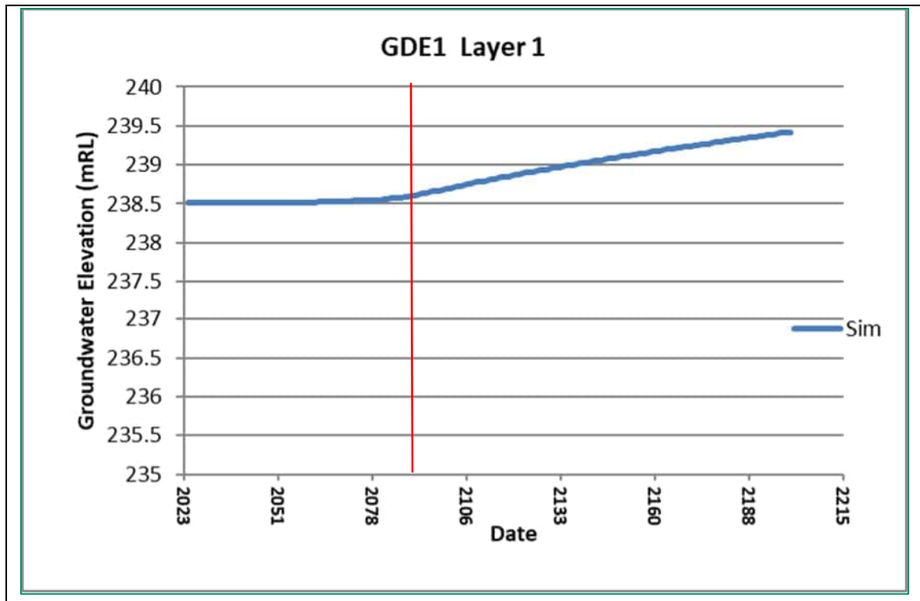
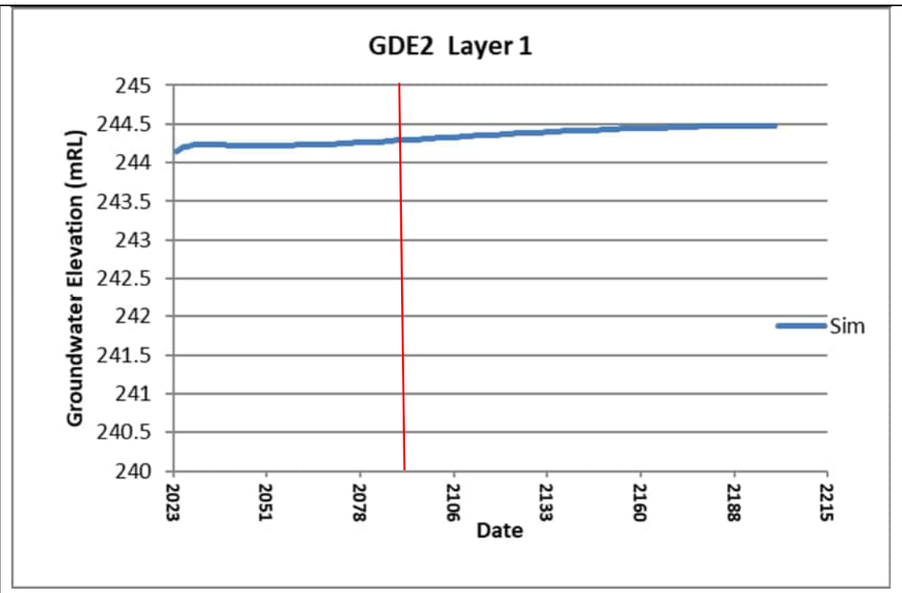


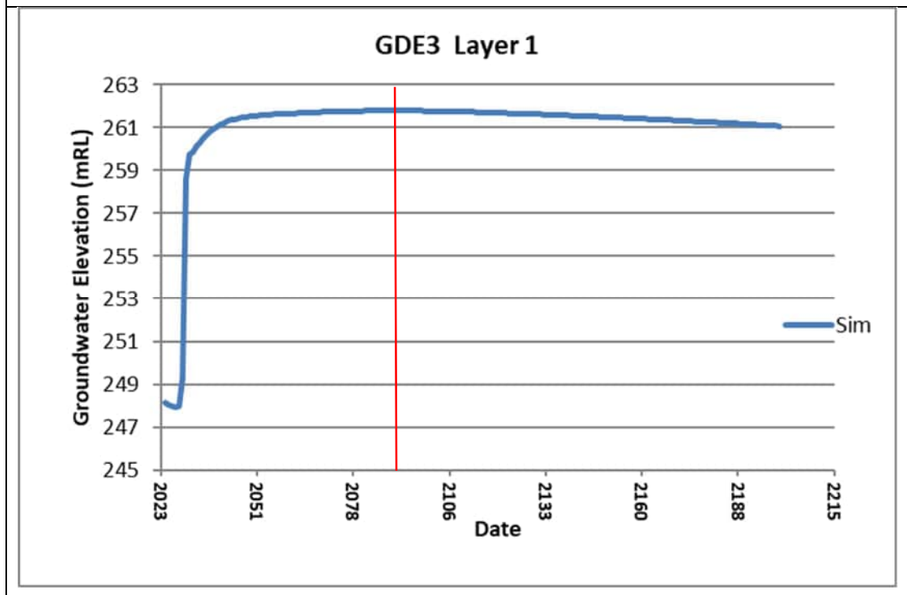
Plate 45 Hydrographs of groundwater elevation at high potential aquatic GDEs



Simulated (sim) groundwater elevation at GDE1 in the surficial cover (model layer 1)
Closure (red line) date 2097



Simulated (sim) groundwater elevation at GDE2 in the surficial cover (model layer 1)
Closure (red line) date 2097



Simulated (sim) groundwater elevation at GDE3 in the surficial cover (model layer 1)
Closure (red line) date 2097

Simulated (sim) groundwater elevation at GDE4 in the surficial cover (model layer 1)
Closure (red line) date 2097

16.0 Uncertainty analysis

16.1 Prediction uncertainty

Groundwater models are simplifications of complex natural systems and are inherently subject to uncertainty. Prediction uncertainty in groundwater modelling arises from various sources, including uncertainties in model conceptualization and parameter estimation. These uncertainties can significantly impact the reliability of model predictions and, consequently, the decision-making processes that rely on these predictions.

The conceptual model represents the understanding of the aquifer system, including its hydrogeological framework, flow processes, and interactions with surface water. Simplifications and assumptions made during the conceptualization phase can introduce uncertainty. However, the effects of alternative conceptualizations on the calibrated model were not explored in this study because the alternatives were considered limited. The current model has been built based on the best available information, including geological and hydrological data, which were deemed sufficient to represent the system conceptually.

Parameter uncertainty is a critical aspect of groundwater modelling that can significantly influence model predictions. Parameters such as hydraulic conductivity, porosity, and recharge rates are often estimated from limited field data, leading to inherent uncertainties. The spatial and temporal variability of these parameters further adds to the complexity. Given the inherent nature of parameter uncertainty, it is essential to incorporate this uncertainty into the model predictions and quantify the potential range of these predictions.

16.2 Approach to parameter uncertainty analysis

This section describes the methodology used to analyse parameter uncertainty in the groundwater model, employing PEST++ in conjunction with the Iterative Ensemble Smoother (IES) algorithm. This approach aligns with the Australian IESC guidelines for robust uncertainty assessment.

This approach provides a comprehensive analysis of parameter uncertainty by estimating posterior parameter distributions that yield an acceptable fit to the historical observations under the Bayesian framework. This method allows for the incorporation of prior knowledge and observational data to refine parameter estimates iteratively. During the iterative process, it employs ensemble-based sampling methods, similar to Monte Carlo simulations, to explore the parameter space and estimate parameter uncertainty. By generating multiple realizations of the model with different parameter combinations, it can assess the sensitivity of model predictions to parameter variations.

This process provides insights into quantifying the range of possible parameter values and assessing the uncertainty of model predictions. The results of this analysis can be used to inform decision-making processes, guide further data collection efforts, and improve the overall reliability of the groundwater model.

16.3 Ingress variation

The model calibration process, utilizing PEST++ IES, yielded multiple model realizations, each representing a unique set of parameter values that achieved a satisfactory fit to the historical observations. The goodness-of-fit for each realization was assessed using the standardized root mean squared error (SRMS), with all realizations achieving values below 10%. This indicates that the calibrated models are capable of replicating the observed data within a reasonable margin of error, providing confidence in the parameter values and the resulting predictions.

These accepted model realizations were then employed to explore the potential range of groundwater ingress into six mine pits: Broadmeadow, Issac, Thiess, R32 East, R32 South, and Goonyella. The ensemble of model predictions generated from these realizations provides a distribution of predicted ingress values for each pit. To interpret the probabilistic nature of these predictions, percentiles were calculated for each pit in every stress period (year) following the guidelines outlined in the Australian

IESC (2018) report. These percentiles translate the predicted ingress values into a likelihood of exceedance:

- <10th percentile indicates it is very likely the outcome is larger than this value
- 10th – 33rd indicates it is likely that the outcome is larger than this value
- 33rd - 67th indicate it is as likely as not that the outcome is larger or smaller than this value
- 67th - 90th indicates it is unlikely that the outcome is larger than this value
- > 90th percentile indicates it is very unlikely the outcome is larger than this value.

16.3.1 Groundwater contribution

Water balance modelling was conducted to predict pit water levels over time, the predictive groundwater modelling allowed for the estimate of groundwater contribution as detailed in Section 15.4. The groundwater contribution, compared to the surface water runoff inputs (derived from residual void water balance modelling Rev D, Section 15.4.1), was conducted based on the mean data compiled for the last 20 years. These statistics, allowing for runoff from different catchments and landcover, plus pit size (direct rainfall) is included in Table 24.

The data indicates the groundwater contribution into the mine pits has historically been around 30% or less of the total influx into the pits.

The contribution for the end of water balance modelling (31 December 2199), using the results of the coupled surface water and groundwater water balance modelling provided an estimate of groundwater contribution in 2199, as included in Table 25.

The contributions, after adopting the Landform #2.3, reduces surface water contribution. This results in the major contributor to the water balance is the groundwater ingress. The ingress contribution indicate that four of the residual voids will function as groundwater sinks. The Isaac and Thiess residual voids, with no groundwater ingress, function as sources, as recognised in Figure 58.

The daily water balance data in Table 25 indicate evaporation at each residual void is orders of magnitude higher than the total ingress during post-closure (end of 2199). This indicates that, allowing for different climate conditions and ingress uncertainty, the influx contributions to the residual voids are unlikely to exceed the evaporation outflux.

The surface water contributions over time are climate (seasonal) related and are markedly higher than the evaporation rate (a daily) basis (see examples for Goonyella Pit influx and outflux in Plate 46 and Plate 47, respectively). This, plus the depth of the residual voids (shade), allows for the development of residual void water levels and not dry residual voids.

Note: Figure 68 indicates that Landform #2.3 includes for limiting natural surface water runoff into the Goonyella Pit, where the final landform diverts clean surface water away from Goonyella Pit (as evident in the small natural catchments). This further reduces surface water ingress at closure resulting in the large change in contribution, such that groundwater comprises the majority of the influx post-closure.

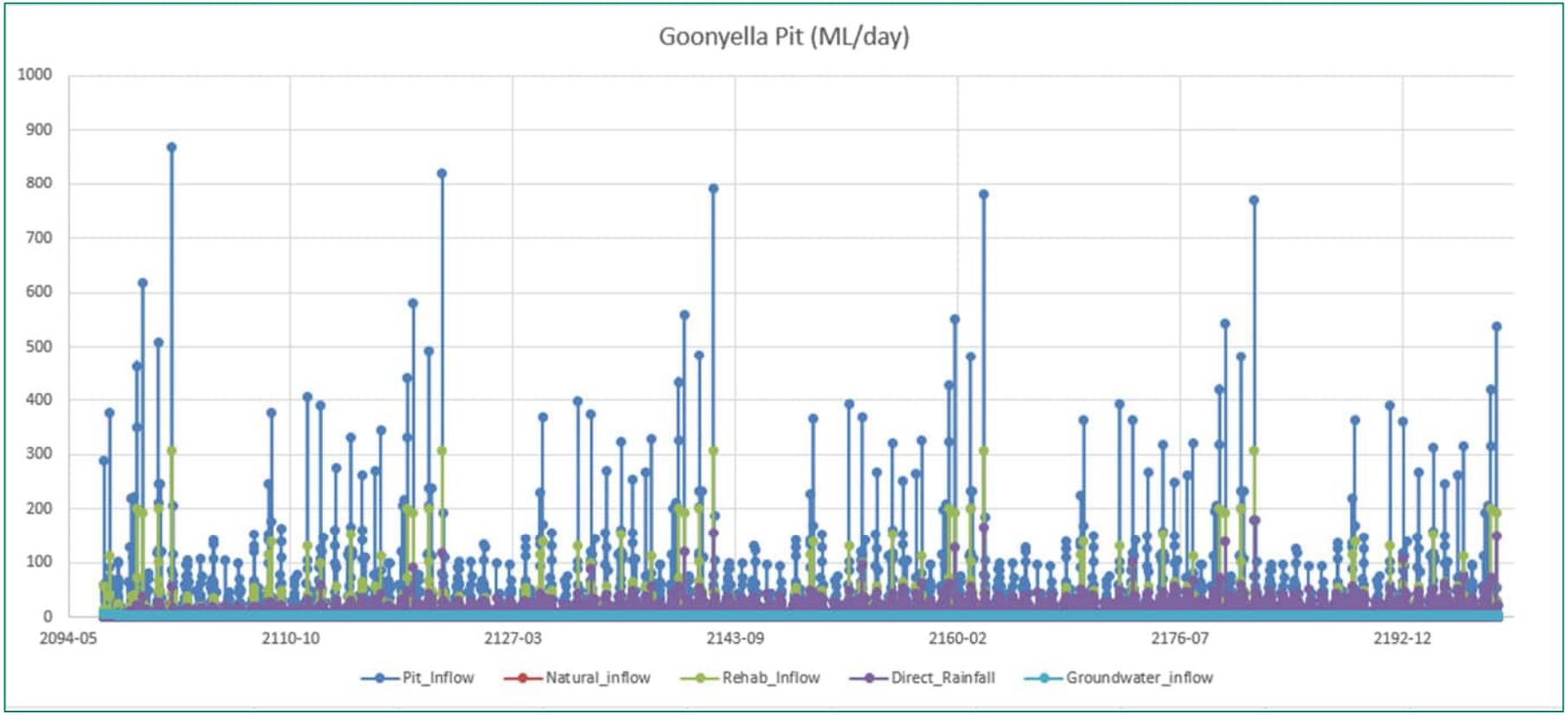
Table 24 GRB mine pit water balance data – mean for last 20 years

Mean for last 20 years	Goonyella	Broadmeadow	Isaac	R32South	R32East	Thiess
Pit Inflow (ML/day)	0.17	0.011	0.005	0.005	0.007	0.018
Natural inflow (ML/day)	0.005	0	0	0	0	0
Rehab Inflow (ML/day)	0.049	0.008	0.012	0.001	0.005	0.045
Direct Rainfall (ML/day)	0.147	0.008	0.007	0.003	0.008	0.016
Groundwater inflow (ML/day)	0.178	0.002	0	0.003	0.008	0
Groundwater outflow (ML/day)	0	0	0.002	0	0	0.0215
Evaporation Actual (ML/day)	0.53	0.029	0.022	0.012	0.029	0.058
Sum (ML/day)	**1.08**	**0.06**	**0.049**	**0.024**	**0.058**	**0.158**
%GW contribution (influx)	32.5	8.5	0.06	25	29	0

Table 25 GRB mine pit water balance data – 31 December 2199

End of P4	Goonyella	Broadmeadow	Isaac	R32South	R32East	Thiess
Pit Inflow (ML/day)	0.0287	0.0019	0.0009	0.0008	0.0012	0.0031
Natural inflow (ML/day)	0.0002	0	0	0	0	0
Rehab Inflow (ML/day)	0.0048	0.0008	0.0011	0.0001	0.0005	0.0043
Direct Rainfall (ML/day)	0.4119	0.0164	0.0223	0.0075	0.0200	0.0192
Groundwater inflow (ML/day)	3.3354	0.0474	0	0.0411	0.1647	0
Groundwater outflow (ML/day)	0	0	0.0594	0	0	0.5242
Evaporation Actual (ML/day)	15.0441	0.9299	0.6100	0.3639	0.8996	1.7333
Sum (ML/day)	**3.7809**	**0.0664**	**0.0243**	**0.0495**	**0.1865**	**0.0266**
%GW contribution (influx)	88	71	0	83	88	0

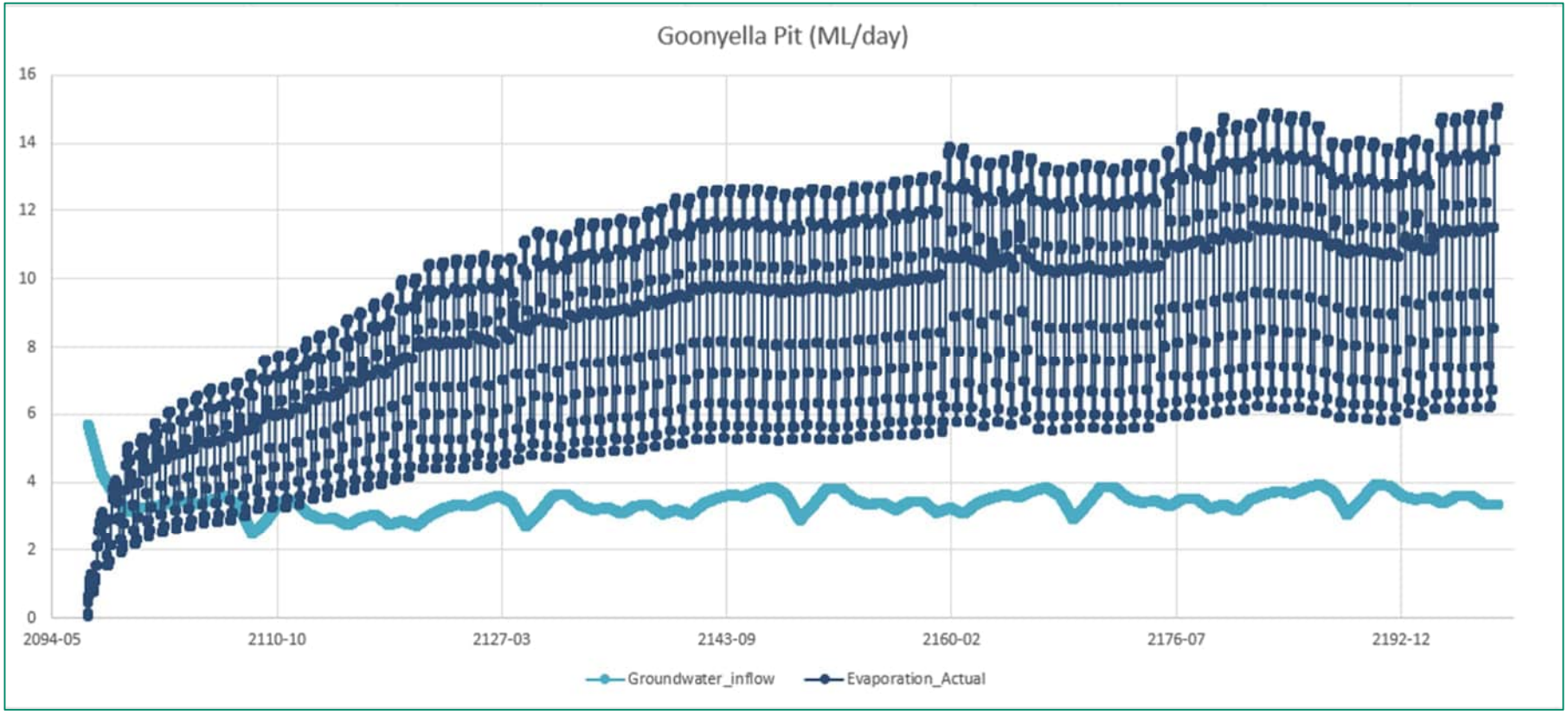
Plate 46 Goonyella Pit influx values in ML/day



The surface water influx is split into catchment areas as included in Figure 68:

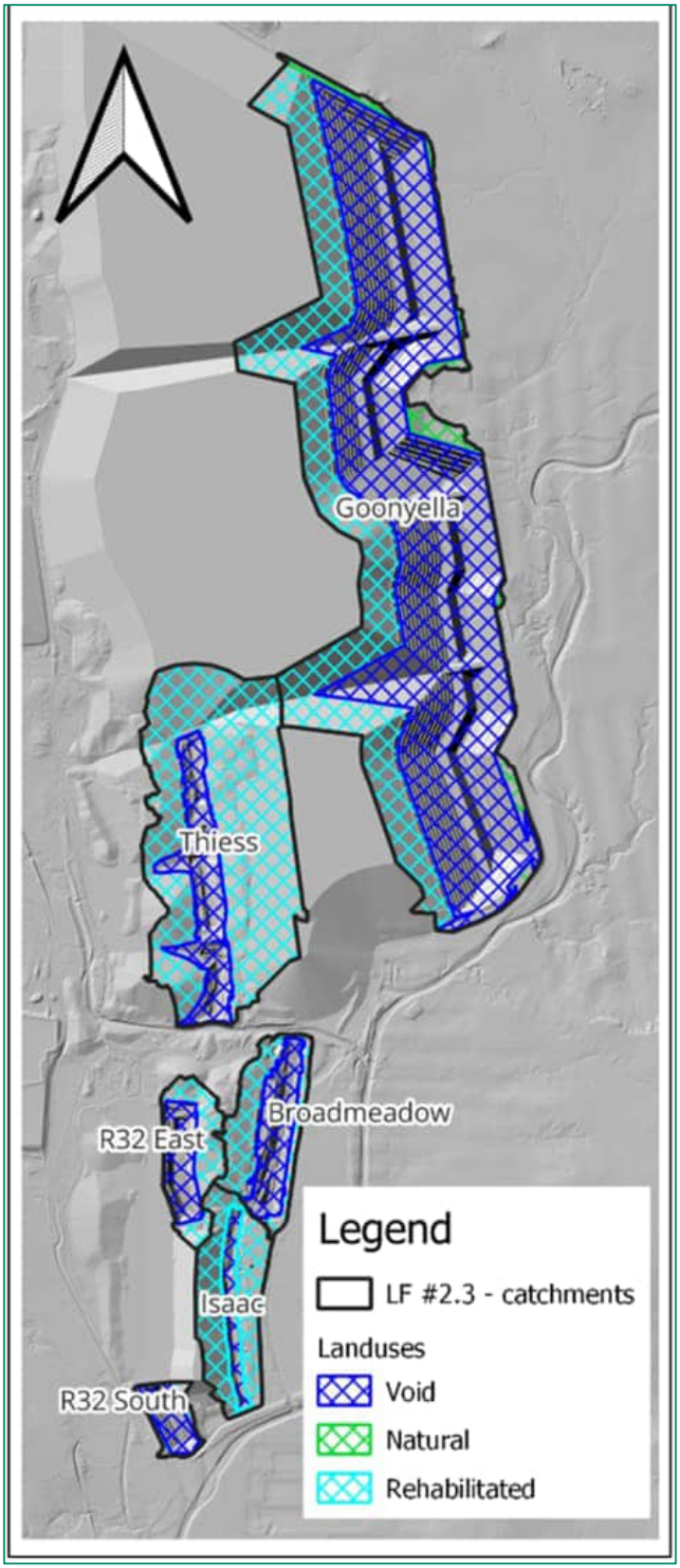
- Pit inflow from void catchments
- Natural inflow from unmined natural catchment areas
- Rehabilitated area inflow from rehabilitated catchments
- Direct rainfall into the residual voids

Plate 47 Goonyella Pit evaporation and groundwater ingress estimates on a daily basis (in ML/day)



Evaporation losses range from 0.005 to 15 ML/day

Figure 68 Catchment delineation for each catchment zone included in the water balance modelling (WSP, 2024)



16.3.2 Broadmeadow Pit

Adopting the uncertainty approach as described above in Section 16.0 a range of ingress estimates were derived through the generation of multiple realizations of the model with different parameter combinations (while the model remains within the acceptable calibration criteria). These percentiles of ingress estimates across the stress periods for Broadmeadow Pit, as included in the model, are included in Plate 48.

The base case (set of model parameters) ingress predictions fall between the 10th percentile (very likely the outcome is larger than this value) and the 90th percentile (very unlikely the outcome is larger than this value), and matches well between the narrow band of estimates derived by the 33rd and 67th percentiles. This narrow band is included in Plate 48.

The ingress estimates, leading to the estimate of the Broadmeadow Pit water level is considered suitable for input into the water balance modelling, as the base case allowed for an estimate that (between 33rd and the 67th percentiles) is not likely to be larger or smaller than these ingress estimate values.

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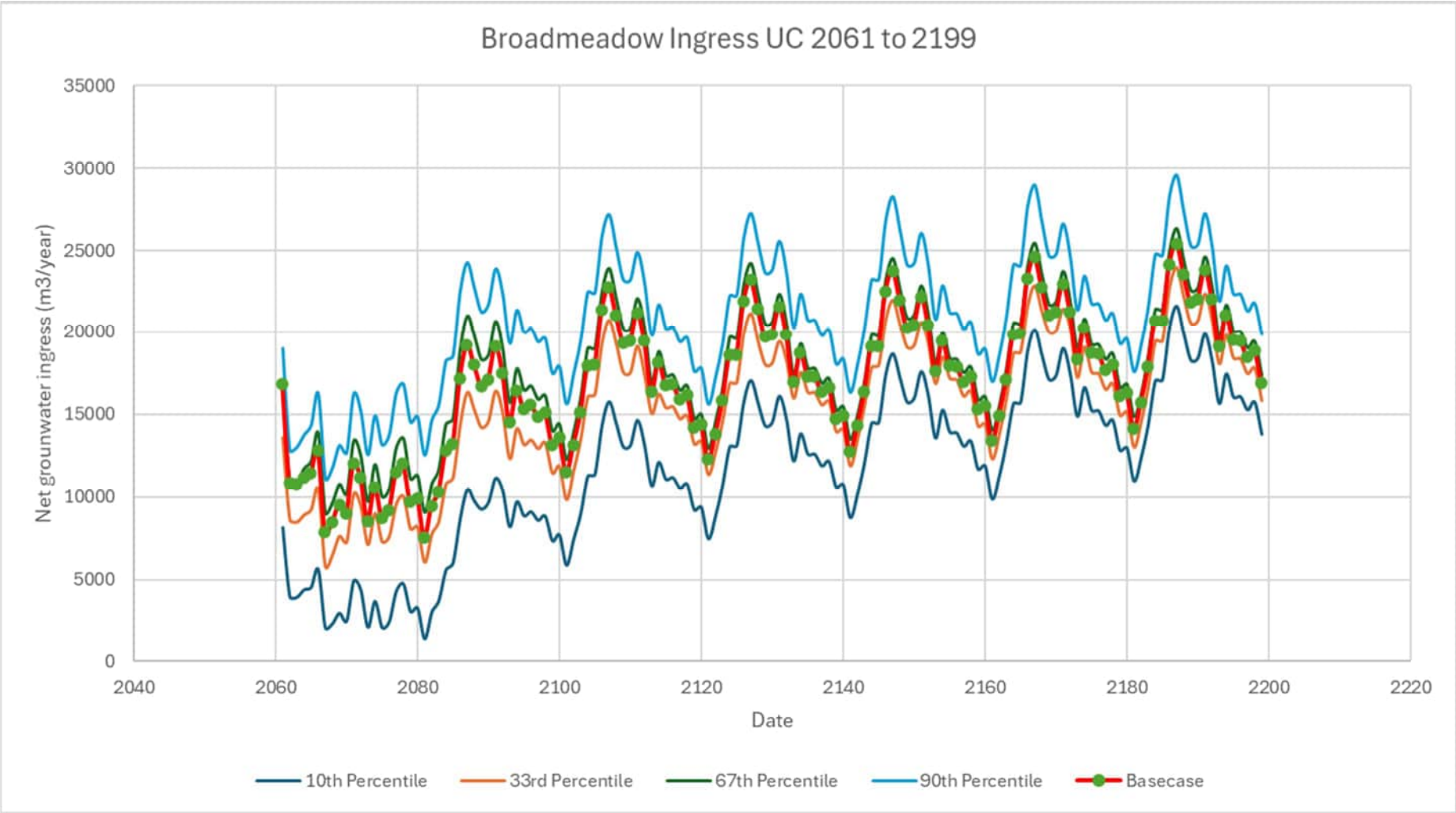
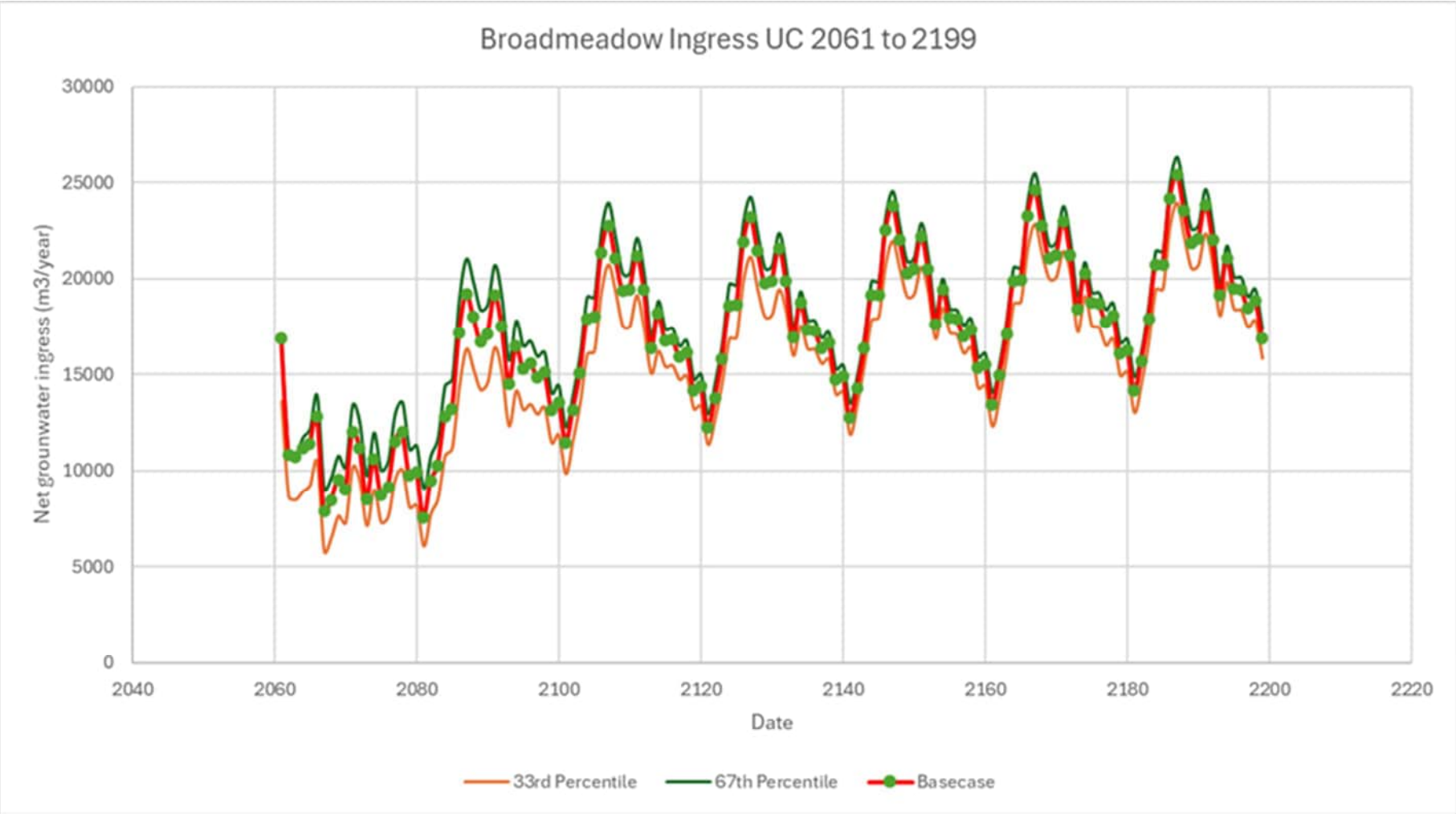
Plate 48 Uncertainty graph for Broadmeadow Pit




Broadmeadow Ingress UC 2061 to 2199
Net grounwater ingress (m3/year)
30000
25000
20000
15000
10000
5000
0
2040
2060
2080
2100
2120
2140
2160
2180
2200
2220
Date
33rd Percentile
67th Percentile
Basecase

16.3.3 Isaac Pit

Groundwater is predicted to flow out from Isaac Pit during mining, decommissioning, and post-closure, as included in Plate 49, as evident from the base case estimates using the parameters adopted in the predictive model.

The multiple realizations of the model using different parameter combinations indicated the predictions were not sensitive to the parameter changes for Isaac Pit, as evident in the narrow band of estimates (considering the 33rd and 67th percentiles).

The base case and 90th percentile are similar indicating that the groundwater outflow from the pit is likely to be lower than included in the water balance model for the Isaac Pit water level predictions.

16.3.4 Thiess Pit

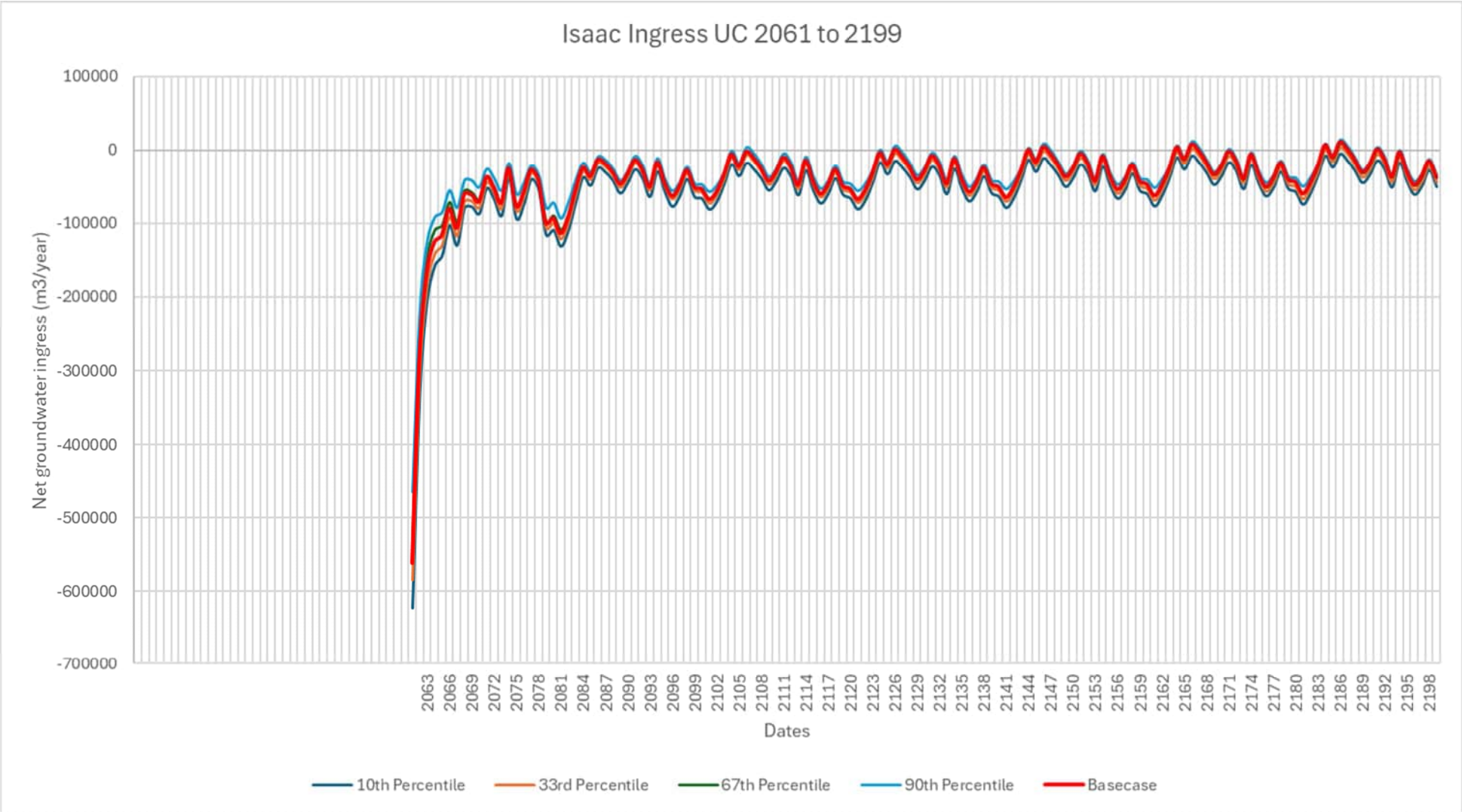
Similar to the Issac Pit , groundwater is predicted to flow out from Thiess Pit during mining, decommissioning, and post-closure, as included in Plate 49, as evident from the base case estimates using the parameters adopted in the predictive model.

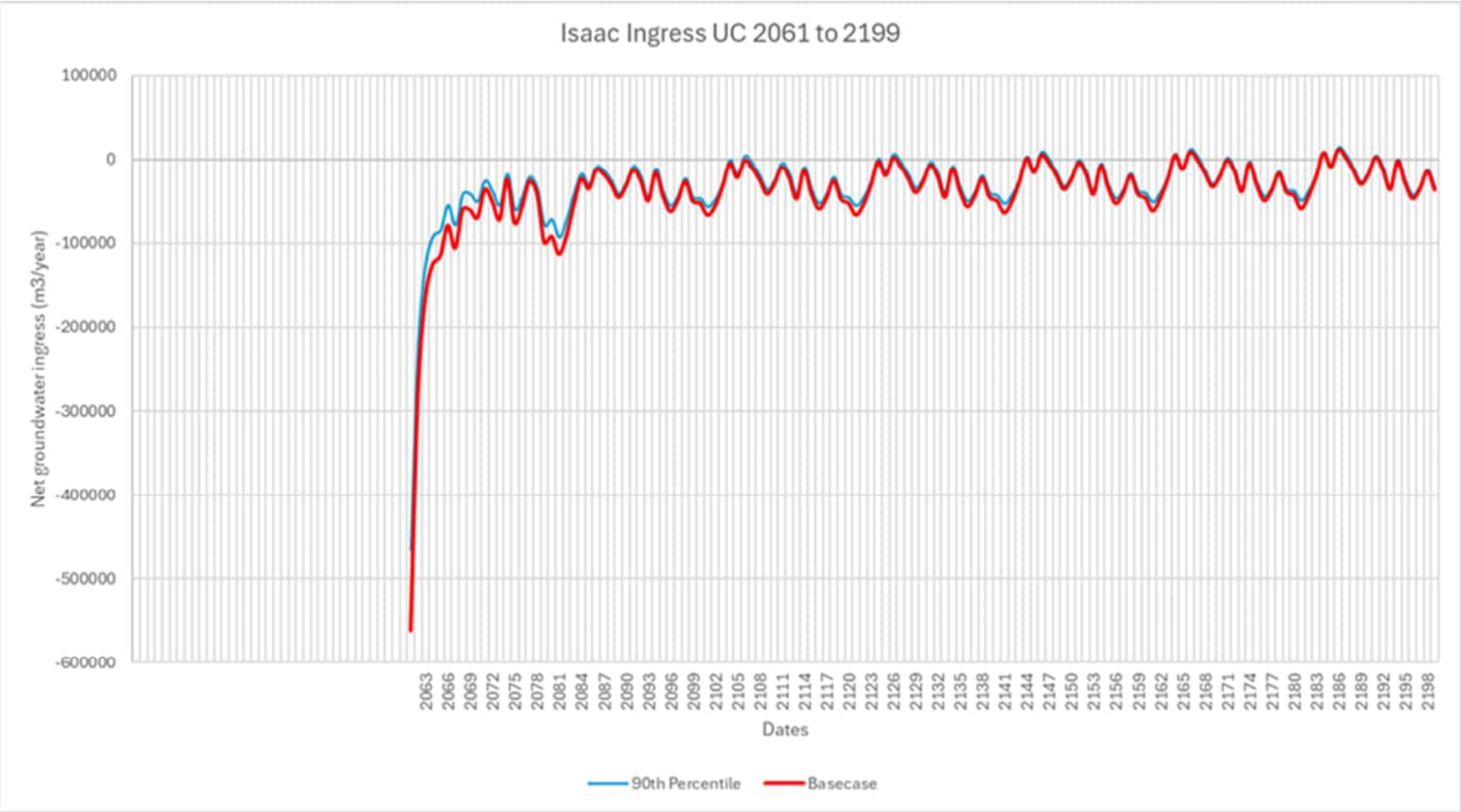
The multiple realizations of the model using different parameter combinations indicated the predictions allowed for the determination of a narrow band of estimates (all indicating groundwater loss post-closure

The base case (set of model parameters) ingress predictions is similar to the 33rd percentile results, which indicates the groundwater loss from the pit is likely to be less than these estimates (noting these are negative values).

Based on the statistics it is likely that the net ingress (loss) from Thiess Pit would be between the 33rd and 67th percentiles, which is not a marked difference.

Plate 49 Uncertainty graph for Isaac Pit




Isaac Ingress UC 2061 to 2199
100000
0
-100000
-200000
-300000
-400000
-500000
-600000
Net groundwater ingress (m3/year)
2063
2066
2069
2072
2075
2078
2081
2084
2087
2090
2093
2096
2099
2102
2105
2108
2111
2114
2117
2120
2123
2126
2129
2132
2135
2138
2141
2144
2147
2150
2153
2156
2159
2162
2165
2168
2171
2174
2177
2180
2183
2186
2189
2192
2195
2198
Dates
90th Percentile
Basecase

16.3.5 R32 East Pit

A range of ingress estimates were derived through the generation of multiple realizations of the model with different parameter combinations for Ramp 32 East. These percentiles of ingress estimates, across the stress periods for Ramp 32 East Pit, are included in Plate 51.

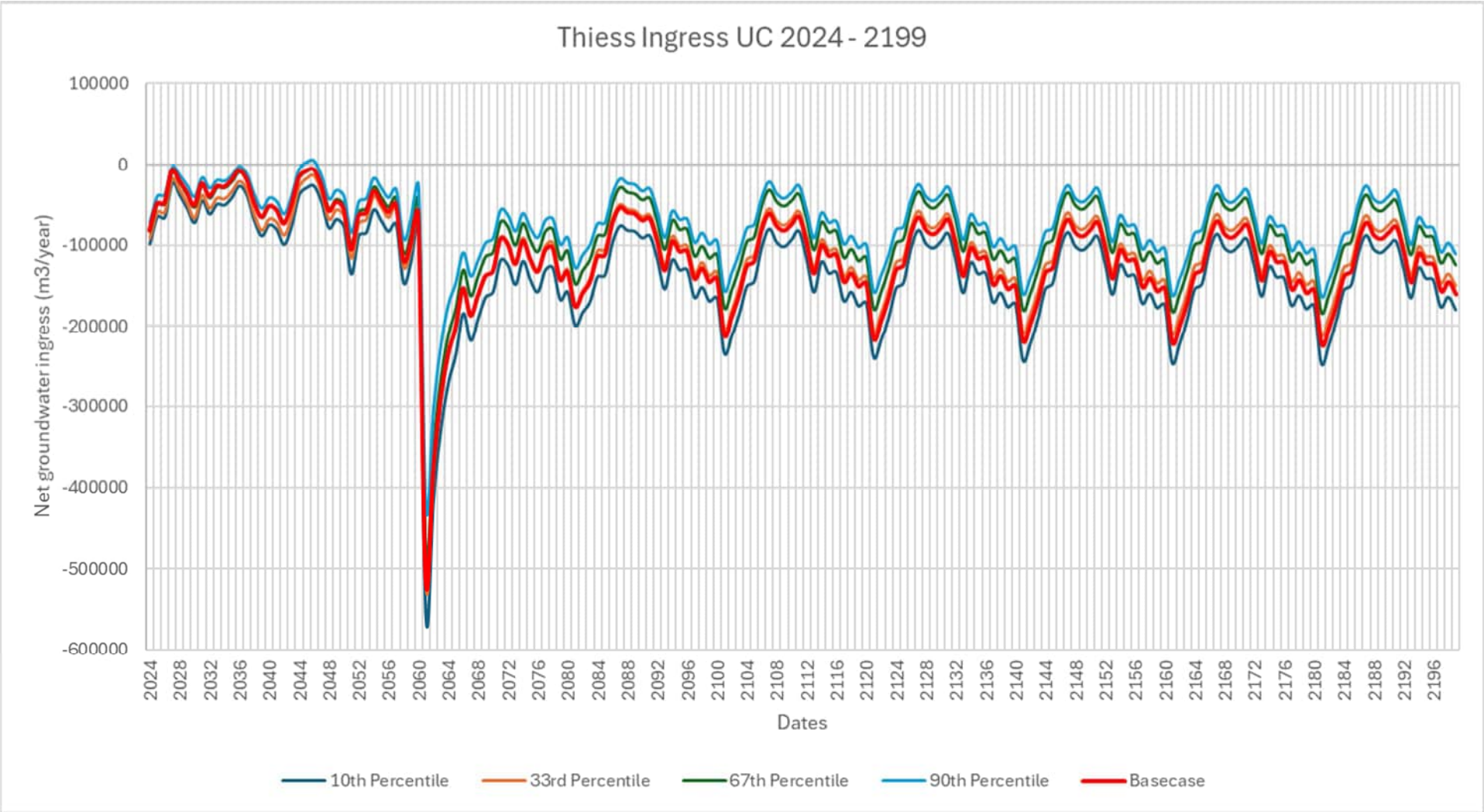
The base case (set of model parameters) ingress predictions fall between the 67th percentile and the 90th percentile (very unlikely the outcome is larger than this value). This indicates that the groundwater ingress to the pit is likely to be lower than included in the water balance model for the Ramp 32 East Pit water level predictions.

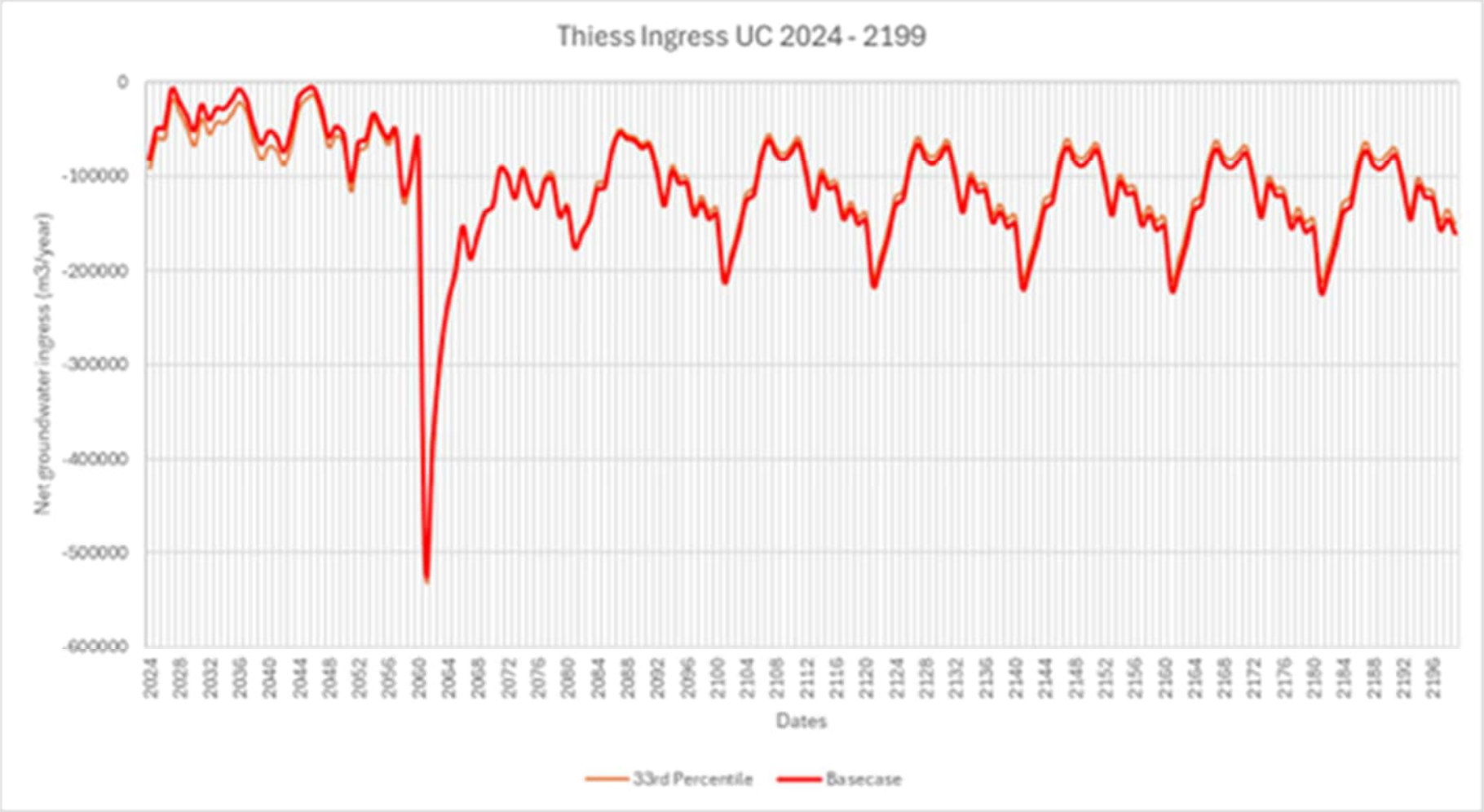
16.3.6 R32 South Pit

A range of ingress estimates were derived through the generation of multiple realizations of the model with different parameter combinations for Ramp 32 South. These percentiles of ingress estimates, across the stress periods for Ramp 32 South Pit, are included in Plate 52.

The base case ingress predictions match well with the 67th percentile results, which indicates that the estimates are likely not to be larger or smaller than these estimates.

Plate 50 Uncertainty graph for Thiess Pit




Thiess Ingress UC 2024 - 2199
0
-100000
-200000
-300000
-400000
-500000
-600000
Net groundwater ingress (m3/year)
2024
2028
2032
2036
2040
2044
2048
2052
2056
2060
2064
2068
2072
2076
2080
2084
2088
2092
2096
2100
2104
2108
2112
2116
2120
2124
2128
2132
2136
2140
2144
2148
2152
2156
2160
2164
2168
2172
2176
2180
2184
2188
2192
2196
Dates
33rd Percentile
Basecase

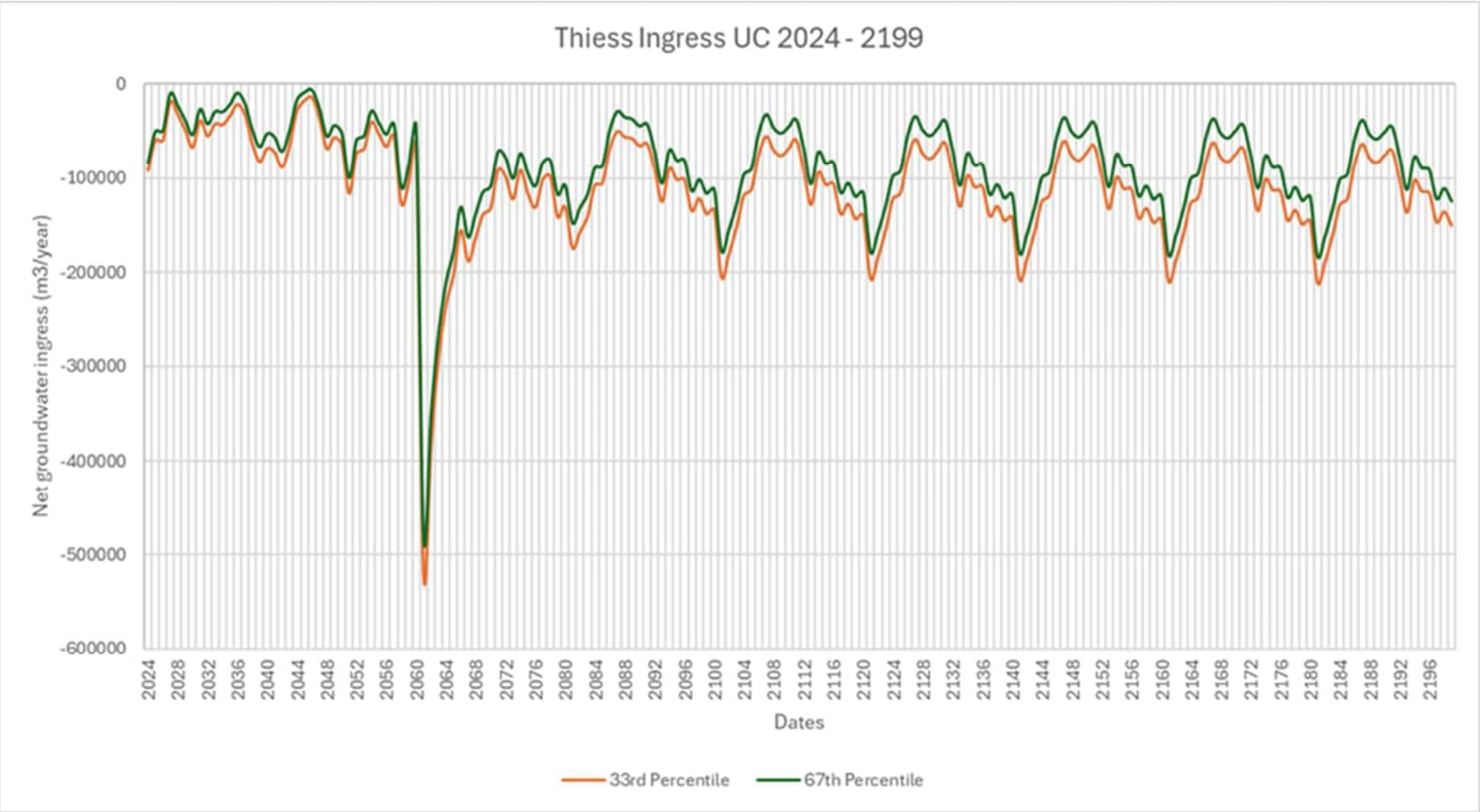
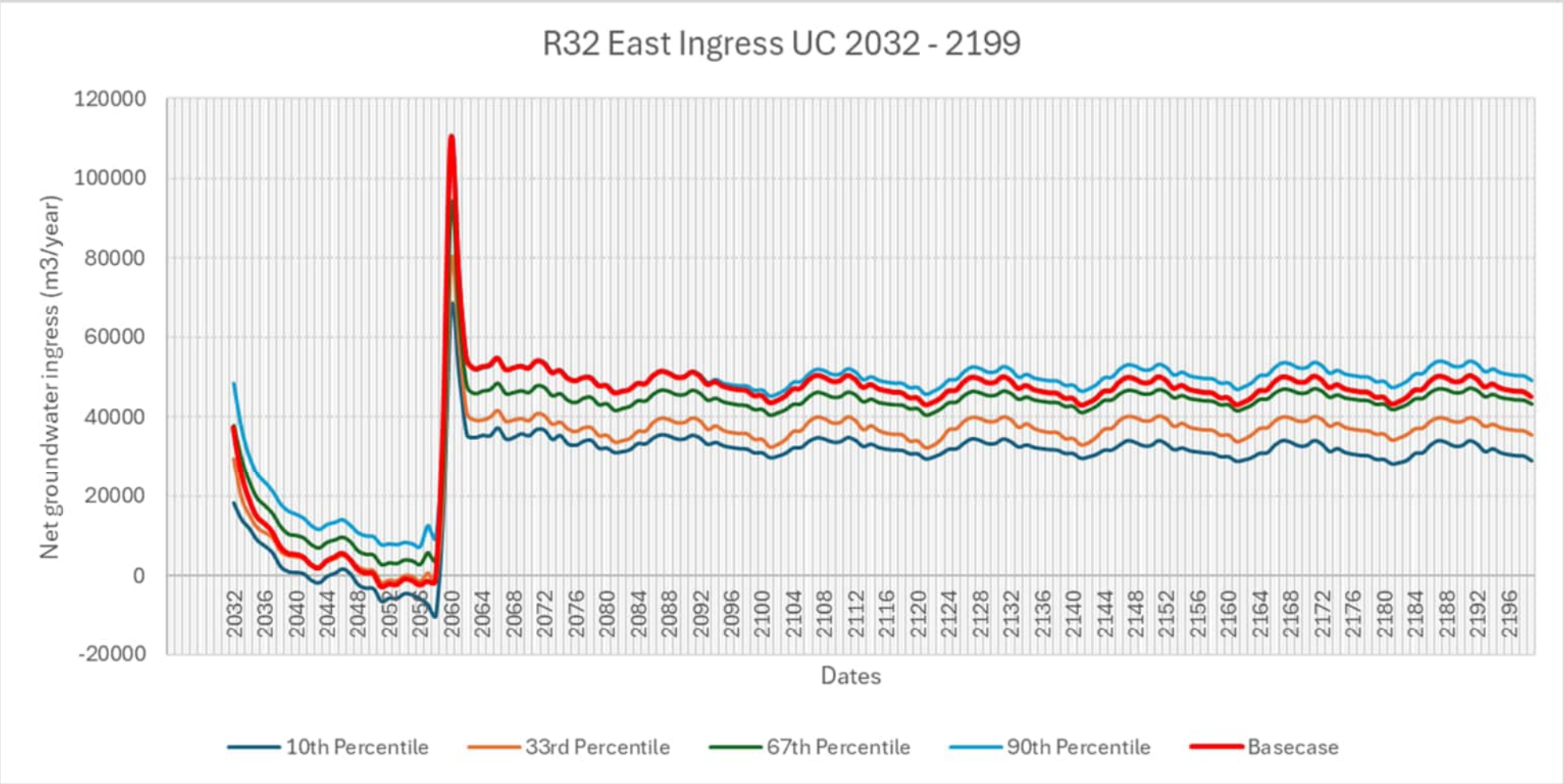

Thiess Ingress UC 2024 - 2199
Net groundwater ingress (m3/year)
0
-100000
-200000
-300000
-400000
-500000
-600000
2024
2028
2032
2036
2040
2044
2048
2052
2056
2060
2064
2068
2072
2076
2080
2084
2088
2092
2096
2100
2104
2108
2112
2116
2120
2124
2128
2132
2136
2140
2144
2148
2152
2156
2160
2164
2168
2172
2176
2180
2184
2188
2192
2196
Dates
33rd Percentile
67th Percentile

Plate 51 Uncertainty graph for R32 East Pit



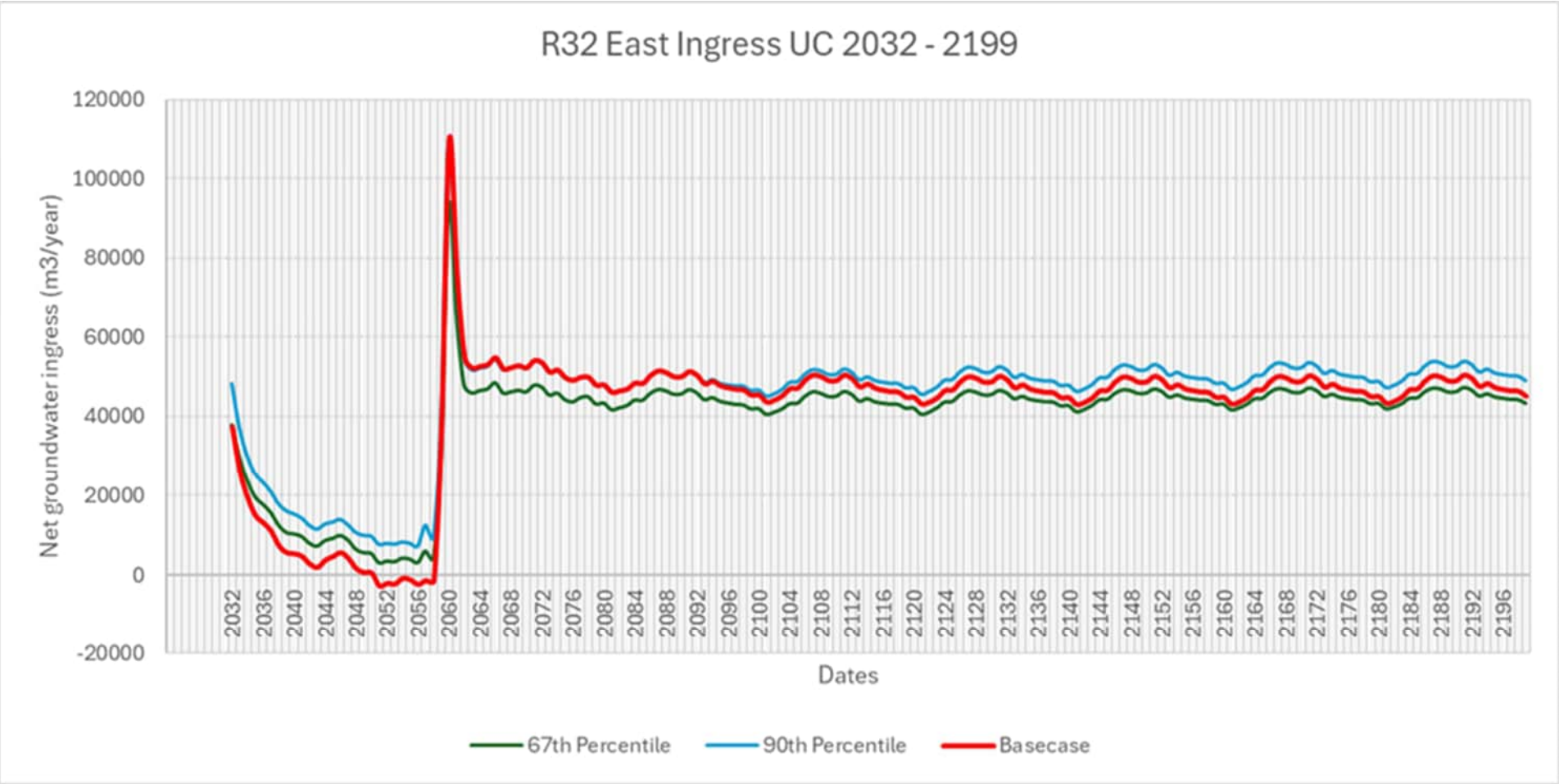
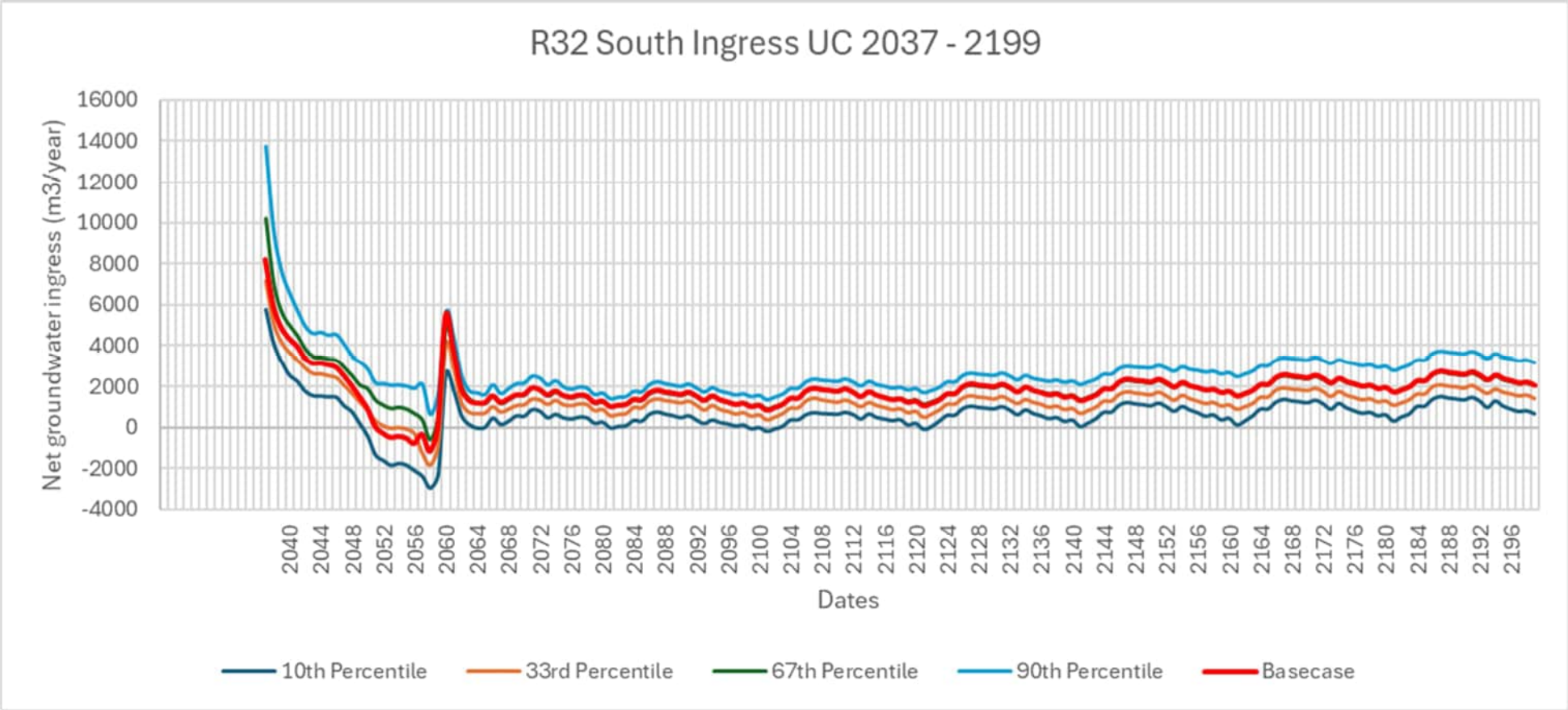

R32 East Ingress UC 2032 - 2199
Net groundwater ingress (m3/year)
120000
100000
80000
60000
40000
20000
0
-20000
2032
2036
2040
2044
2048
2052
2056
2060
2064
2068
2072
2076
2080
2084
2088
2092
2096
2100
2104
2108
2112
2116
2120
2124
2128
2132
2136
2140
2144
2148
2152
2156
2160
2164
2168
2172
2176
2180
2184
2188
2192
2196
Dates
67th Percentile
90th Percentile
Basecase

Plate 52 Uncertainty graph for R32 South Pit



16.3.7 Goonyella Pit

The uncertainty approach allowing for the quantifying of a range of possible parameter values and assessing the uncertainty of model predictions, was conducted for the Goonyella Pit. The range of groundwater ingress, in m^3/year, for the 50 realisations are presented as percentiles in Plate 53.

The base case parameter set included in the predictive modelling input into the Goonyella Pit water level modelling is recognised as conservative, where the base case is very similar to the 90th percentile of the uncertainty realisations after 2144 (see below). This indicates that the groundwater ingress volumes used in estimating the pit water level is unlikely to be larger than this value.

The base case model predictions, comprising the majority influx contribution to the residual void water balance (Section 16.3.1), is within the higher predictions from the uncertainty modelling. This implies that the pit water level may be lower than currently predicted. This indicates that the Goonyella Pit is not likely to NOT act as a groundwater sink and has negligible risk of overtopping or decant in the long term.

16.3.8 Ingress comments

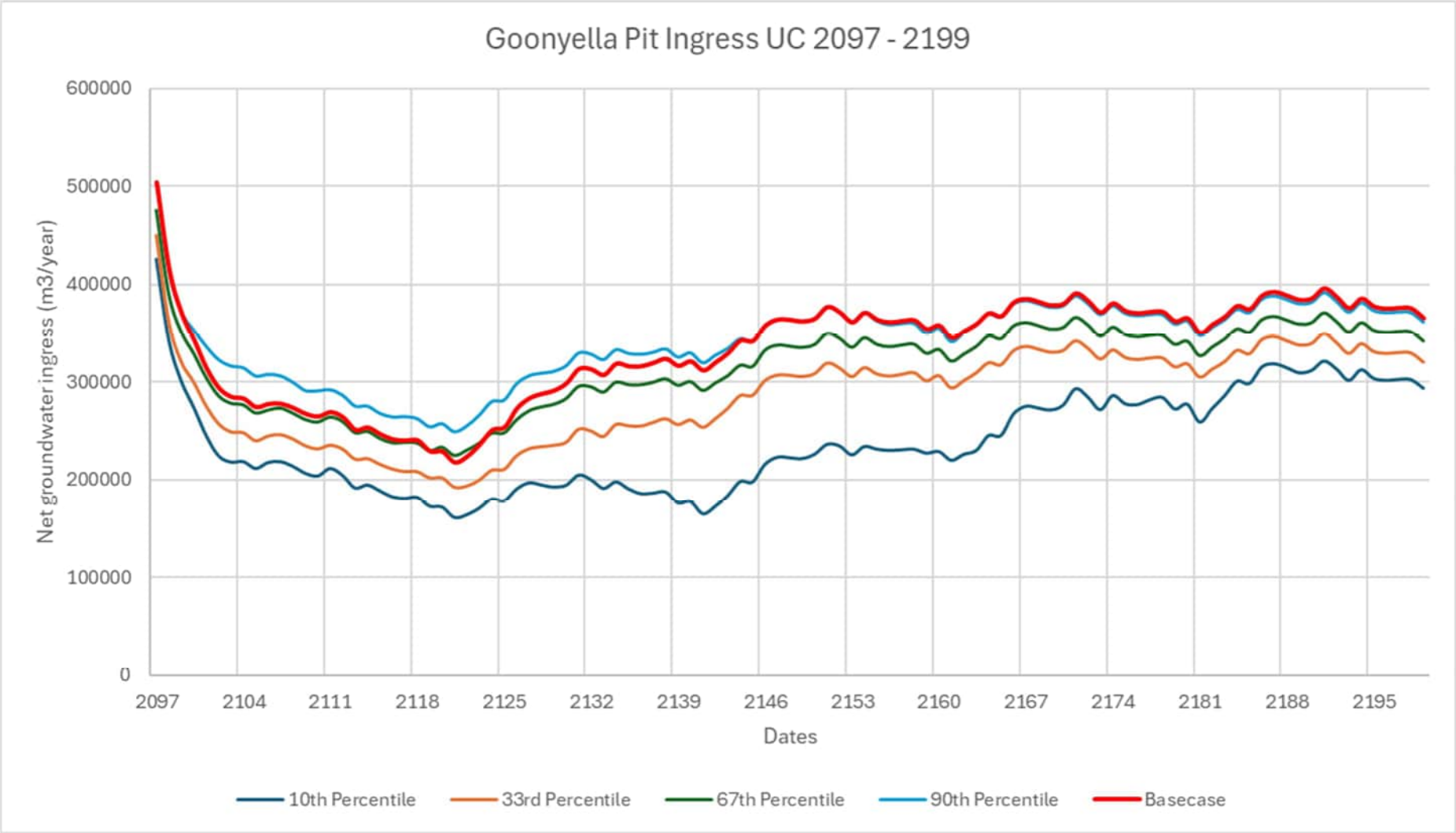
The base case parameters adopted in the groundwater model, allowing for groundwater ingress (or outflow) for the residual void water balance modelling, when considering the uncertainty analysis results allows for confidence in the predictions of pit water levels across the Project.

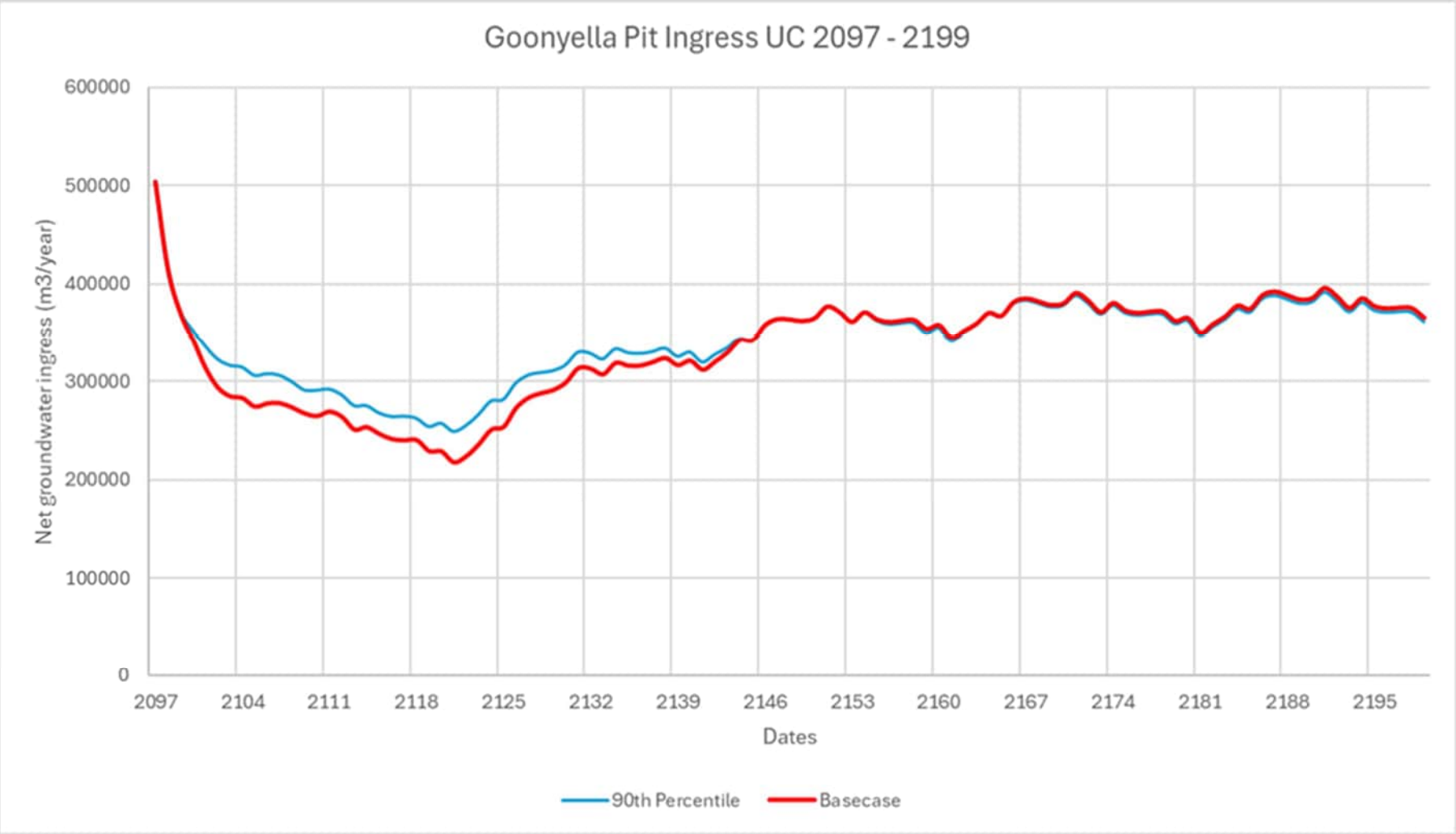
The dominant evaporation, orders of magnitude higher than the total influx estimates even when considering the upper groundwater (majority contribution) ingress estimates from the uncertainty analysis, indicate that the residual voids recognised to function as groundwater sinks will continue to do so.

The predictions of groundwater ingress into Goonyella residual void, within the higher predictions resulting from the uncertainty analysis parameter combinations, allows for confidence that the pit water level will be deep, some 20 mAHD (> 100 m deeper than other pit water levels) as detailed in Section 15.4.2.6. This deep groundwater sink influences long term groundwater flow patterns and prevents residual void and possible mine waste seepage water migration away from the Project.

The influence of the Goonyella residual void indicates there is no need for future (pit) water reduction requirements.

Plate 53 Uncertainty graph for Goonyella Pit




Goonyella Pit Ingress UC 2097 - 2199
Net groundwater ingress (m3/year)
600000
500000
400000
300000
200000
100000
0
2097
2104
2111
2118
2125
2132
2139
2146
2153
2160
2167
2174
2181
2188
2195
Dates
90th Percentile
Basecase

17.0 Conceptual Site Model – Post-Closure

17.1 Post-closure conceptual model

A conceptual model of the post-closure groundwater conditions, on completion of mining activities, rehabilitation, decommissioning, reinjection of water into the underground workings, and recovery of groundwater levels to pseudo-steady conditions is included in Figure 69, based on the end of mining CSM discussed in Section 11.0 (for open cut and underground workings) and the post-mining groundwater modelling presented in Section 13.0.

17.2 Assessment

There is no evidence from a groundwater perspective that the final landform #2.3 is unsuitable for the closure, based on an assessment of the groundwater regimes and predictive groundwater modelling.

The hydrogeological assessment identified the following key features:

- Residual void pit water level predictions, using the groundwater ingress, for the Goonyella Pit, stabilises markedly below the post-closure recovered groundwater elevations for all directly impacted hydrostratigraphic units, and below the other five residual void pit water levels. This groundwater sink effectively limits any potential poor quality water migrating away from the Project (Section 15.6 and 15.7).
- Residual groundwater drawdown within the MCM target coal seams as caused by the approved mining operations, with ongoing evaporative discharge from the residual voids, resulting in continued inwards hydraulic flow gradients in the coal measures to three of the six residual voids (Section 15.7).
    - Groundwater outflow from Thiess and Isaac pits is predicted to be captured within Goonyella Pit (Section 15.7).
    - Broadmeadow residual void is predicted to have outflow during the prediction periods, as detailed in Section 15.6. Long term stabilisation of groundwater levels and the residual void water level indicate groundwater outflow will reduce or cease in the long term (Section 16.3.1).
- The Goonyella residual void is predicted to capture any seepage from mine waste (TSF, MIA, rejects) and spoil / backfill areas, as evident in the particle tracking simulations (Section 15.7.2).
- The Goonyella residual void is predicted to influence groundwater levels within the Broadmeadow underground workings, were after water is introduced the (recovered) groundwater levels within the are predicted to decrease marginally.
    - Section 15.4.3.3 indicates that the GMS groundwater levels will increase by 200 m in 2092 (water introduced into the underground workings) from the initial 2024 groundwater elevations, this will decrease to 190 m difference in 2199 due to ingress into Goonyella residual void.
    - Section 15.4.3.4 indicates that the GLS groundwater levels will increase by 60 m in 2092 (water introduced into the underground workings) from the initial 2024 groundwater elevations, this will decrease to 50 m difference in 2199 due to ingress into Goonyella residual void.
- Little to no additional impact on surficial aquifers including the Isaac River alluvium caused by the PRCP Plan's final landform (15.5.1 and 15.8.2).
- Little to no impact on environmental (GDEs) receptors caused by the PRCP Plan's final landform (Section 15.8).
- The continuous removal of groundwater in perpetuity from the Goonyella residual void indicates that groundwater levels in proximity to the residual void will not recover.

- A single water supply bore, in proximity to the Goonyella Pit, will become dry as a result of approved mining. No anthropogenic receptors are identified to be impacted by the PRCP Plan's final landform (Section 15.8.1).

17.3 Source-Pathway-Receptor Analysis

A graphical representation of the CSM in source-pathway-receptor (SPR) format, with particular focus on the post-mining period, is presented as Figure 70.

The groundwater assessment for the PRC Plan does not identify a complete exposure pathways from the sources to water supply bores and ecological receptors. The Isaac River alluvium is not affected by drawdown and recharged from losing streams not the sources listed. The only water source bore identified to be affected is located in proximity to the Goonyella Pit highwall. This bore will be impacted by approved mining and is therefore not predicted to be impacted due to mine closure.

Figure 69 Post-closure conceptual model for the Goonyella Pit and underground workings

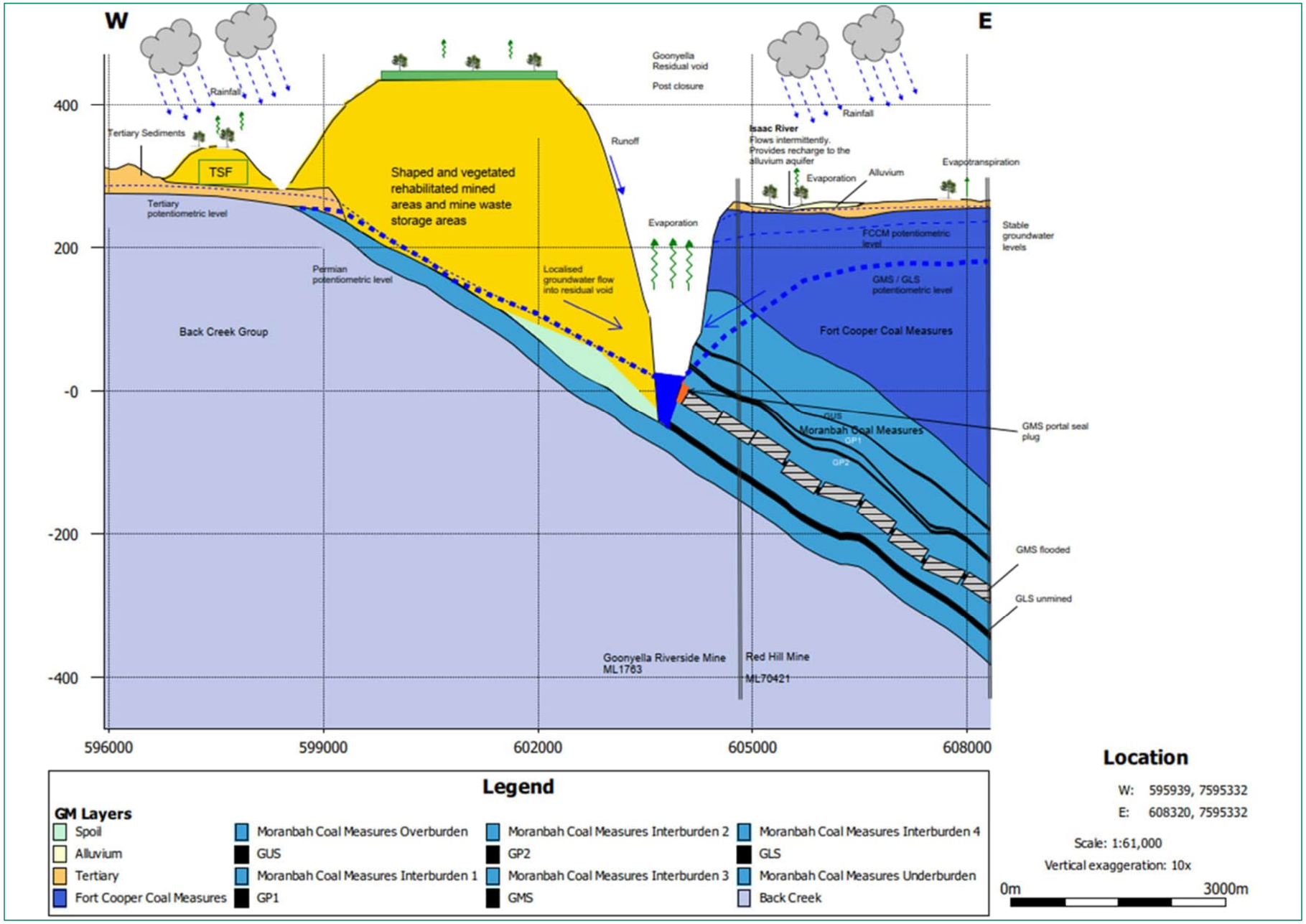


Figure 70 Source-Pathway-Receptor pathways post-closure

	Primary Sources		Secondary Sources		Transport Mechanisms		Exposure Pathways		Exposed Population
X	Residual Voids	X	Mine altered groundwater	X	Groundwater transport	X	Groundwater extraction		Water supply
X	Spoil / backfill areas					X	GDEs use		Industrial
X	MIA						Baseflow to surface water		Agricultural
X	TSF & Reject dumps								Ecological
X	Mine water storage		Surface water						
		X	Impacted soil, sediment	X	Leaching				

X - Potential

0 - Not applicable

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Appendix A

Red Hill Mining Groundwater Modelling

Report

Red Hill Mining Lease EIS

Groundwater Impact Assessment

24 SEPTEMBER 2013

Prepared for
BM Alliance Coal Operations Pty Ltd

42627136

URS

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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

1

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;

- 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.

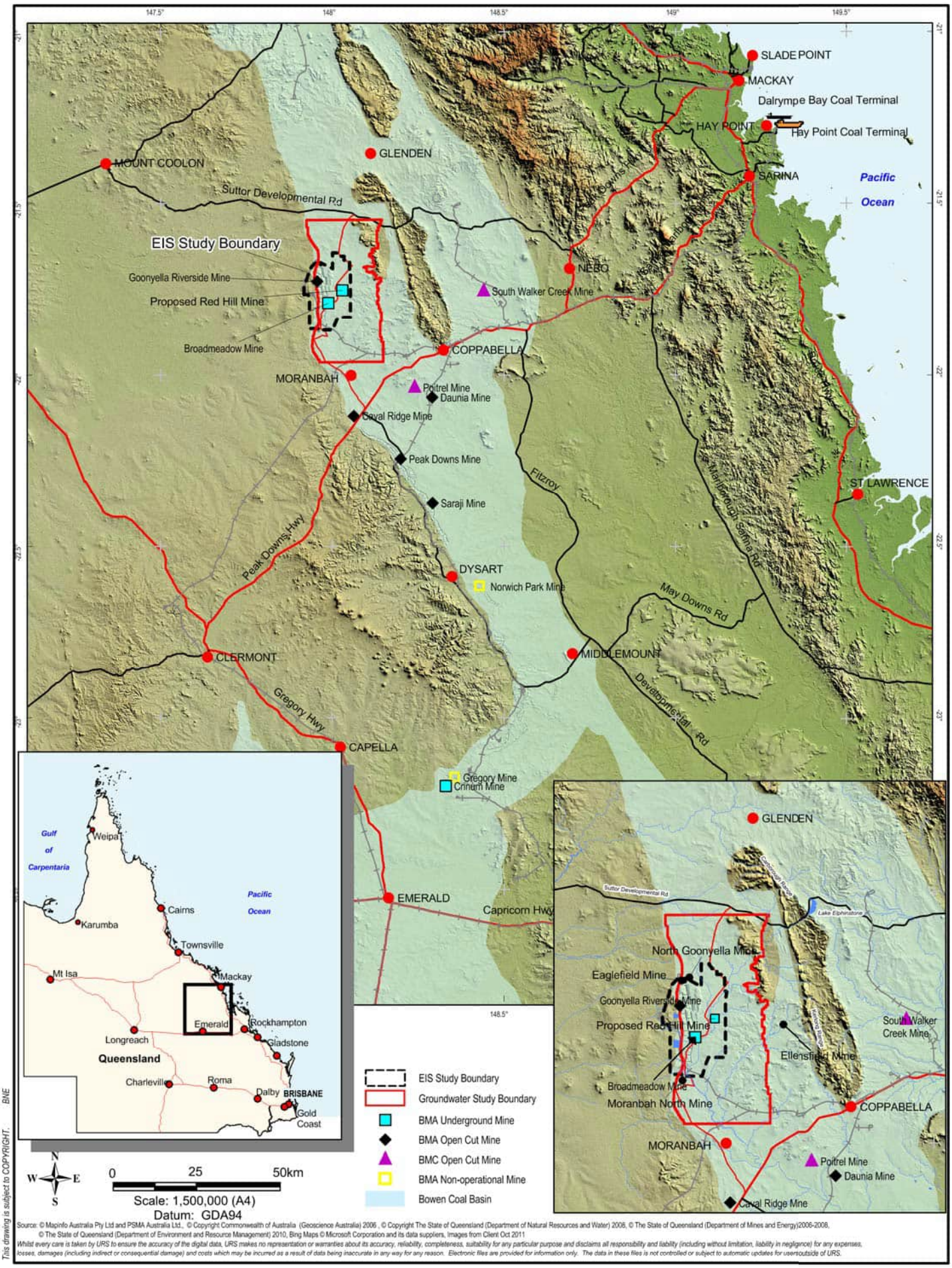
This standalone technical report provides details of an assessment of potential groundwater impacts associated with the proposed project, and includes recommended mitigation measures and monitoring protocols.

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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BHP Billiton Mitsubishi Alliance

RED HILL MINING LEASE
GROUNDWATER IMPACT ASSESSMENT

SURVEY AREA LOCALITY

URS

GROUNDWATER

Figure: **1-1**

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2

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.

3

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).

4 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)

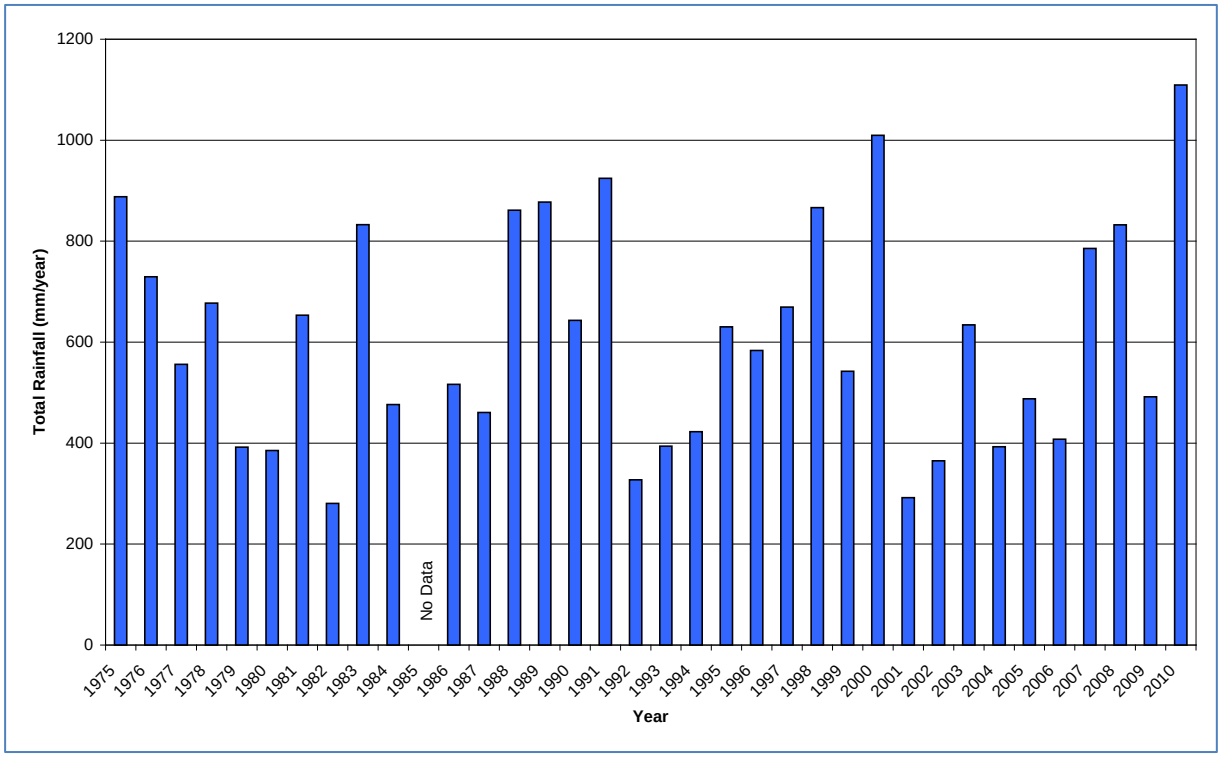
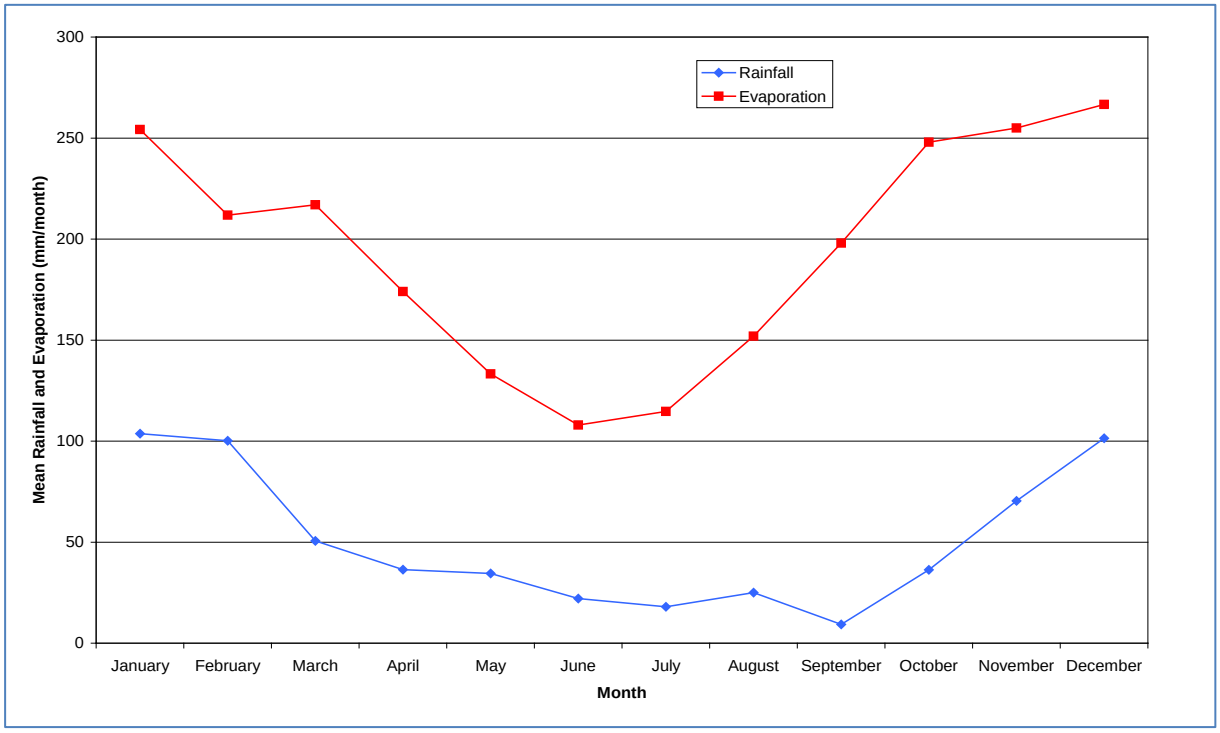


Chart 4-2 Mean Monthly Rainfall and Evaporation at the Moranbah Monitoring Station (BoM station no: 034038, 1986 to 2010)



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.

5

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.

5 Geological Setting

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
Tertiary		Suttor Formation				Clay, silts, sand, gravel, colluviual 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	Bowen Basin	Blackwater Group	Rangal Coal Measures		Sandstone, siltstone, mudstone, coal, tuff, sandstone	100 m	Outcrops or subcrops in the majority of the survey area
Permian	Late	Bowen Basin	Blackwater Group	Fort Cooper Coal Measures	Burngrove Formation	Mudstone, siltstone, sandstone, coal, tuff	400 m	Outcrops or subcrops in the majority of the survey area
Permian	Late	Bowen Basin	Blackwater Group	Fort Cooper Coal Measures	Fair Hill Formation	Labile sandstone, quartzose sublabile sandstone, siltstone, mudstone, calcareous and tuffaceous sandstone, volcanic conglomerate, carbonaceous mudstone, coal	400 m	Outcrops or subcrops in the majority of the survey area
Permian	Late	Bowen Basin	Blackwater Group	Moranbah Coal Measures		Quartzose to sublabile, locally argillacoues sandstone, siltstone, mudstone, carbonaceous mudstone and coal	250 m	Outcrops or subcrops in the majority of the survey area
Permian	Early to Middle	Bowen Basin	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	Basement	Silver Hills Volcanics			Rhyolite, dacite, rhyolitic ignimbrite, volcaniclastic sediments, sinter, minor sandstone and siltstone	Unknown in survey area	Outcrops west of the survey area and is inferred to form basement under the Bowen Basin in the mine areas
Proterozoic		Basement	Anakie Metamorphic Group			Siltstone, fine sandstone, phyllite, schist, commonly cleaved and multiply deformed	Unknown in survey area	Outcrops west of the survey area and is inferred to form basement under the Bowen Basin in the mine areas

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

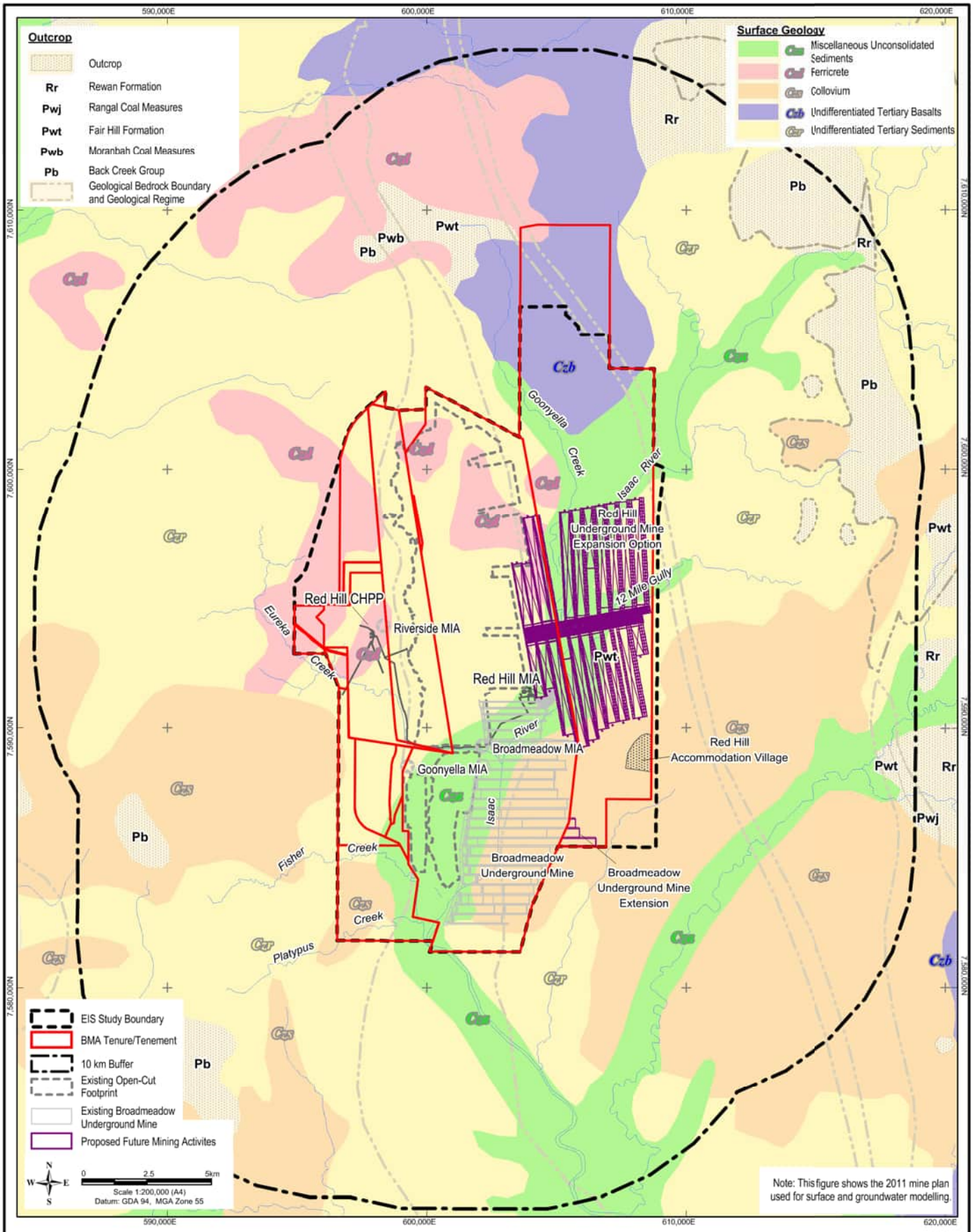
The mid-Tertiary Suttor Formation and its equivalents occur throughout the region, though outcrop is not continuous, and much of the Tertiary sequence is concealed by younger alluvium and colluvium. These strata consist of basalt, clay, silt, sand, weakly cemented sandstones, lignite and laterites. The 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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SURFACE GEOLOGY OF THE SURVEY AREA

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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,

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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TYPICAL GEOLOGICAL CROSS SECTION

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Figure: **6-1**

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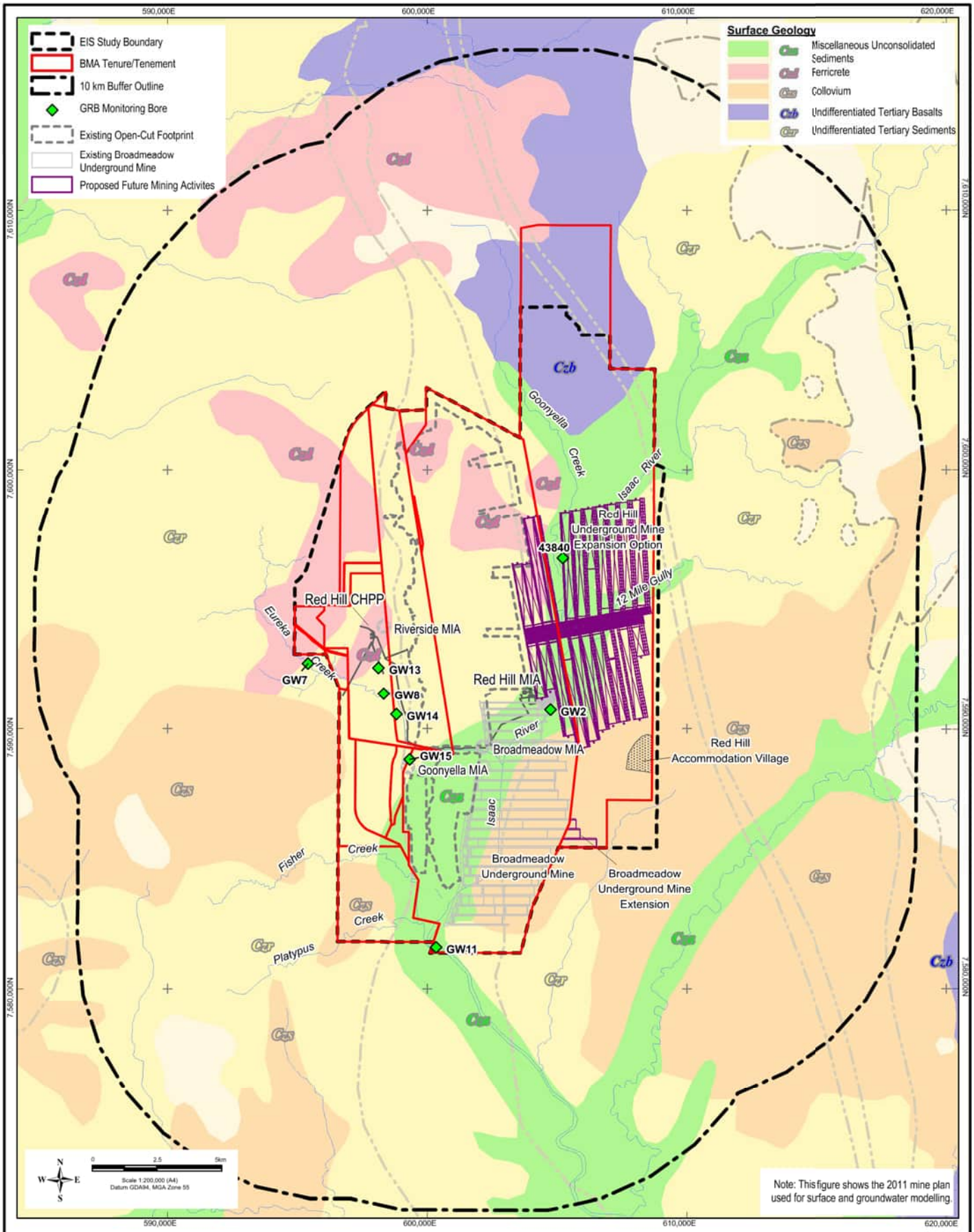

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GROUNDWATER IMPACT ASSESSMENT

QUATERNARY AND TERTIARY FORMATIONS WITHIN AND SURROUNDING THE EIS STUDY AREA

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Figure: **6-2**

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6 Hydrogeological Regime

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.

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.

6 Hydrogeological Regime

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.

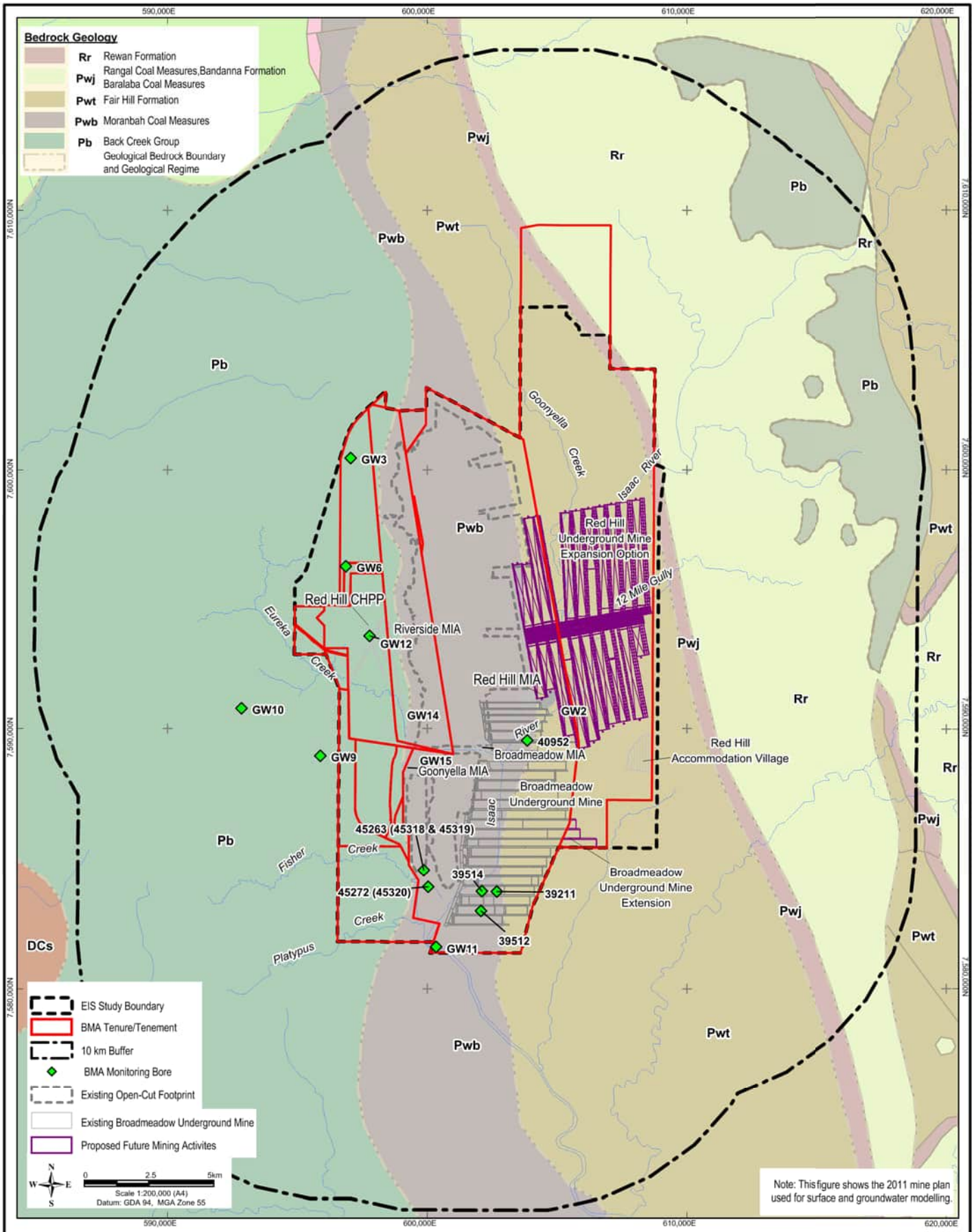
A relationship was determined for permeability variation with depth, ash, and gas content as part of this study. This relationship is:

- 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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PERMIAN AND TRIASSIC FORMATIONS WITHIN AND SURROUNDING THE EIS STUDY AREA

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Figure: **6-3**

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6 Hydrogeological Regime

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.

6 Hydrogeological Regime

Chart 6-1 Histogram of Airlift Yields of Exploration Bores

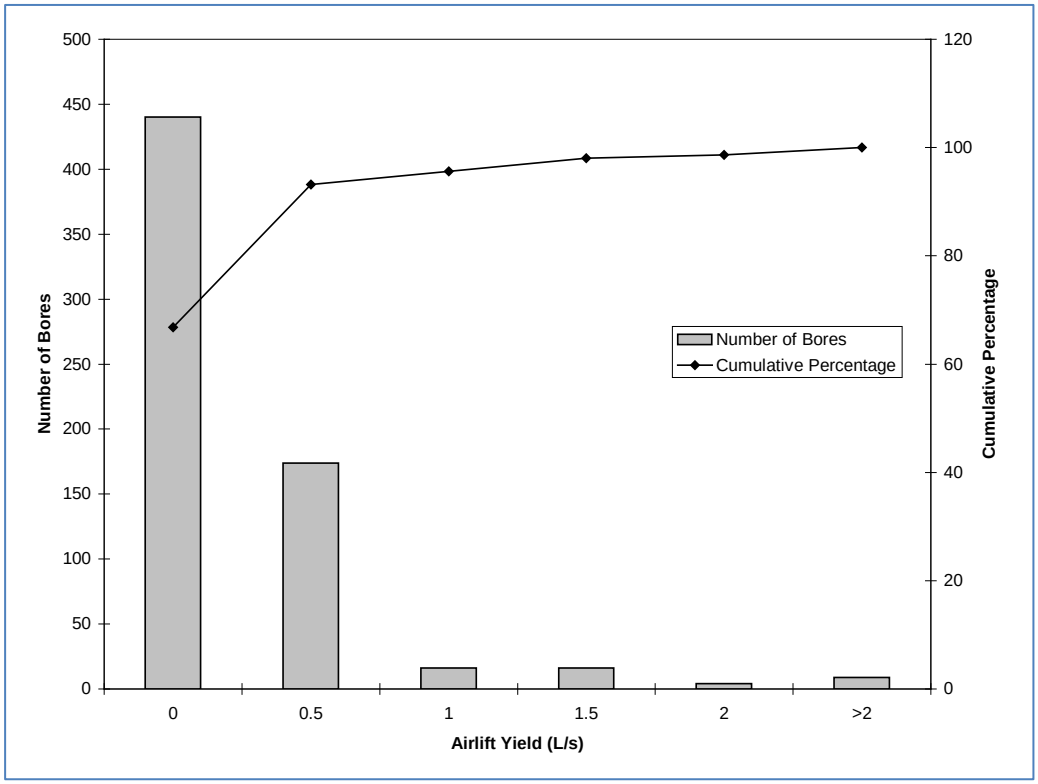
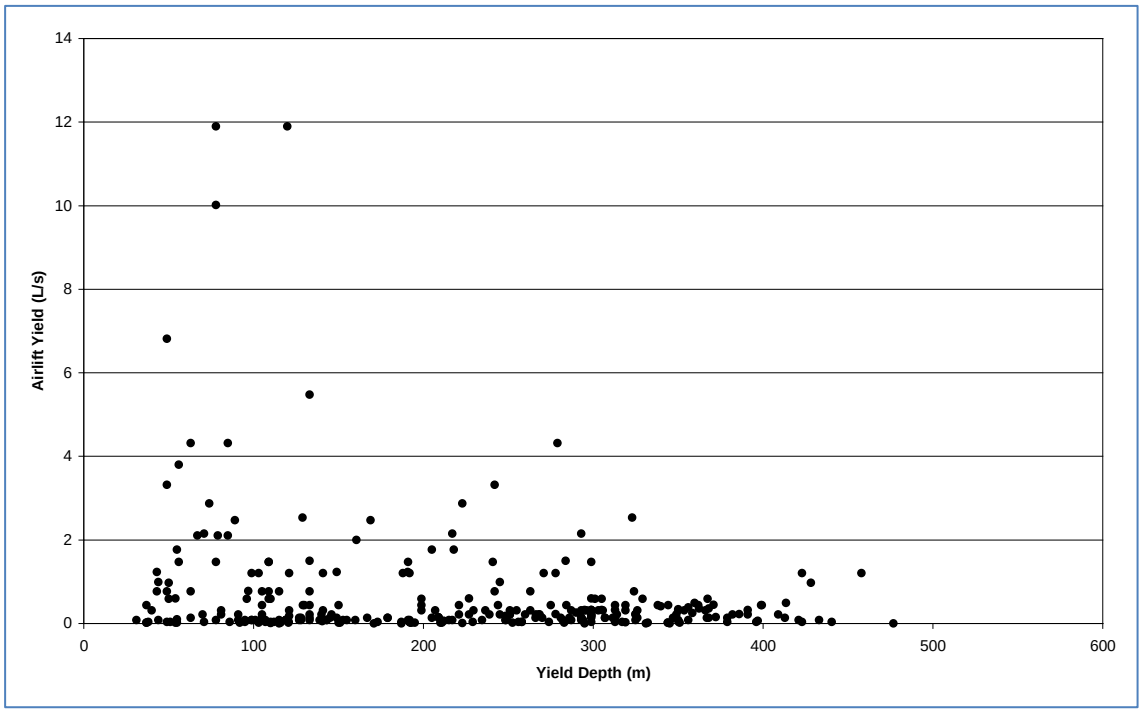


Chart 6-2 Airlift Yield and Airlift Depth for Exploration Bores



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

6 Hydrogeological Regime

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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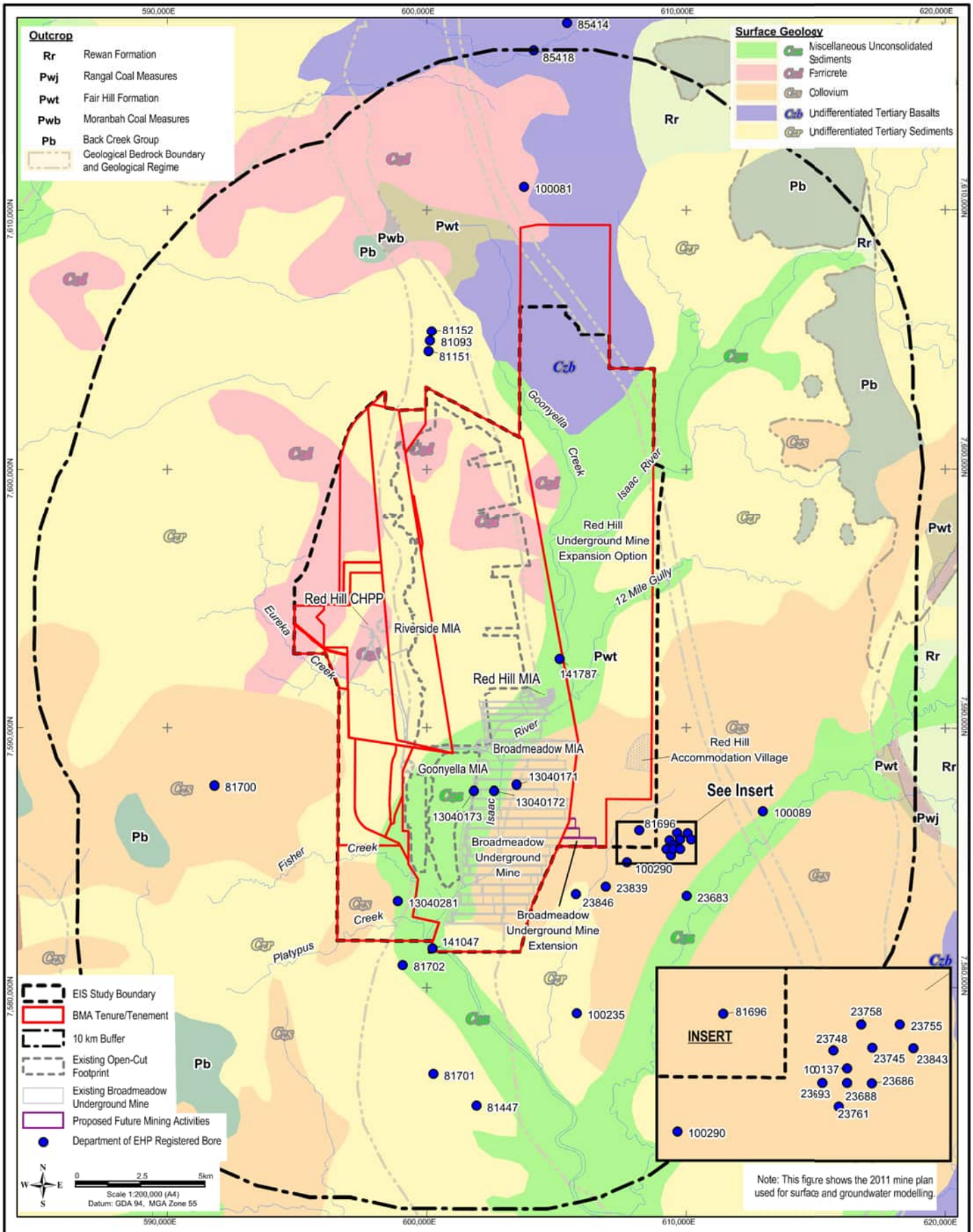
Table 6-4 Summary of Information Collected During Bore Census

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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RED HILL MINING LEASE
GROUNDWATER IMPACT ASSESSMENT

LOCATION OF NRM REGISTERED BORES AND BORE CENSUS

URS

GROUNDWATER

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.

7

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:

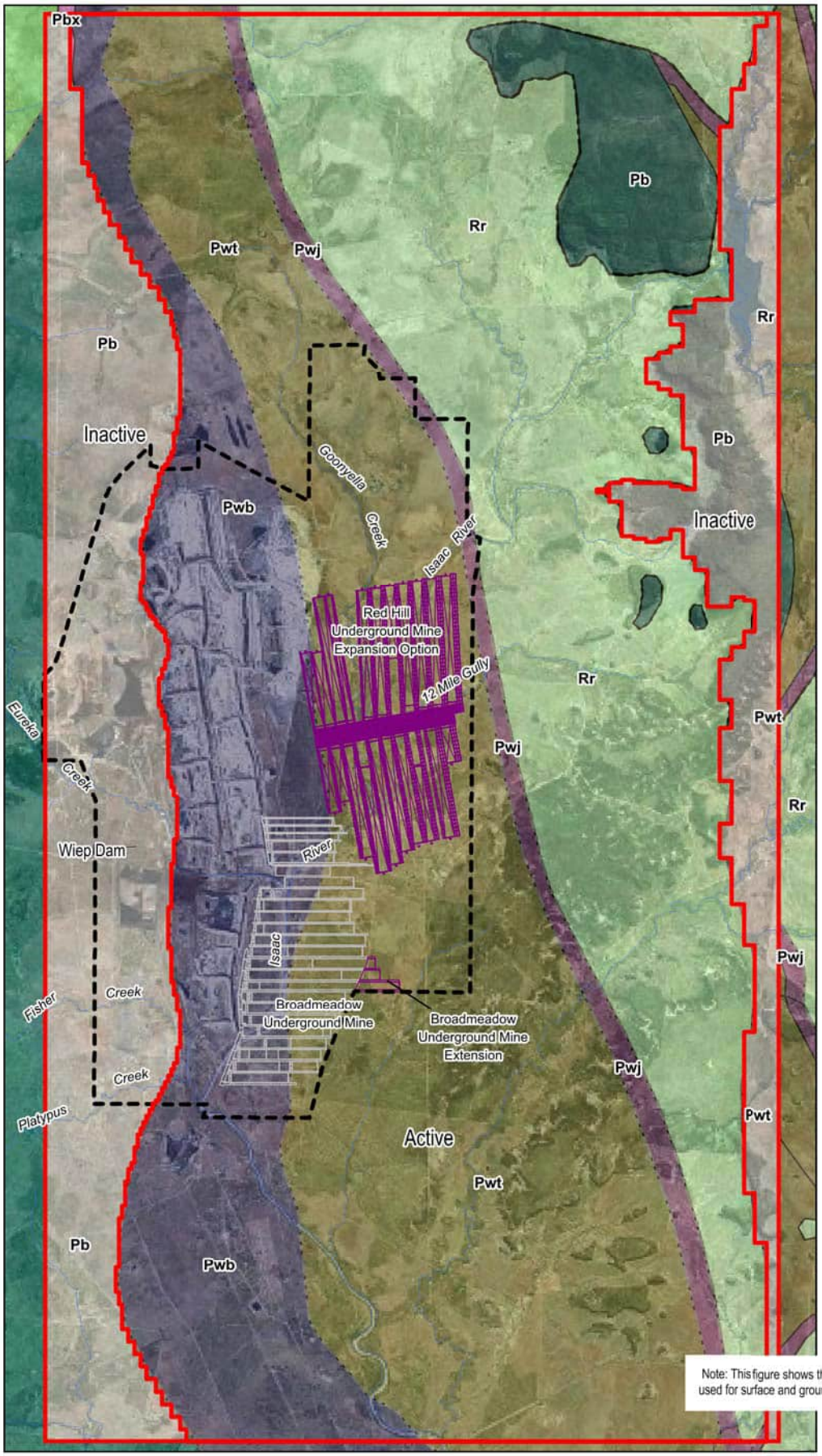
- the outcrop/subcrop of the Back Creek Group to the west of the mine;
- a system of thrust faults approximately 10 kilometres to the east of the proposed RHM that offset the Moranbah Coal Measures; and
- an arbitrary distance of approximately 25 kilometres to the north and south of the RHM that was 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.



Bedrock Geology

Rr	Rewan Formation
Pwj	Rangal Coal Measures
Pwt	Fair Hill Formation
Pwb	Moranbah Coal Measures
Pb	Back Creek Group

EIS Study Boundary

Model Boundaries

Existing Underground Mining Operations

Proposed Underground Mining Operations

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Scale 1:200,000 (A4)
Datum: GDA 94, MGA Zone 55

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

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NUMERICAL MODEL EXTENT

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GROUNDWATER

Figure: **7-1**

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

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

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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:

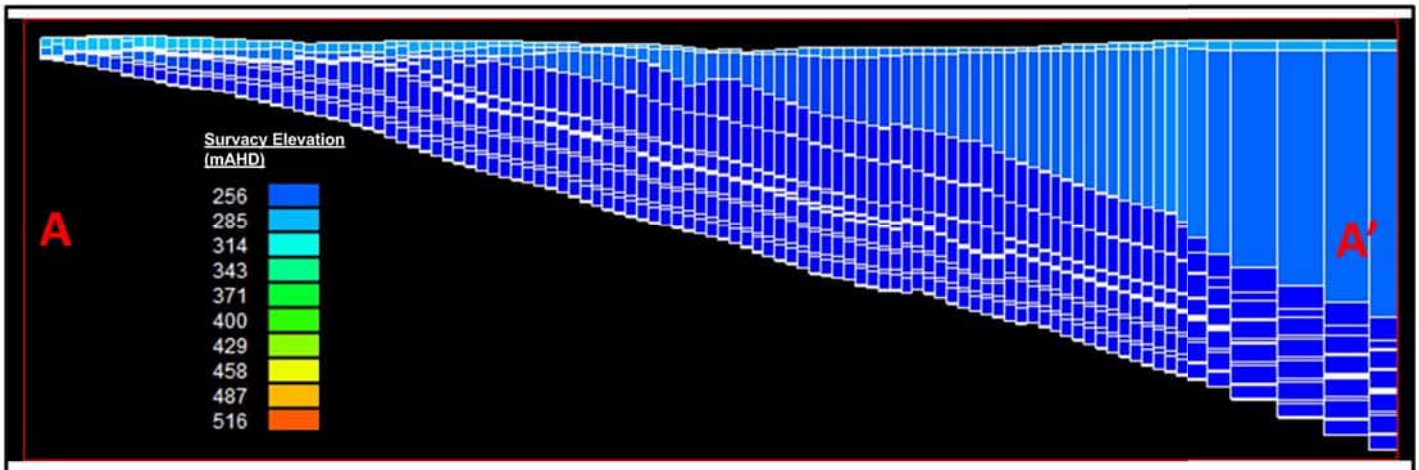
- **Top inflow boundary** comprising recharge and evaporation. Available precipitation and evaporation data was reviewed / verified;
- **Horizontal inflow boundary** based on groundwater level data, which is used to determine the model's east, west, north, and south boundary conditions. Geological log 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.

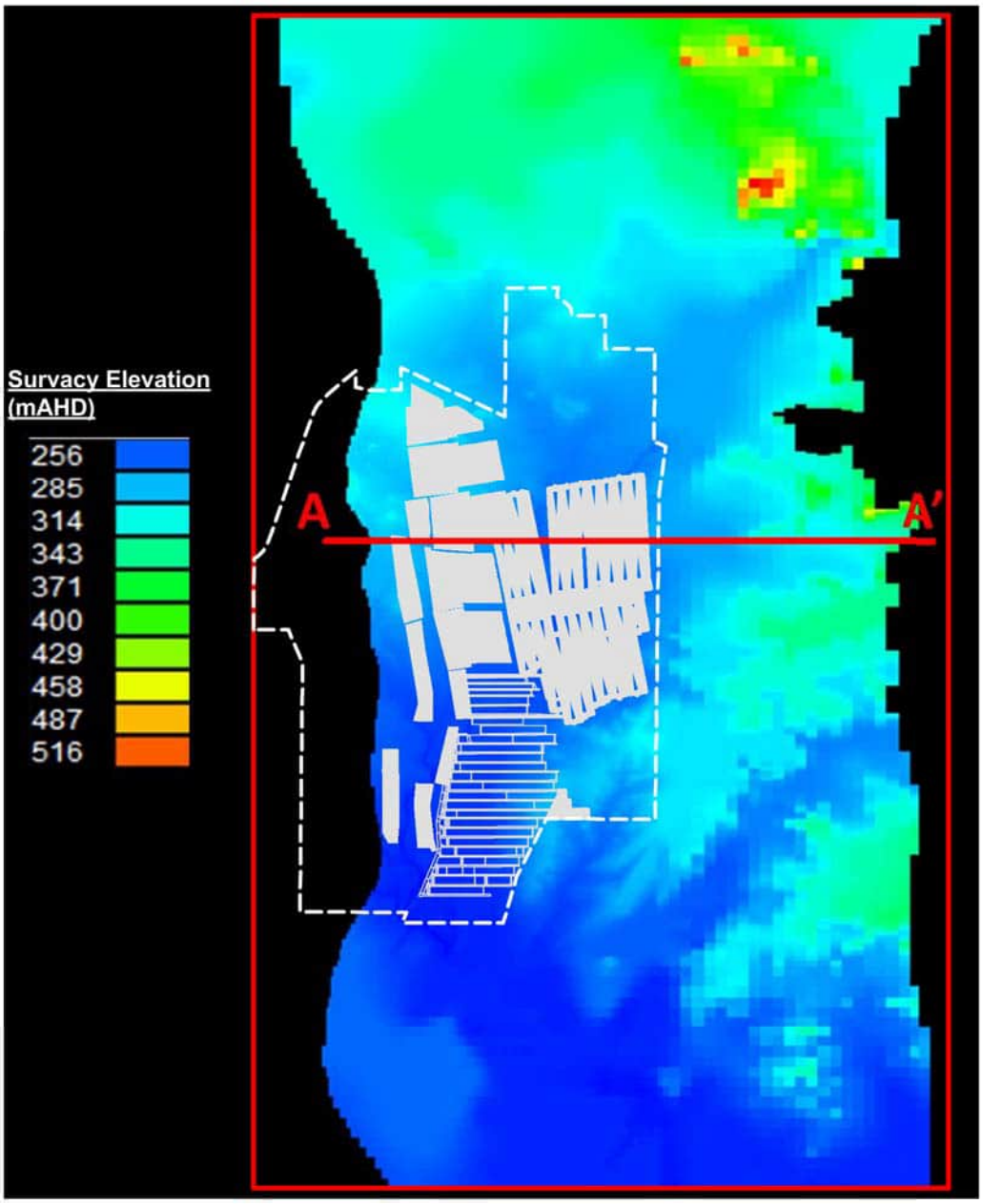
7.3.3 Model Layers

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'.





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Scale 1:250,000 (A4)

EIS Study Boundary

Open-Cut and Underground Mining Operations

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

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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

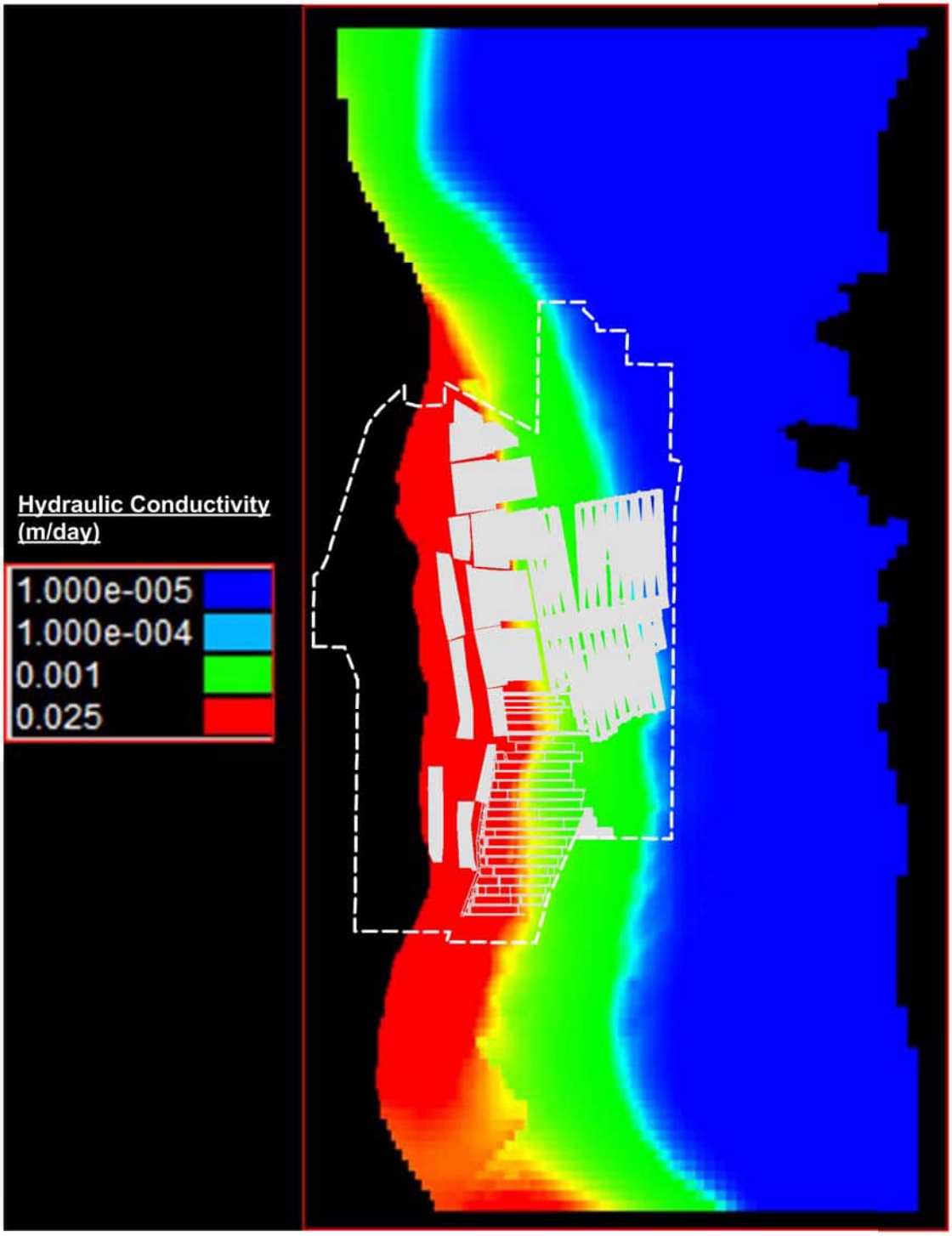
Parameterization

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:

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

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).



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EIS Study Boundary

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

URS

GROUNDWATER

Figure: **7-4**

File No: **42627136-g-2103.wor** Drawn: **VH** Approved: **CT** Date: **24-06-2013** Rev.**A** A4

7 Numerical Modelling

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 Numerical Modelling

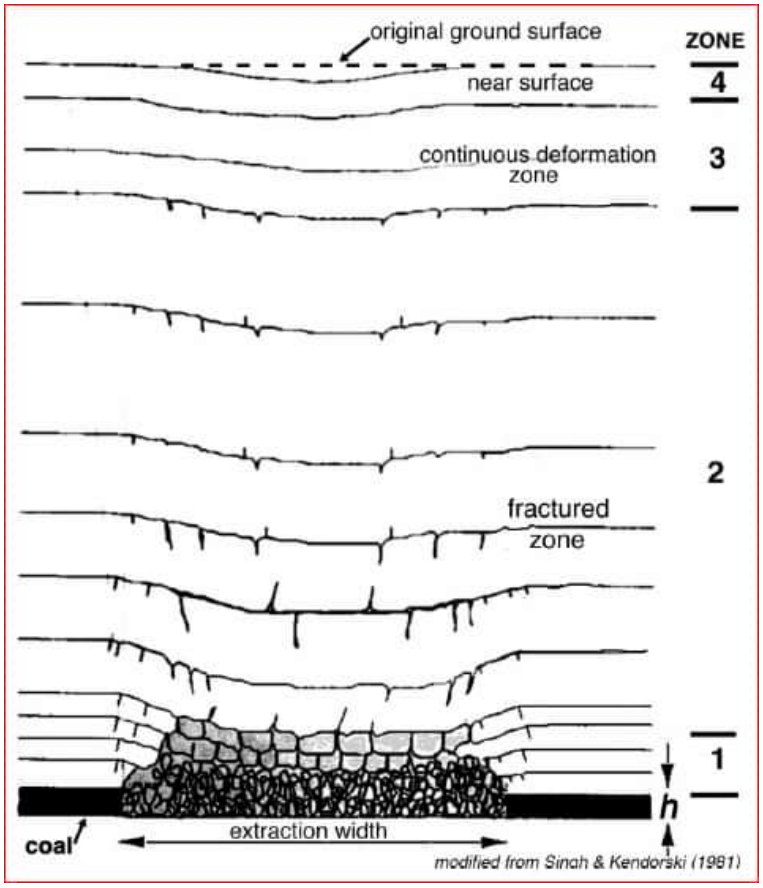
7.3.7 Simulation of Mine Dewatering considering Goaf Alteration

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.

7 Numerical Modelling

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

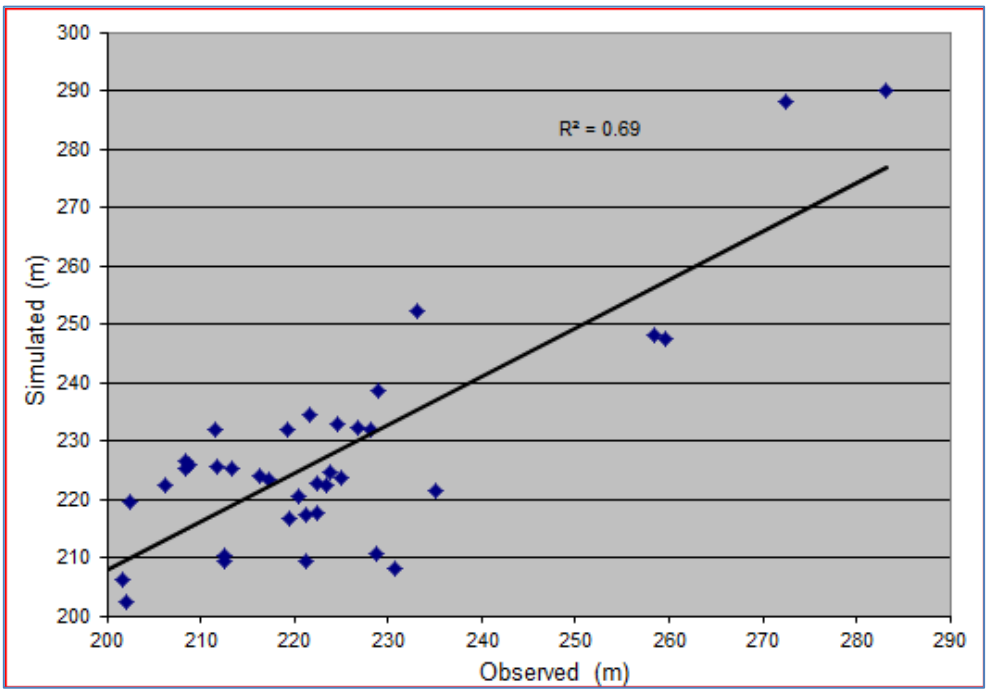
7.4.3 Calibration Assessment

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

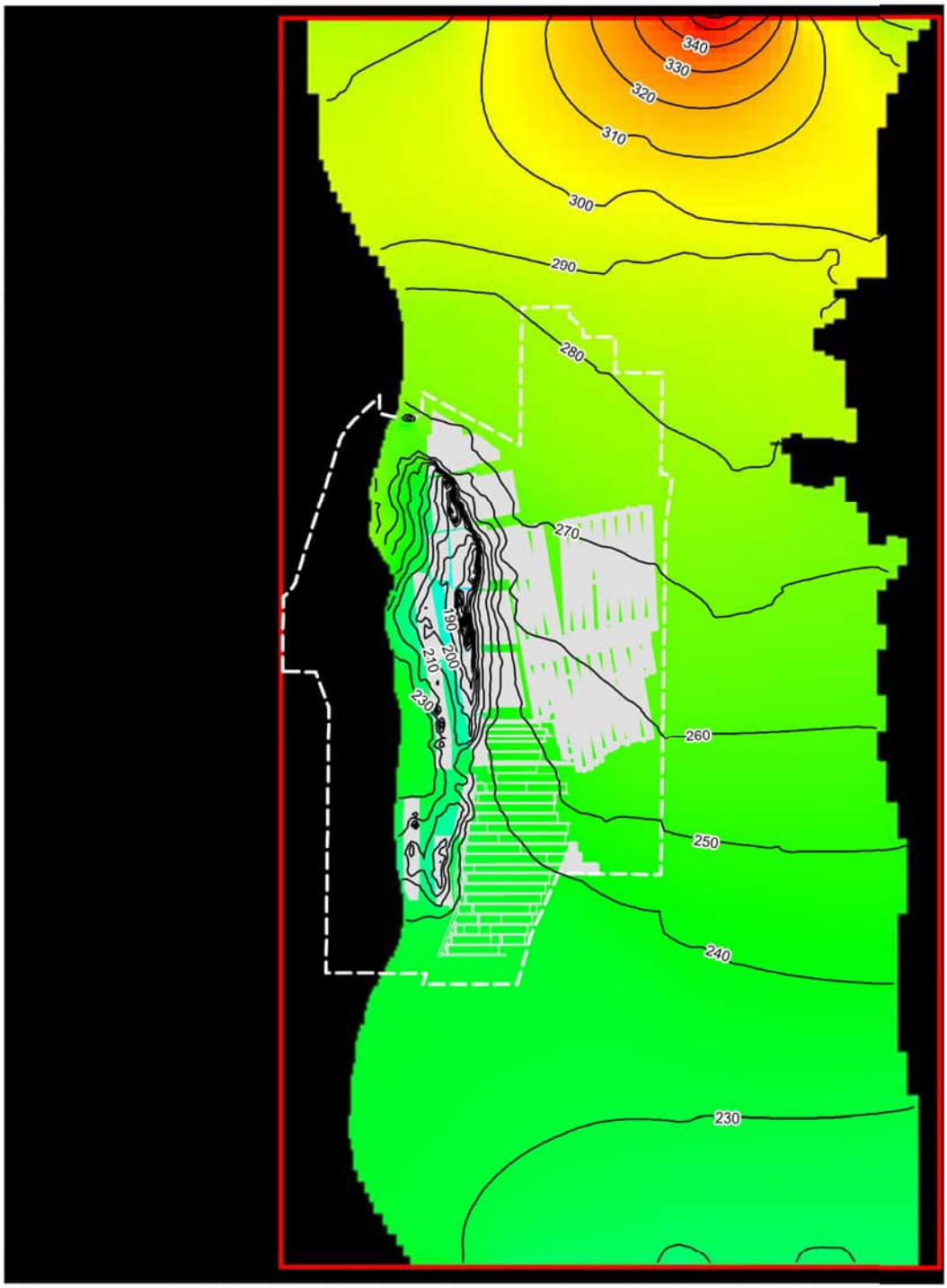
Model Layer	Unit	K (horizontal) (m/day)	K (vertical) (m/day)
13	GMS	Distribution*	Distribution* x 0.1
14	interburden	1.08E-04	1.08E-05
15	GLS	Distribution*	Distribution* x 0.1
16	interburden	1.08E-04	1.08E-05
17	Base	1.08E-04	1.08E-05
Recharge		1.00E-07 m/day	

* 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

URS

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**.

7 Numerical Modelling

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**			

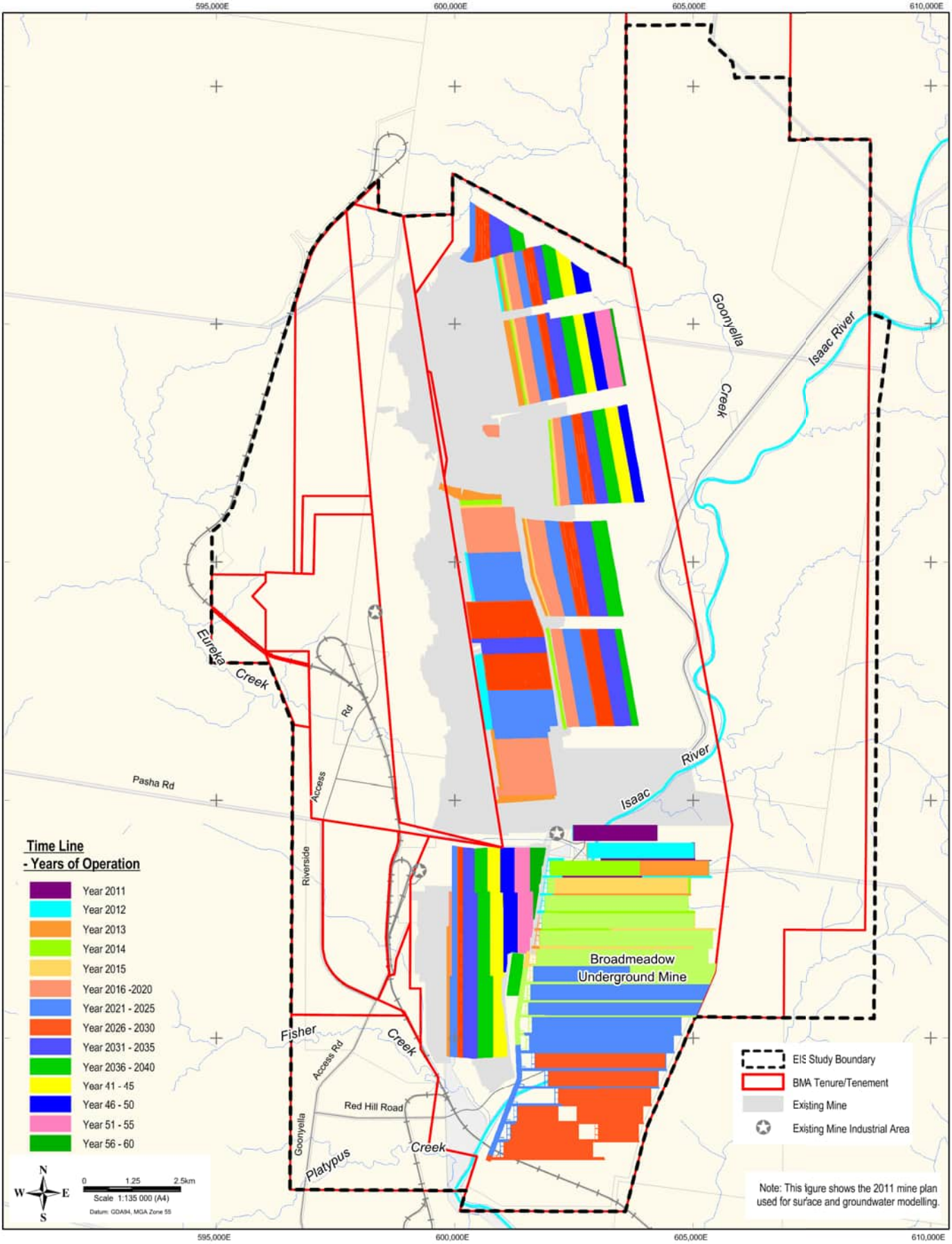
* K distribution derived from the WDS regression formula- 233.52*EXP(-0.016*depth)

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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GROUNDWATER IMPACT ASSESSMENT

MINE PROGRESSION FOR EXISTING APPROVED GOONYELLA RIVERSIDE AND BROADMEADOW MINES

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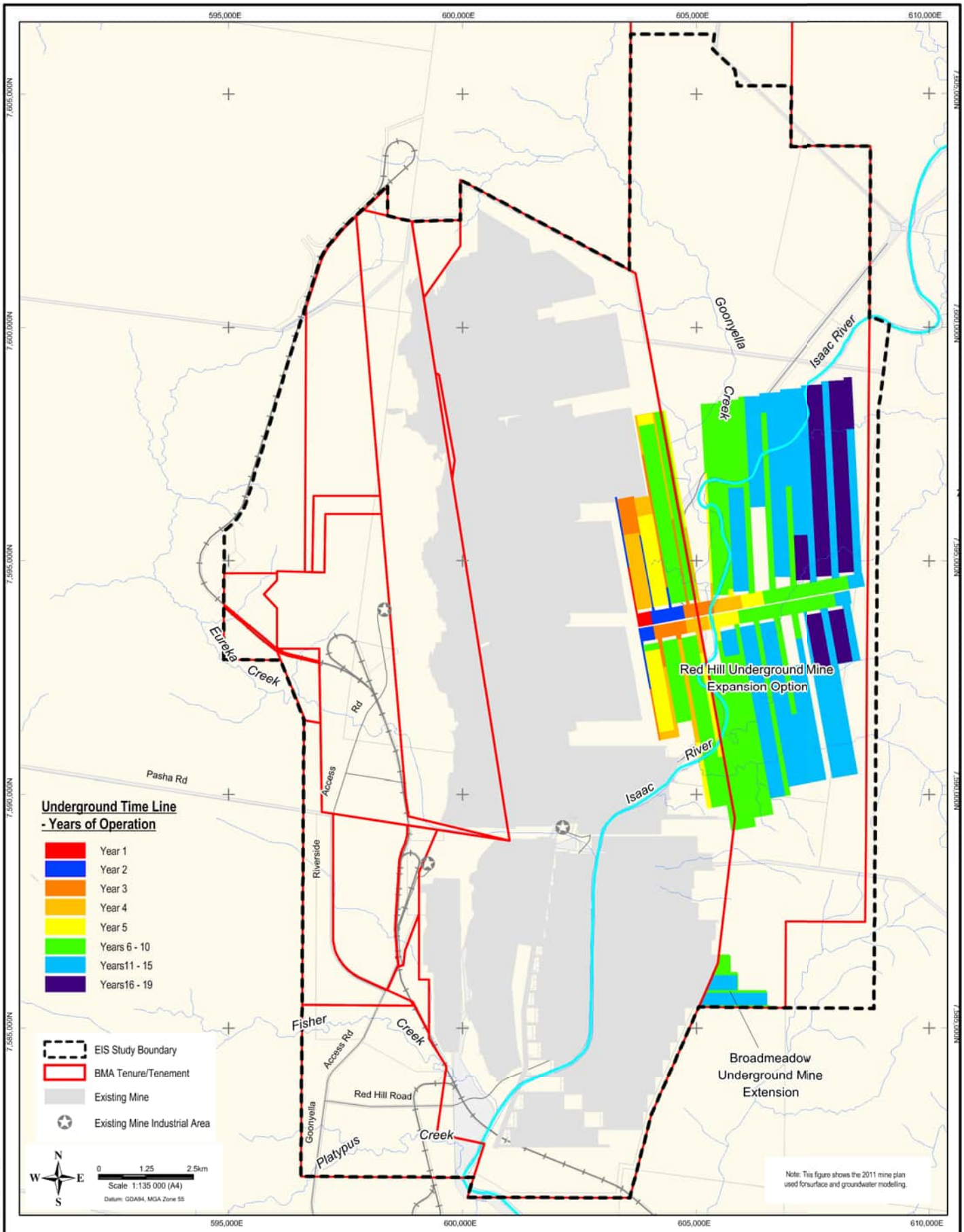
GROUNDWATER

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

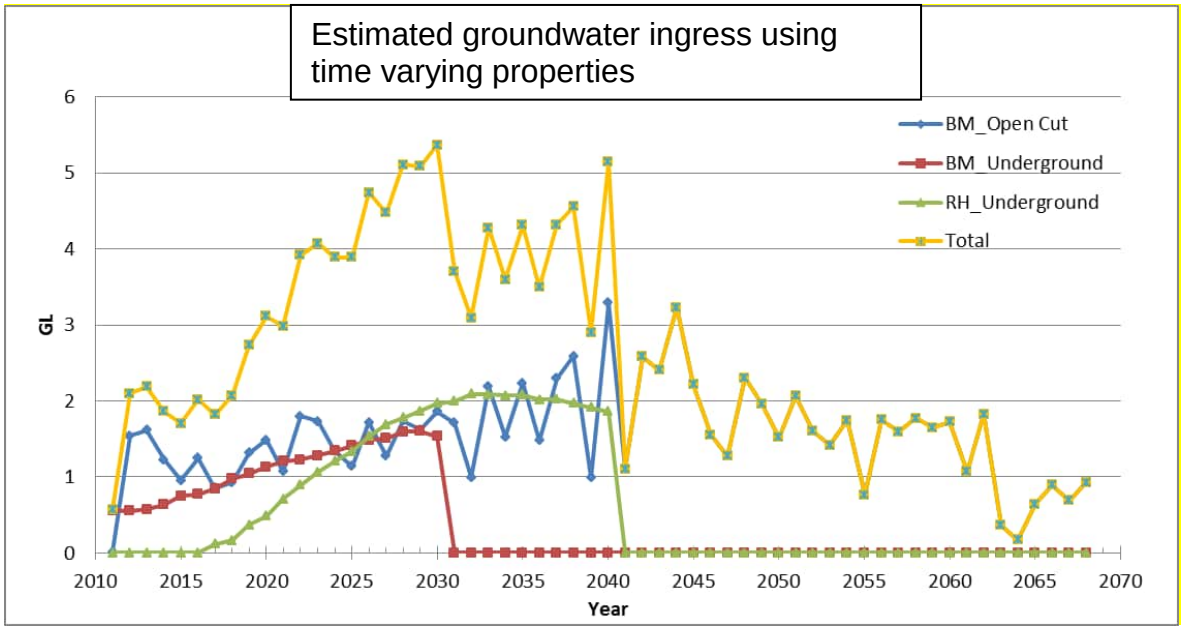
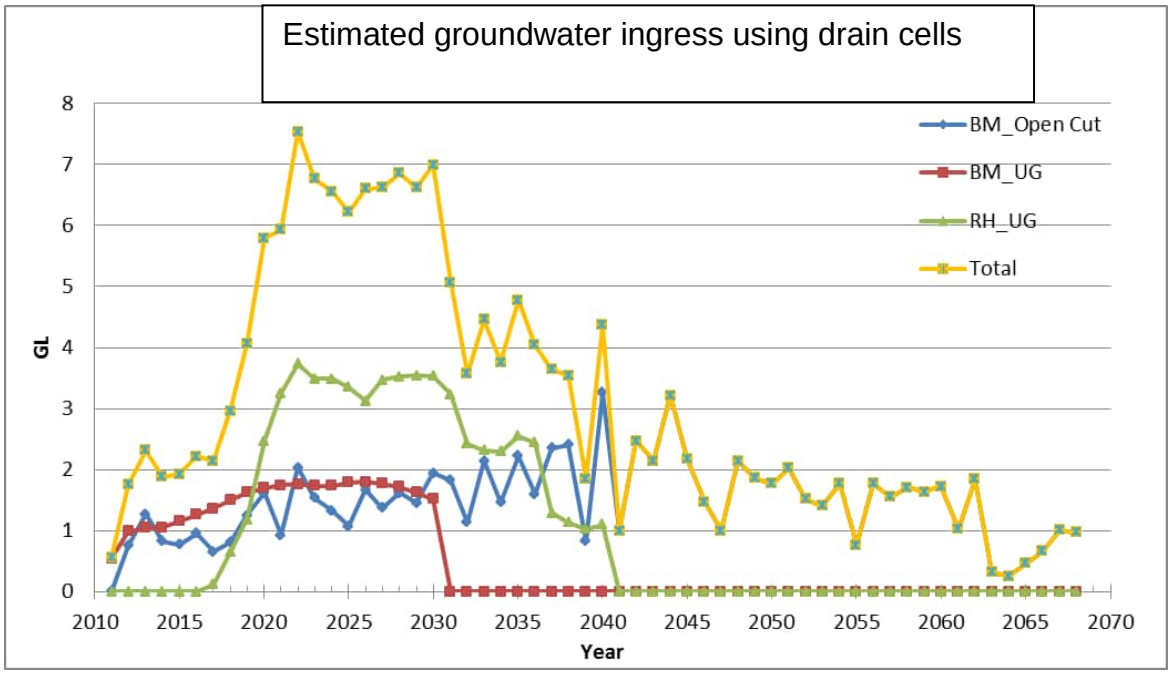
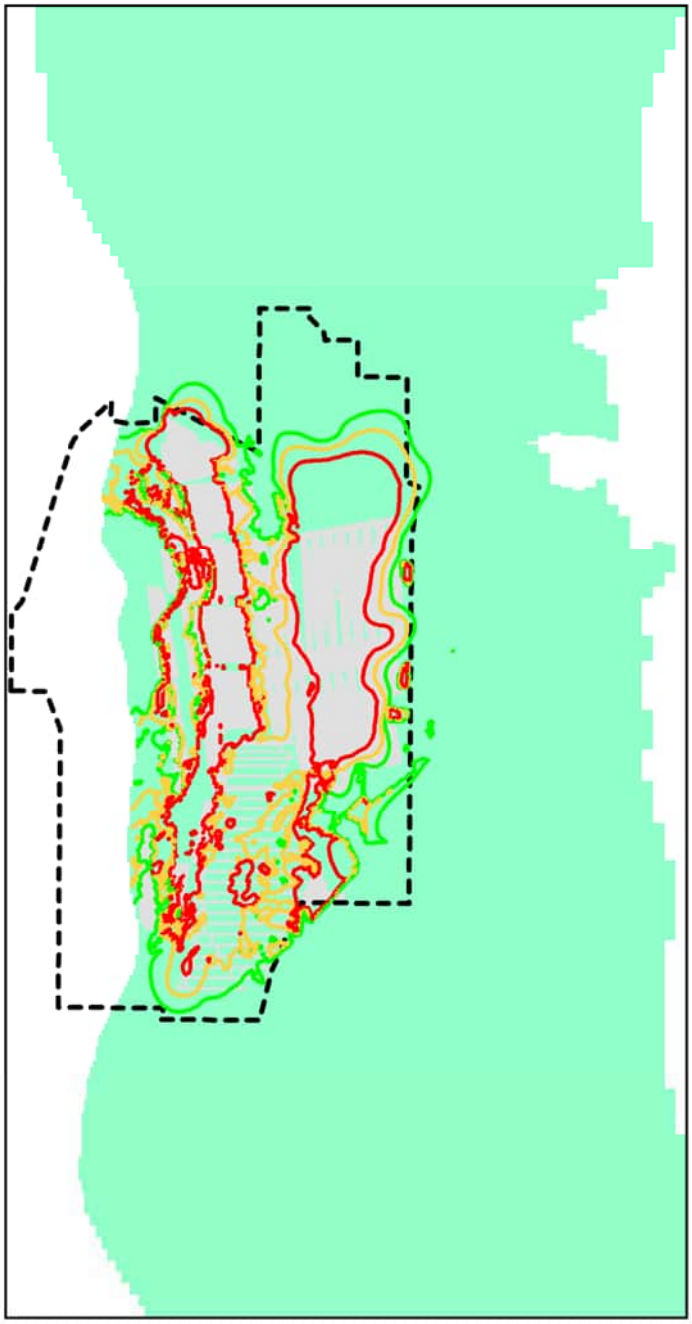
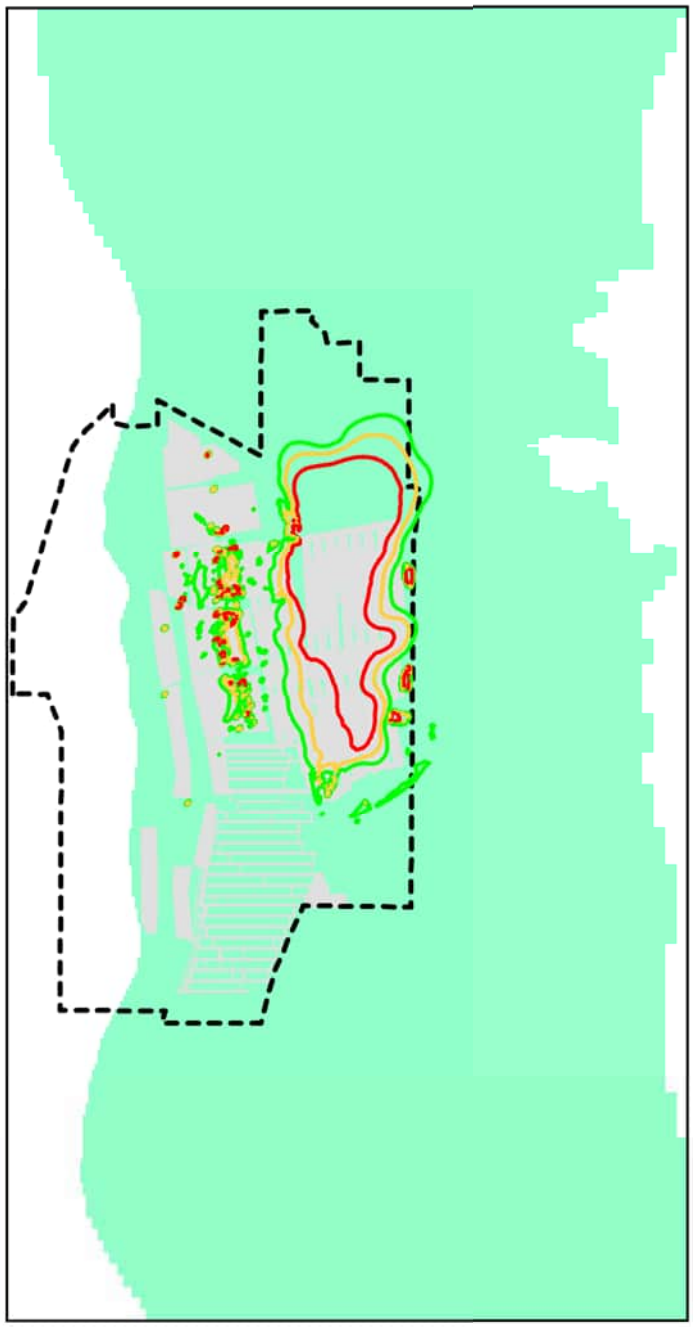


Chart 7-3 Estimated Total Groundwater Ingress Using Drain Cells





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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RED HILL MINING LEASE
GROUNDWATER IMPACT ASSESSMENT

MODELLED DRAWDOWN IN TERTIARY/QUATERNARY FORMATIONS AT END OF 2040

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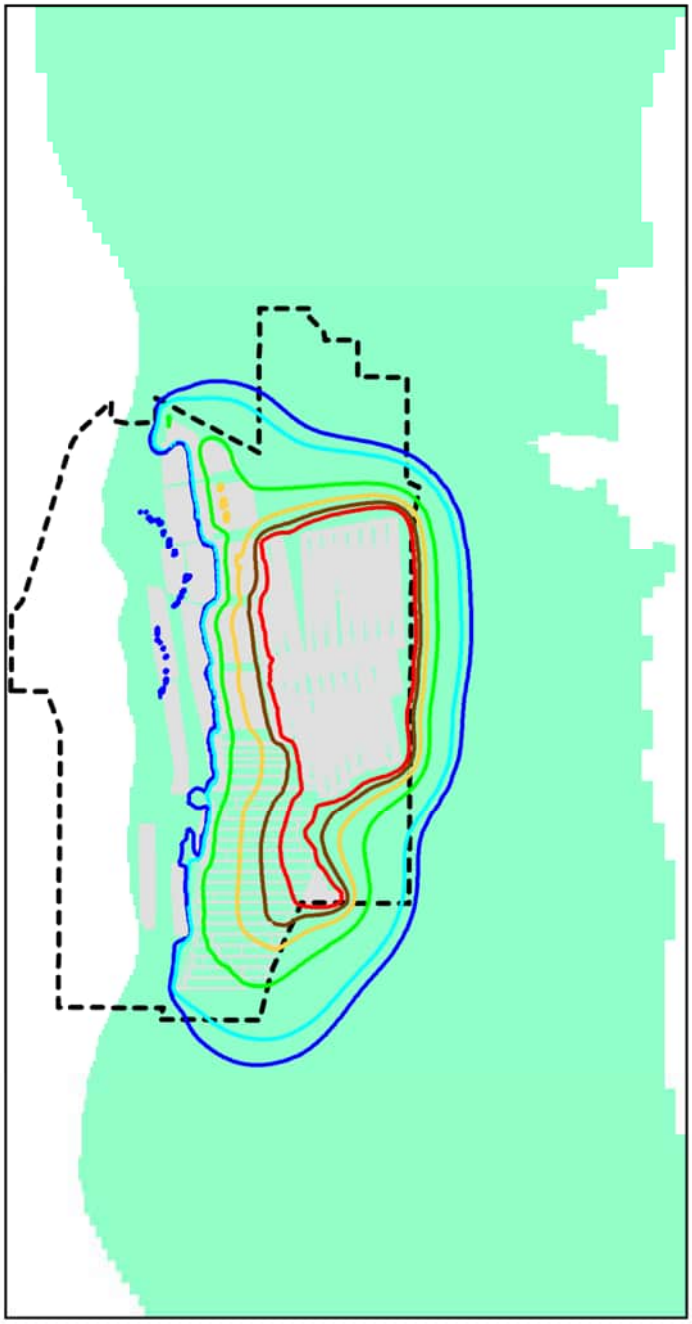
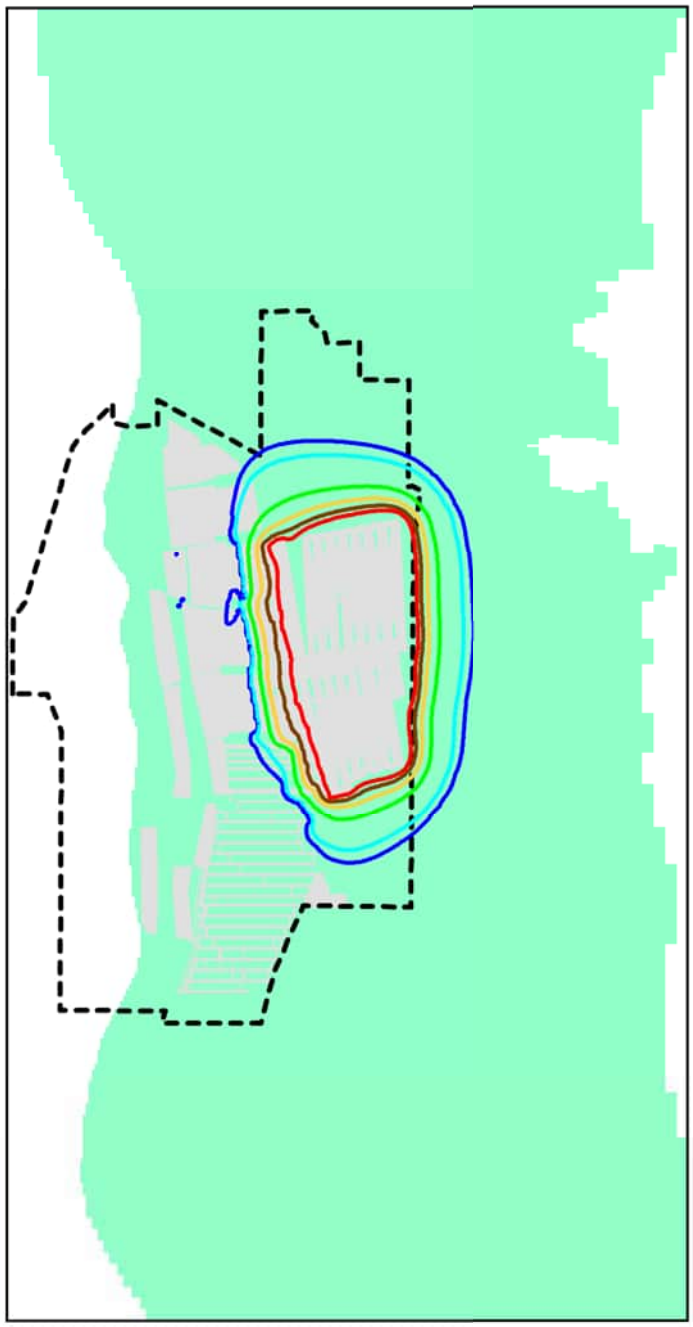
GROUNDWATER

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

Drawdown (m)

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

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

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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GROUNDWATER IMPACT ASSESSMENT

MODELLED DRAWDOWN IN GMS AT END OF 2040

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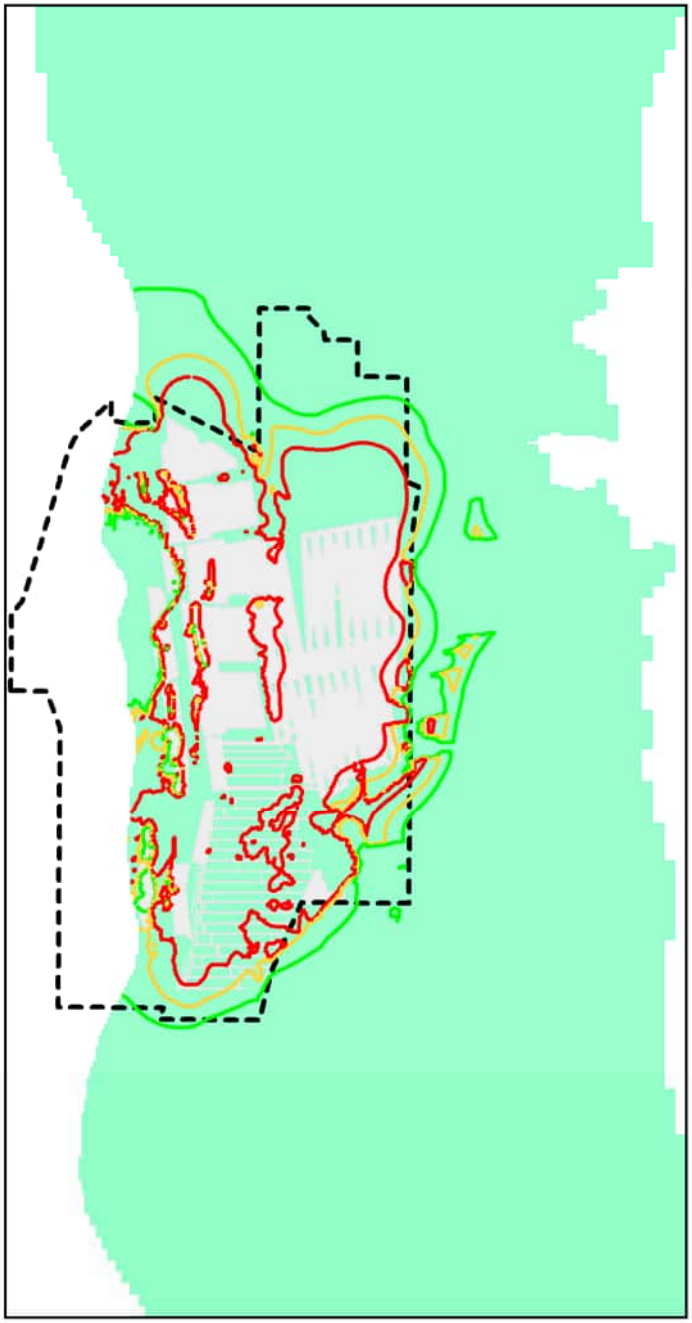
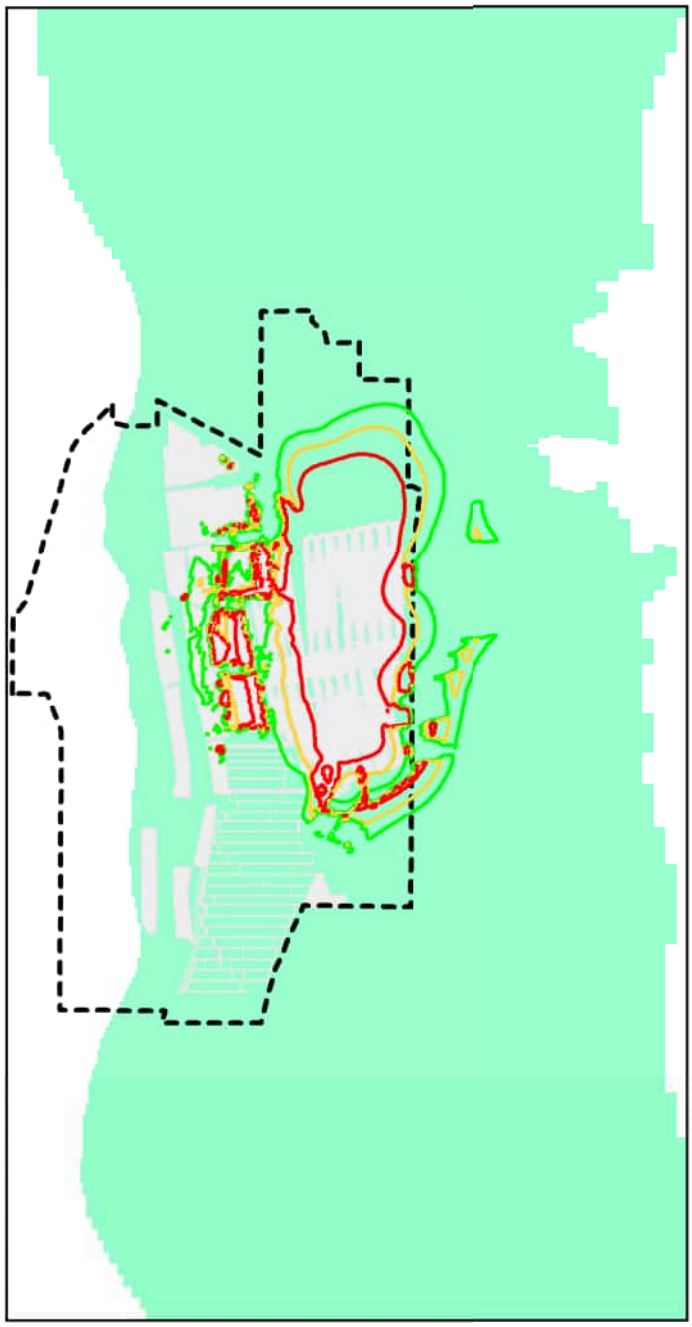
GROUNDWATER

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.

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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GROUNDWATER IMPACT ASSESSMENT

MODELLED DRAWDOWN IN TERTIARY/QUATERNARY FORMATIONS AT END OF 2068

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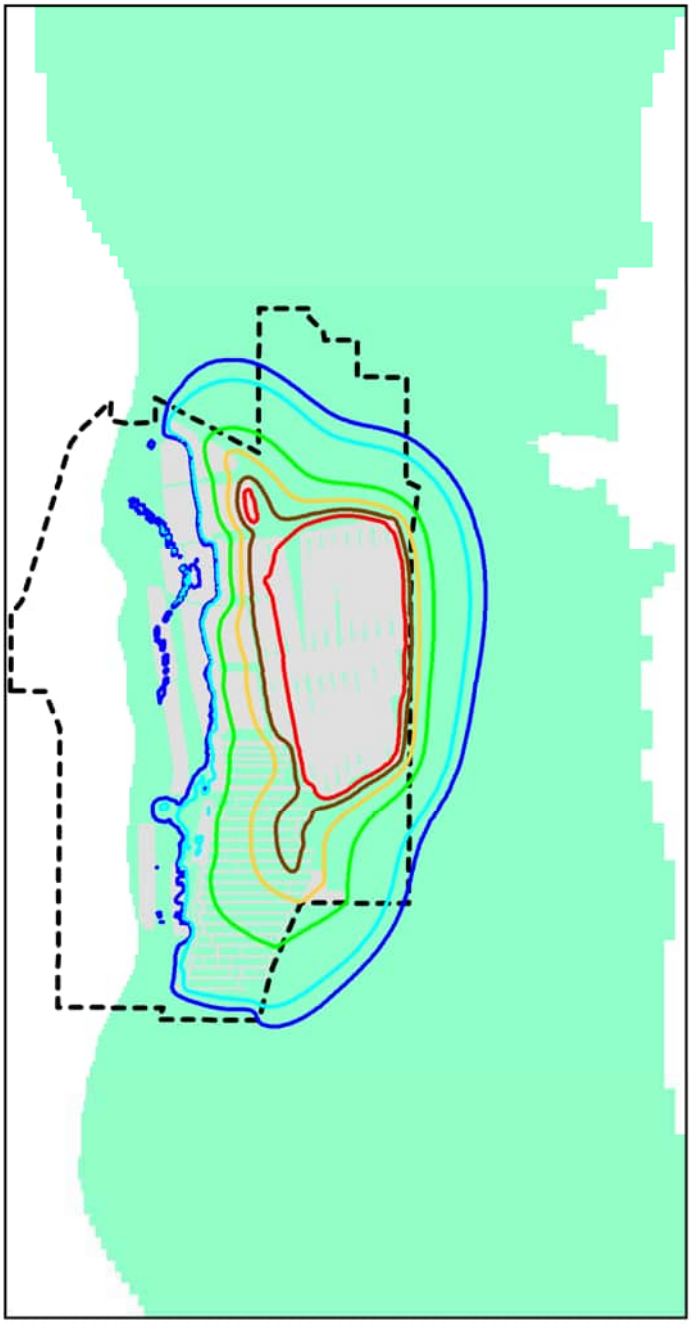
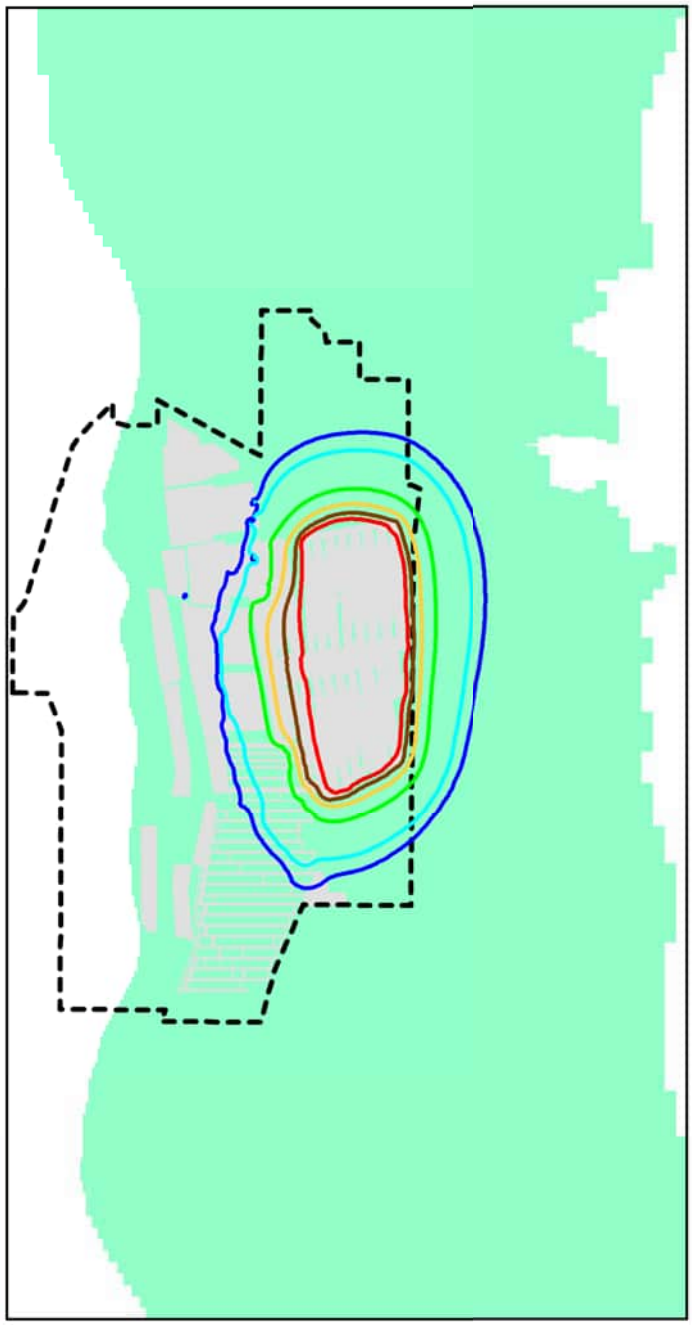
GROUNDWATER

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.

Drawdown (m)

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

EIS Study Boundary

Open-Cut and Underground Mining Operations

Model Extent

N W E S

0 3.75 7.5km

Scale

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GROUNDWATER IMPACT ASSESSMENT

MODELLED DRAWDOWN IN GMS AT END OF 2068

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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

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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

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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.

8 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.

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

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”.

10

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Appendix B

Geotechnical Report

BYRNES GEOTECHNICAL

ACN 633 507 623

BMA

Estimating changes in hydraulic conductivity induced by BMA longwall and pillar extraction mines.

BMA-11 Groundwater report

Date: 29/04/2024

R.W.Seedsman

RPEQ

WORKING DRAFT
FOR INTERNAL BHP REVIEW

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EXECUTIVE SUMMARY

As the PRCP process has evolved, it has become apparent that there is a need to provide hydraulic conductivity and porosity estimates of the ground impacted by longwall extraction.

This is a somewhat controversial environmental issue in the NSW coalfields with different opinions held by mining companies, consultants, regulators, and environmental groups. The NSW experiences are not directly transferable to the Bowen Basin as the Queensland mines are much shallower.

This report reviews the evolution of hydrogeological models related to longwall extraction and introduces a geotechnical model for overburden fracturing that can be used to estimate hydraulic conductivity and porosity.

Recommendations are made on how the model could be implemented in groundwater studies.

WORKING DRAFT
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1 INTRODUCTION

Longwall mining involves wide extraction faces such that the overburden progressively collapses – in fact progressive collapse is essential. One factor in the design of longwall mines has been the prevention of unacceptable large inflows of water into the workings. The recognised hazards included consideration of whether flow rates in access roadways present a hazard during evacuation of the work force, whether there is adequate pumping capacity to remove the water, or whether there is adequate storage volume down-dip.

It is important to note that there are relatively few cases in which the prediction of mine water inflow is critical. The empirical models appear to work well, although they were severely tested in the case of Crinum North and subsequently revised.

As the technology developments allowed wider extraction panels, concern has arisen about the possible impact longwalls may have on the gradual lowering of water tables in near-surface aquifers. The mining depths associated with these environmental impacts are much greater than those involved in the inflow hazard and there is no evidence that the outflows from the aquifers result in hazardous inflows to mines. In NSW the environmental issue relates to longwall extraction under water catchments and it was also a component of EIS studies into longwall mining in the Galilee Basin relative to the Great Artesian Basin.

Compared to NSW, the depths of the BMA mines are much less such that caving extends to the overburden collapses extends to the surface. The mine geometry s referred to as “supercritical” compared to the NSW cases which are “subcritical”. There has been relatively little attention paid to the hydrogeological conditions of supercritical geometries.

This document presents a brief outline of the evolution of hydrogeological models and makes recommendations on how they can be applied to the preparation of PRCP management plans.

2 AVAILABLE DATA AND OBSERVATIONS

Longwall mining results in fracturing of the rock mass as the overburden sequence collapses/caves into the void left by the extraction of the coal. This is an intrinsic part of the mining system. Observations of the results of the collapse are limited to the sides of the collapse at seam level and also the ground conditions if there has been subsequent mining in overlying seams. There have been examples where longwall caving has been exposed during subsequent surface mining of lower seams but any studies of these have not been presented in the public domain. The collapse of the overburden can extend to the surface and result in mining-induced subsidence which has been extensively studied.

2.1 Seam level

At seam level at Mandalong Mine in NSW, which is considered to be typical of most longwall mines, the majority of visible blocks in the collapsed volume (Figure 1) were smaller than 0.8m, with only one between 0.8 and 0.9m in size, and another with a mean size of around 1m (Seedsman et al, 2023).

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Figure 1Typical nature of caved material at seam level

2.2 Overmining

Evidence from multiseam mining when conducted in an ascending order is that the bedding layers and orientation are maintained despite the vertical subsidence they have experienced. Mark et al (2007) produced a prediction equation for successful multiseam mining which suggests mining can be conducted at about 10 m above the lower seam if there is acceptance of additional ground support, and at about 35 m above the lower seam without any additional ground support. The author has direct experience with overmining in Australia that is consistent with this prediction.

Mining at Cumnock Colliery in the Lower Pikes Gully seam 35 m above 2.8 m thick lower seam (Li and Cairns, 2000) identified a consistent feature referred to as a D zone (Figure 2). Within the zone, the strata were delaminated with some open vertical fractures with apertures of several millimetres; ribs had open joints and small vertical steps. It was found to be very predictable by extending lines at angles of α = 15° (fracture angle) and β = 35° (full collapse angle) from the goaf edge. There was no noticeable fracturing/displacement above the majority of the mined-out underlying Liddel Seam. Chekan and Listak (1993) discuss the possible presence of a mining-induced shear zone present in a similar location.

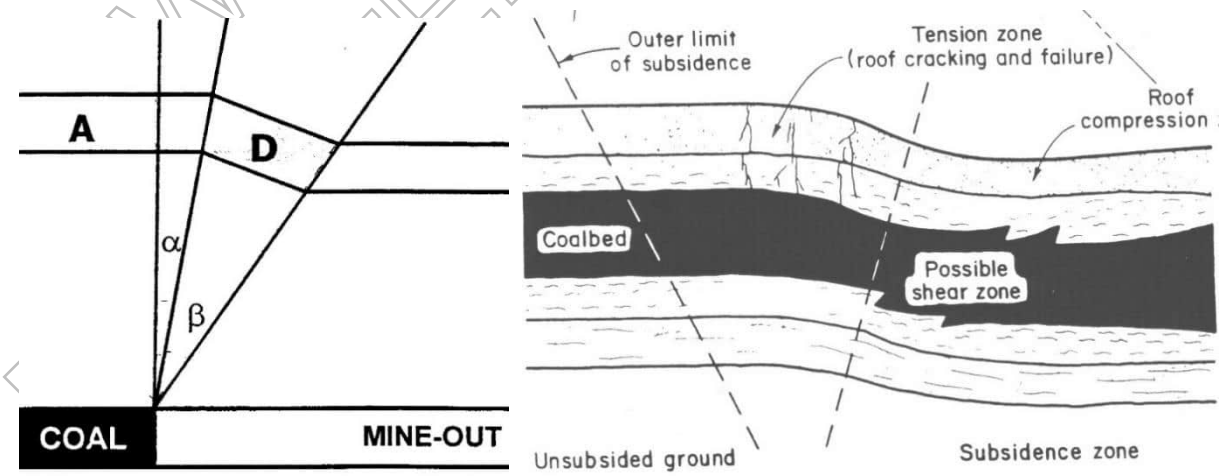

Figure 2 Mining conditions reported from overmining (left - Li and Cairns, 2000; right Chekan and Listak, 1993).

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2.3 Physical models

Physical models published by Whittaker and Reddish (1989) indicate there is negligible disruption to the layering during collapse (as experienced in overmining), negligible dilation along the centreline of the collapsed rock mass, there is a void at the top of the collapse that is about half the extraction thickness, and there is some dilation to the sides of the extraction consistent with D zone concept discussed [illegible]).

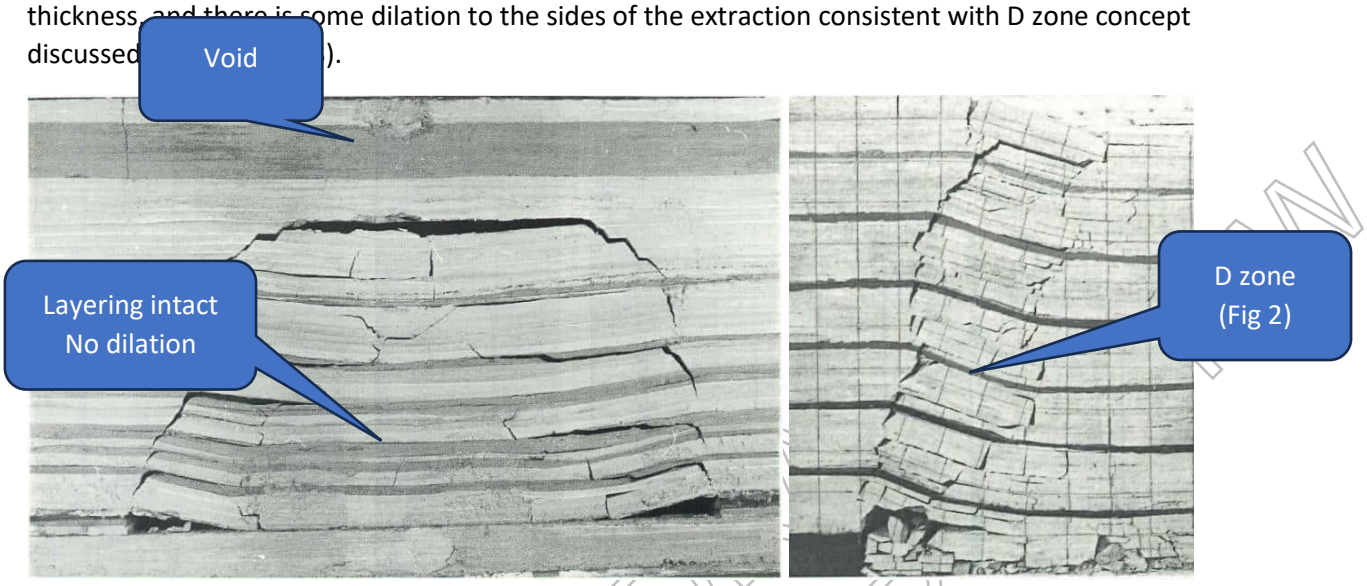

Figure 3 Physical models provide examples of collapse that are consistent with reported mining conditions.

Based on physical models such as Figure 3, identified continuous and discontinuous cracking with heights of A and B respectively , restricted to the sides of the cave. Discontinuous cracking reaches the surface when surface tensile strains are about 35 mm/m, and continuous cracking intersects the surface at 55 mm/m (Figure 4).

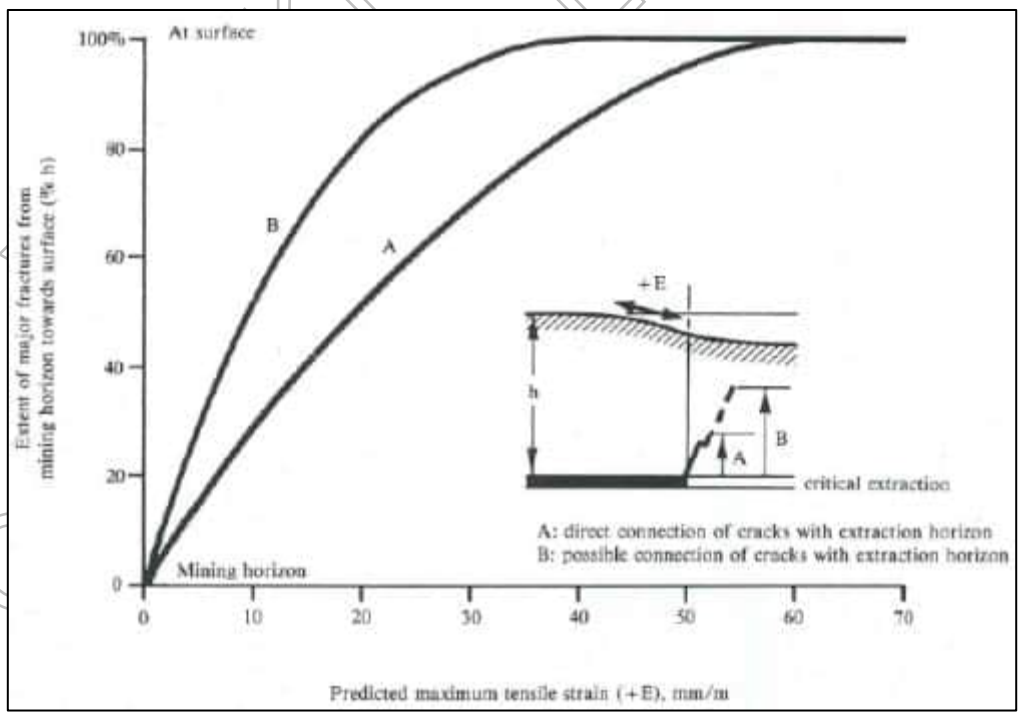

Figure 4 Zone A and Zone B fracturing in the Whittaker and Reddish model (note that the definition related to cracks at the edge of the extraction.

2.4 Surface subsidence

Surface subsidence data is typically presented in a normalised form with a smooth design line drawn to encompass most of the data (Figure 5). This can lead to the arguable interpretation that subsidence and hence overburden collapse is a smooth continuous process. An alternative interpretation of subsidence data invokes a step change between a subsidence/extraction thickness ratio of 0.2 to a Smax/T of 0.60 which also represents the change between subcritical to supercritical mine geometries. This step in the vertical movement would require that the underlying material has experienced little dilation between the layers as they collapsed – this is consistent with the overmining observations and also with physical models.

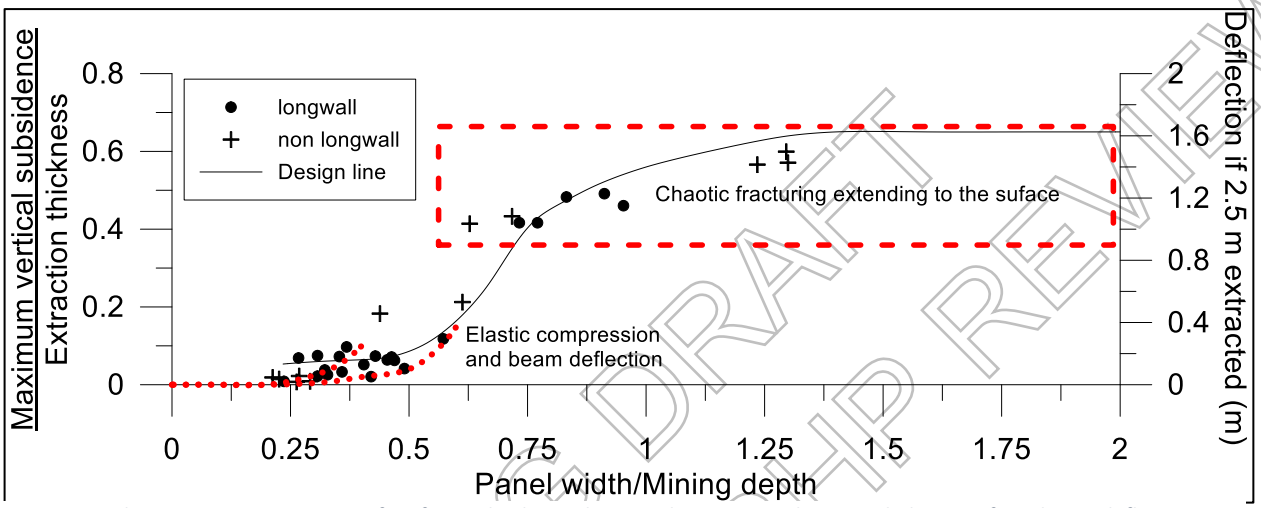

Figure 5 Alternative interpretation of surface subsidence data involving a step change in behaviour from beam deflection to chaotic fracturing.

3 MODELS FOR WATER INFLOWS

3.1 Kendorski models

Kendorski et al (1979) presented an assessment of the hazards of uncontrolled mine water inflows and this work was subsequently developed to produce one of the standard models for longwall collapse (Kendorski, 1993) which invokes four horizontal zones with their geometry defined as ratios of the extracted thickness (T). Other workers have used different terms for essentially the same zones. Progressing upwards from the mined coal seam, these zones are (Figure 6):

- Caved – the zone immediately above the mined coal, described as highly broken and chaotic with a thickness of between 2T to 10T.
- Fractured – described as having layering intact but some fracturing associated with the collapse of the rock mass, with a thickness of between 24T to 30T. Unacceptable flow into mine workings is possible through the fractured zone.
- Dilated – described as characterised by opening of the bedding but no collapse fracturing and with a thickness of up to 60 T. There is no increase in the vertical conductivity but there is an increase in horizontal conductivity.
- Constrained and Unaffected - where there is no bedding opening and no collapse fracturing.

Values for hydraulic conductivity were not provided.

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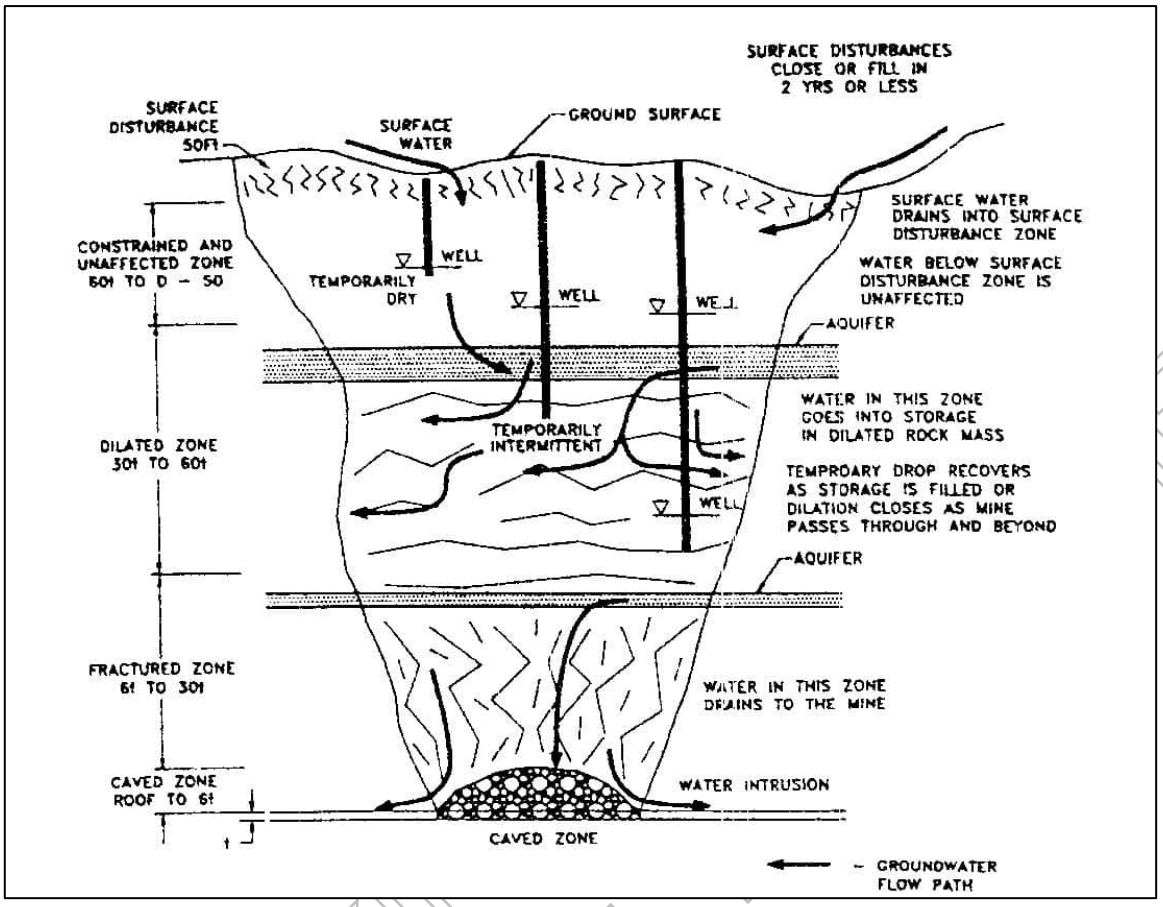

Figure 6 Kendorski 1993 inflow model

One difficulty with this model is that there is no reference to the width of the longwall extraction – recognising the rapid evolution of longwall mining in recent decades it is quite possible that the widths were in the order of 150 m. Another difficulty is the view that there is no increase in vertical conductivity in the dilated zone – perhaps this was in the context of hazardous mine water inflows and not meant to be an absolute statement.

3.2 Ditton and Merrick model

Ditton and Merrick (2014) developed equations to predict the heights based in panel width as well as extraction thickness specific to Australian mining conditions and geometries (Figure 7). They also extended the concept from rib-side cracking to zones across the full extraction to mirror the Kendorski model.

Zone A is referred to as the Continuous Fracture Zone, with continuous relating to connected fractures to the extraction level. The definition does not highlight the location of the continuous fractures being at the sides of the cave. For a 340 m wide face and 5 m extraction, the central prediction for Zone A only extends to the surface for depths less than 120 m (Figure 7).

Zone B is referred to as Discontinuous Fracture Zone. In a consulting report Ditton stated that: "*Overall the majority of the B Zone is considered to be a "constrained dilated" strata zone, with low connectivity potential to the mine workings. The B Zone therefore represents a sub-surface fracturing zone that causes only minor groundwater system disturbance*." For a 340 m wide face,

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Zone B is present at the surface for depths in excess of 120 m for the central prediction of Zone A or at depth in excess of 170 m for the upper bound prediction of Zone A.

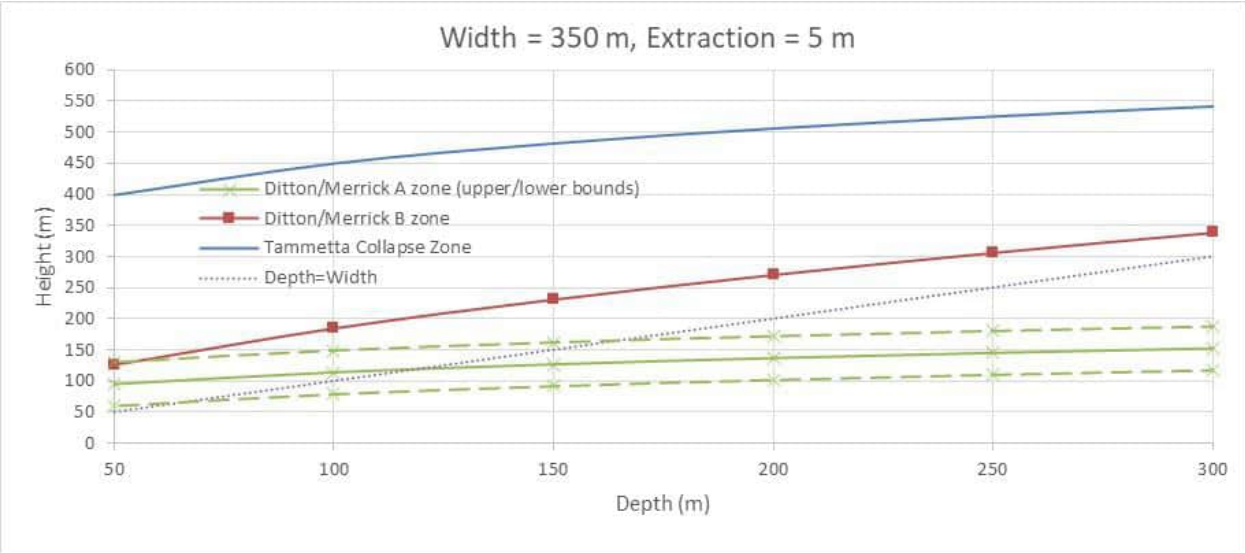

Figure 7 Ditton/Merrick and Tammetta zones

Specific hydraulic conductivity values are not given allocated to the A and B zones.

The application of the Ditton and Merrick method is assessed to be valid for the prediction of mine water inflows. Its application to environmental assessments has been questioned, probably in the context of what is "minor groundwater disturbance". For a 340 m wide face, the prediction of Zone B conditions at depth in excess of 120m/170m may be at odds with the likely surface subsidence of about 3.5 m indicating chaotic collapse extending to the surface.

3.3 Strata Control Technology model

The ACARP report (SCT 2008) used the FLAC numerical program along with in-house developed FISH codes to examine mine water inflows. FLAC is a continuum code which, by definition, does not consider dilation of fractures. The method is reported to simulate rock failure and hence fracturing and then provide a fracture aperture with a width equal to the non-elastic deformation assuming 1 fracture per element in the model: these widths are then used to calculate conductivity using standard fracture flow equations. Details of the method, including the size of each element, have not been published and hence are not subject to peer review.

The upper diagram in Figure 8 presents an example of the predicted hydraulic conductivity and it is noted that the patterns of conductivity, which are a function of the fracturing, have little resemblance to the physical models. The fracture models are not consistent with the reported ground conditions during overmining.

SCT (2008) also includes a cross plot of mining depth, vertical subsidence and average overburden conductivity. This average conductivity value relates to the average over a vertical profile, presumably at the centreline of the extraction – how it relates to the conductivity in a horizontal plane is not provided noting that the minimum conductivity in a horizontal plane would control inflows from the surface.

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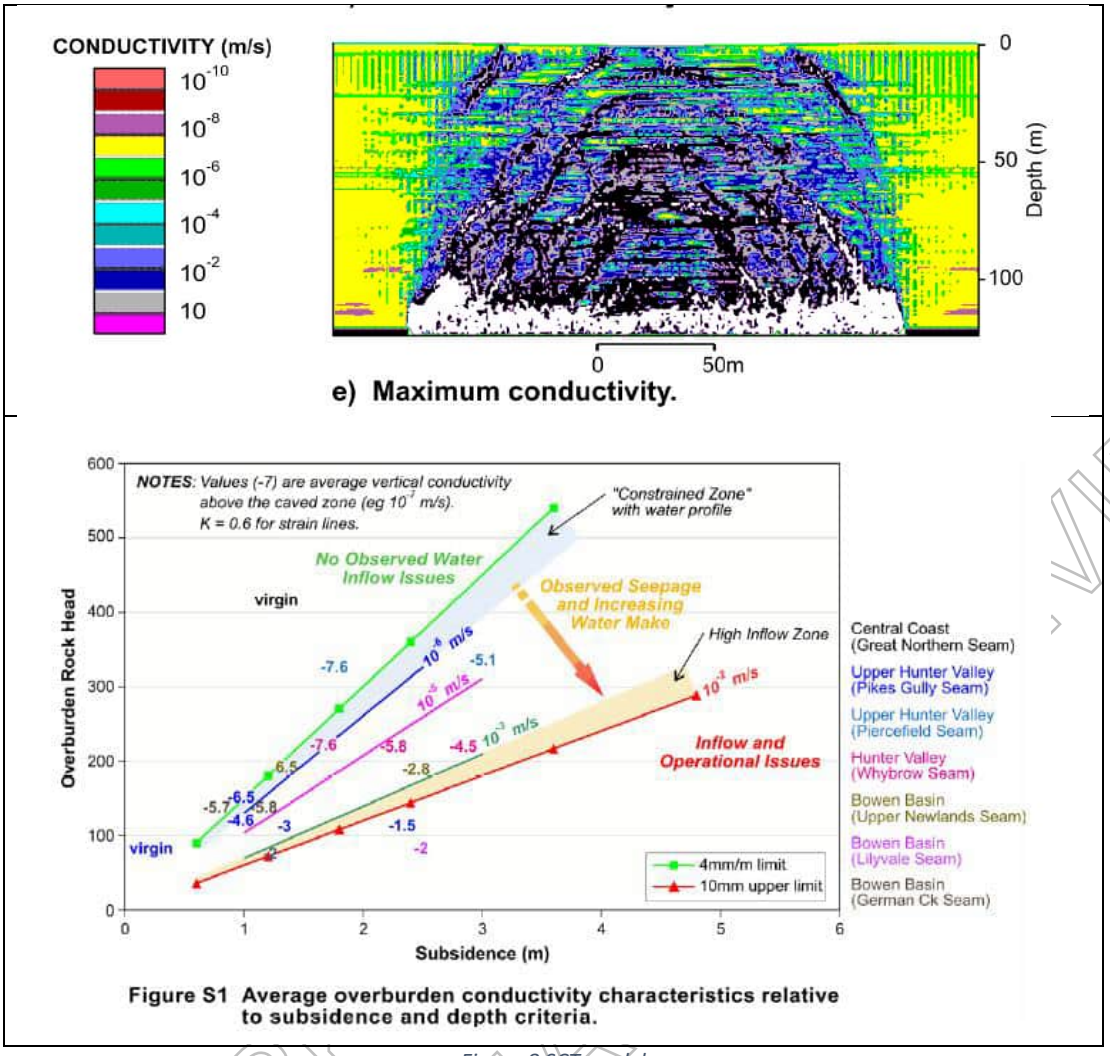

Figure 8 SCT model

4 MODELS FOR SHALLOW GROUNDWATER IMPACT

4.1 Tammetta model

Tammetta (2012) was primarily concerned with the impact of longwall on shallow ground water resources (Figure 9). His work was based on the interpretation of piezometer data to indicate the zone of complete groundwater drainage (unsaturated) which he refers to as the "Collapsed Zone". The maintenance of instrumentation, in particular cabling, is a challenge when differential movements in the caving overburden could be in the order of 1-2 m. The possibility of loss of signal due to cable breakage instead of a drop in the standing water level was not considered. We have concerns about the integrity of the data base that was utilised. The predictive equation for the height of a parabolic-shaped collapsed zone with complete drainage is independent of the overburden geology. The predicted height of his collapsed zone is significantly greater than that for Ditton/Merrick's Zone B (Figure 7) and in all cases implies connection to the surface for a 340 m wide longwall for all depths considered.

Tammetta (2013) provides empirical data on hydraulic conductivity from lugeon testing in boreholes. He presents data that indicate a 2 orders of magnitude increase down the panel centreline within the upper portion of the collapsed zone, and 1 order of magnitude above the collapse zone. There are no data for the lower portion of the collapsed zone but he extrapolates very high values.

FOR INTERNAL WORK VIEW

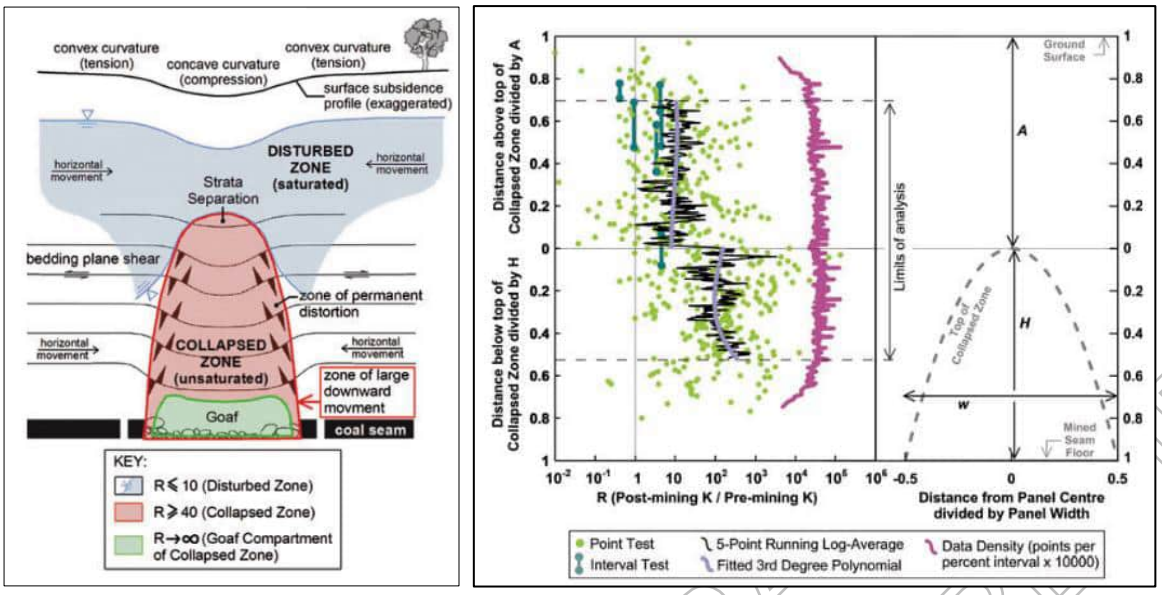

Figure 9 Tammetta's model for the extent and hydraulic conductivity in the Collapsed Zone.

The essential difference is that the Tammetta model allows the prediction of drainage path from the surface to the mine workings over a much greater range of depths compared to the Kendorski and Ditton/Merrick models. The hydraulic conductivity proposed by Tammetta is sufficient to impact shallow groundwater users but not present an inflow hazard to the underground mine.

The conceptual caving model presented in Galvin (2016) combines the Kendorski model with the zones limited by angles of draw with a derivative of the Tammetta collapsed zone within the fractured zone. Kendorski dilated zone is renamed as the constrained zone.

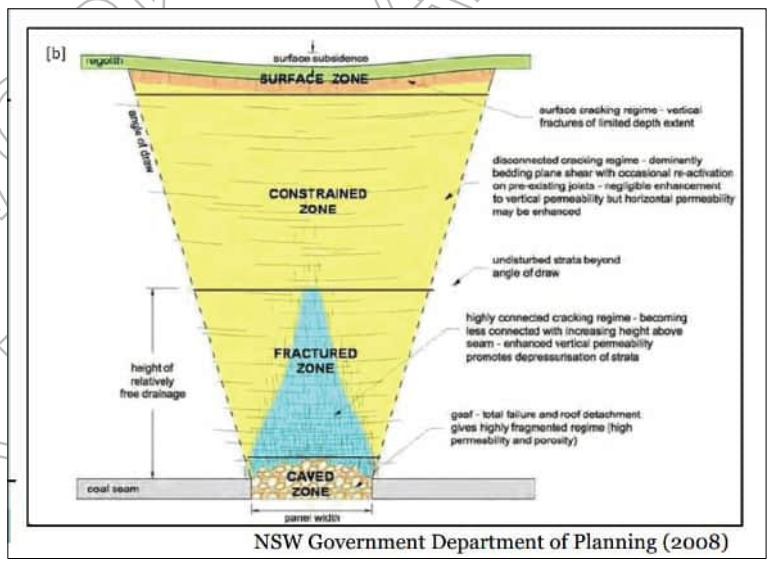

Figure 10 The Mackie conceptual model (Galvin, 2016)

4.2 CSIRO models

In a number of ACARP reports, CSIRO has developed a set of complex DEM (Discrete Element Method), PFC (Particle Flow Code) and finite element simulations to estimate hydraulic conductivity. DEM and PFC offer the possibility of specifically considering apertures which are then imported into

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a finite element code to assess hydraulic conductivity. The resulting fracture models are similar to the SCT models (Figure 11) and hence inconsistent with the observed mining conditions and the physical models. The results are presented in terms of changes in the permeability (which is the same as changes in hydraulic conductivity) and show extreme variation – up to 5 orders of magnitude at some depths.

The same limitations for application to mine closure studies are present – not readily accessible, possibly not representative of actual mine conditions, and lack of precision in terms of predicted hydraulic conductivity.

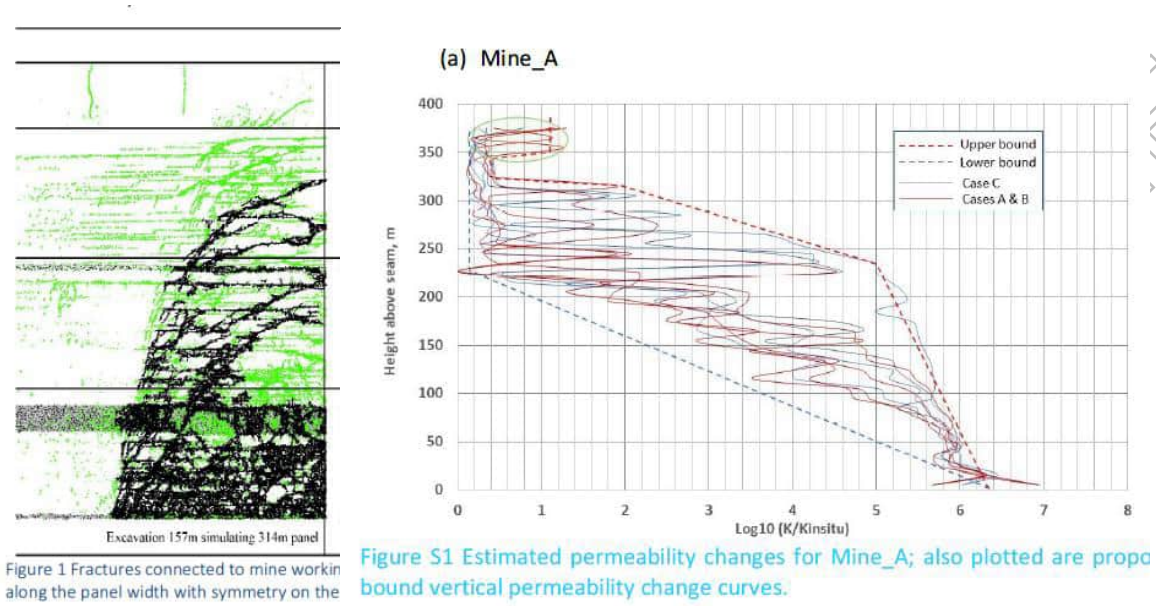

Figure 11 CSIRO model

5 GEOTECHNICAL MODEL

5.1 Background

The previous 2 sections of this report outline some of the weaknesses of the available empirical models. In this context, the comment by Gavin (2017)[1]

> *The authors of the five reports relevant to this summary document are consistent in their advice that neither the Tammetta equation nor the Ditton equation for the height of free drainage is robust because neither properly and adequately accounts for geology, the mechanics of rock behaviour and time dependent hydrogeology processes. This has implications for the construction and calibration of some numerical models which have found application to Dendrobium Mine and, hence, to the reliability of predictions based on these models. Models may need to be updated and rerun.*

In the past 2 decades Crinum Mine conducted longwalling under a laterally extensive aquifer and as a result of intensive monitoring of ground levels and mine pump outs was able to supply key data to test the predictions of the available empirical models. An alternative model has been developed and reported in 3 peer-reviewed technical papers.

[1] Galvin and Associates Pty Ltd. 2017. Summary and explanation of height of fracturing issues at Dendrobium Mine. Report for NSW Department of Planning and Environment. Report No, 1716-11/1b.

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5.2 Inflows to Crinum Mine

Seedsman (2019) analysed several years of mine pump-out data for a shallow longwall mine in the Bowen Basin (Crinum North) that was located under a columnar-jointed basalt aquifer that was recharged three times by rainfall (Figure 12.

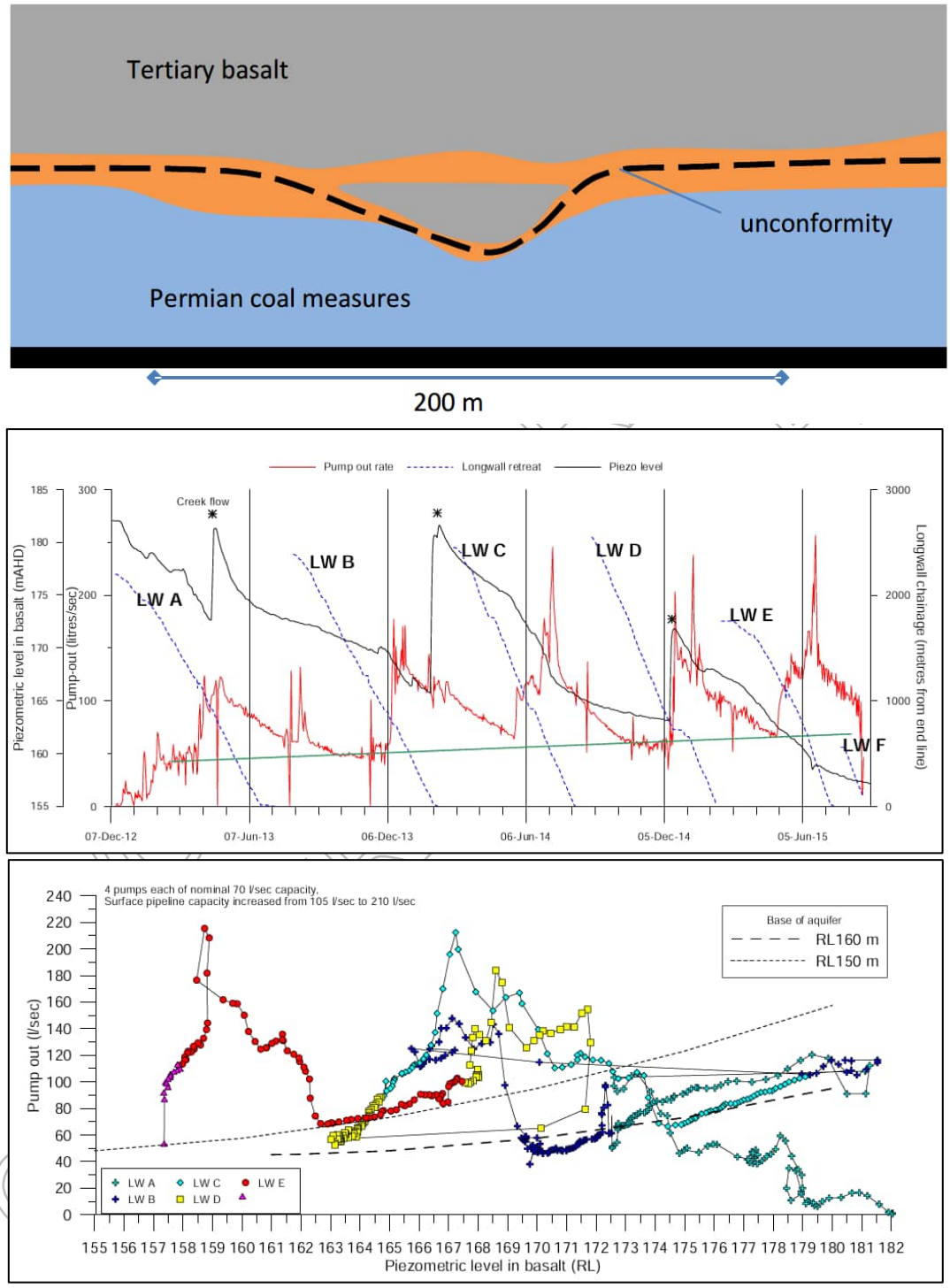

Figure 12 Crinum North: top is geological cross section at natural scale, middle are trends in pump out rates (black line), longwall retreat (dashed blue line), and groundwater level (black line), lower – cross plot of groundwater level and pumpout rate.

The pump-out rates did not increase with the progressive extraction of each longwall panel indicating that inflow was not related to cross-sectional area in a standard Darcian approach. Likewise, the peak pump-out rate did not correspond to the highest groundwater level. It was also noted that pump-outs were not required if the face was not moving, even when the basalt aquifer was recharged. Considering the data in the context of Dary flow, it was concluded that the inflow paths had different cross-sectional areas and hydraulic conductivity to those in the empirical models.

The proposed explanation was that inflow to the mine was related to a fracture connection to the aquifer that progressed with the retreating longwall face (Figure 13)– this was called the Enhanced Conductivity Zone (ECZ). The explanation also included the possibility of the material at the base of the collapse softening in the presence of water and then consolidating with a consequent major reduction in hydraulic conductivity – this was called the Potential Consolidation Zone (PCZ).

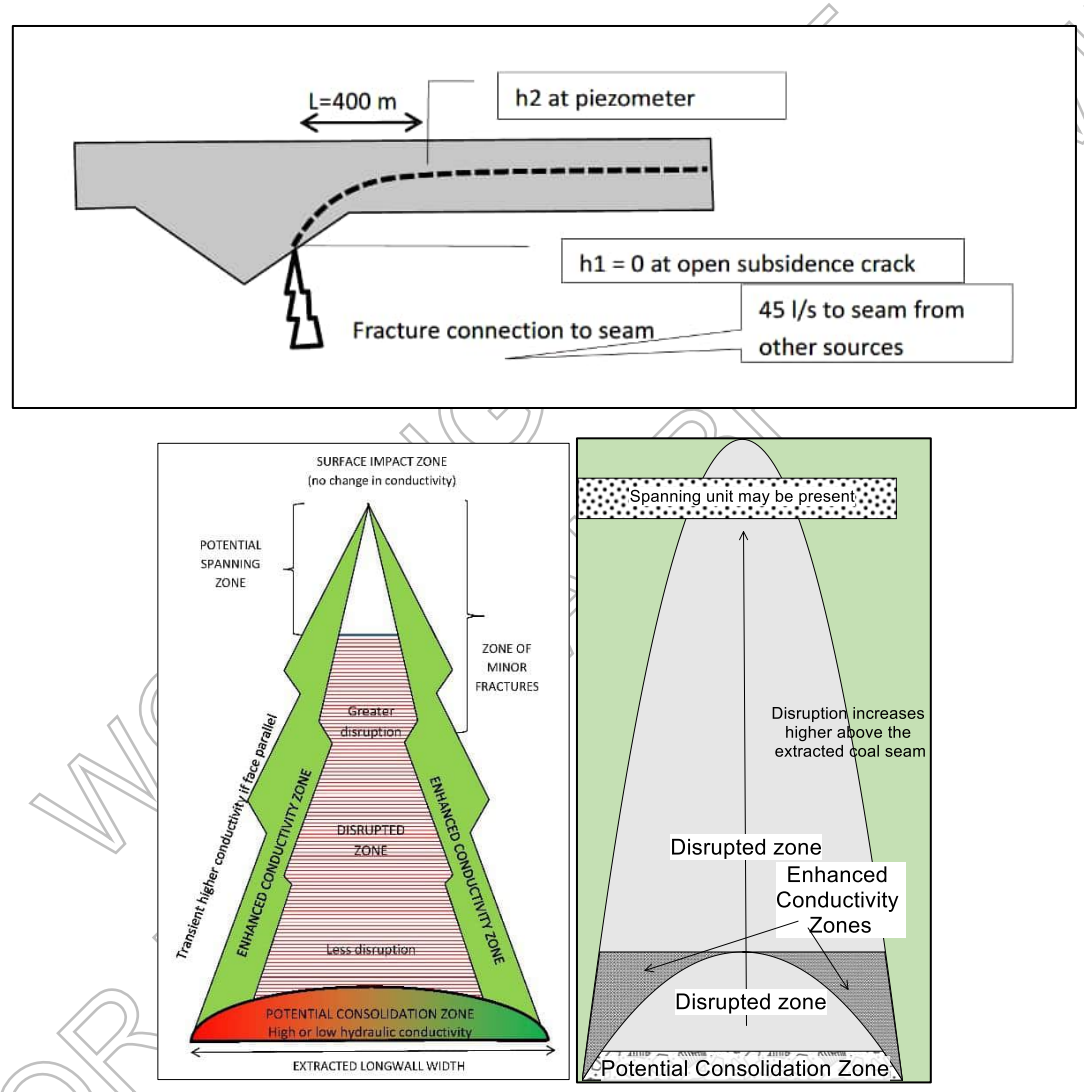

Figure 13 Evolution of the geotechnical model

5.3 Further development

These ideas were further developed in Seedsman (2021, 2023) with the following (Figure 13):

- The simple triangular-shape of the disrupted zone replaced by a parabolic shape following some numerical analysis of failure in bedding rock masses.

- The height of the disrupted zone is a function of the average thickness of the bedded units in the overburden. The default height is two times the extraction width which is equivalent to the panel geometry that represents the step from subcritical to supercritical (Figure 5).
- The ECZ geometry is based on the D zone angles (Figure 2, with overall shape defined by two parabolas. The ECZ is the locus for high inflows so its height should be similar to heights of Kendorski fractured zone or Zone A.
- It was suggested that the limit of spanning deformation would be in the order of 400 mm. A corollary of this was that if the surface subsidence developed between adjacent chain pillars was in excess of this amount then there would be a fracture connection – albeit possibly tortuous – between the surface and the underground workings.

In research examining the possible use of abandoned longwall mines as lower reservoirs for pumped hydroelectric schemes, Seedsman et al (2023) focussed on the likely hydraulic properties of the various zones. Hydraulic conductivity within the ECZ and Disrupted zone was estimated using a simple geometric model (Figure 14) for the increase in length along a given horizontal line because of downward movement and assuming a given spacing of fractures (be they joints or mining induced). The model assumes no dilation at the centreline above the PCZ. The dilation is equally distributed between the fractures and conductivity is calculated based on laminar fracture flow with smooth interfaces. The predicted conductivity is isotropic. The parameters for the PCZ were derived from large scale permeameter tests. Figure 15 presents the data for conductivity and porosity.

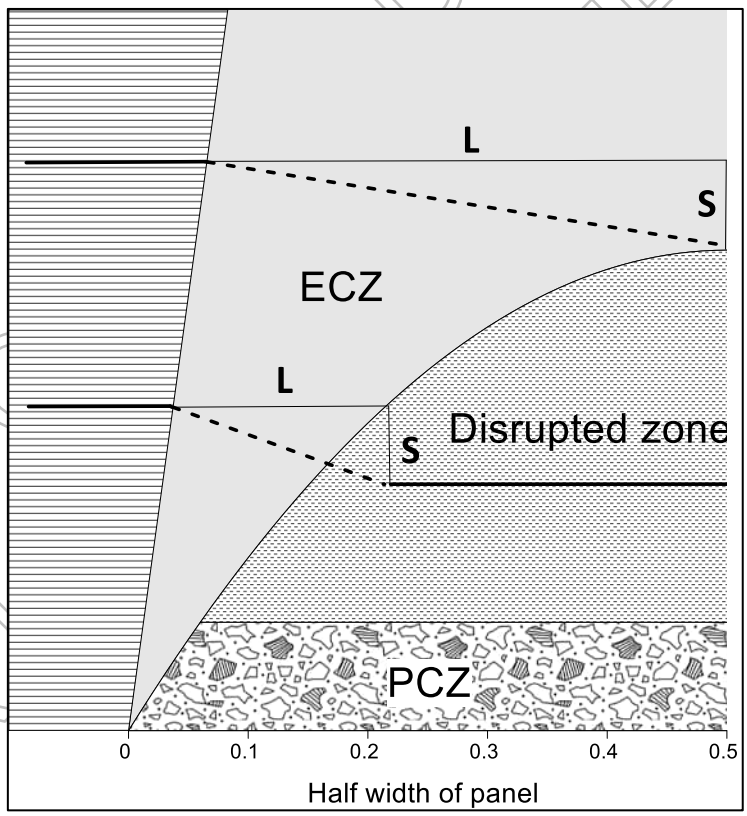

Figure 14 Basis of the geotechnical crack dilation model

The ECZ has conductivities in the order of 0.1-10 m/s with the higher values near the extraction. The values for the PCZ decrease progressively from the edge of the extraction in response to increasing consolidation associated by the progressive increase height of the goaf pile.

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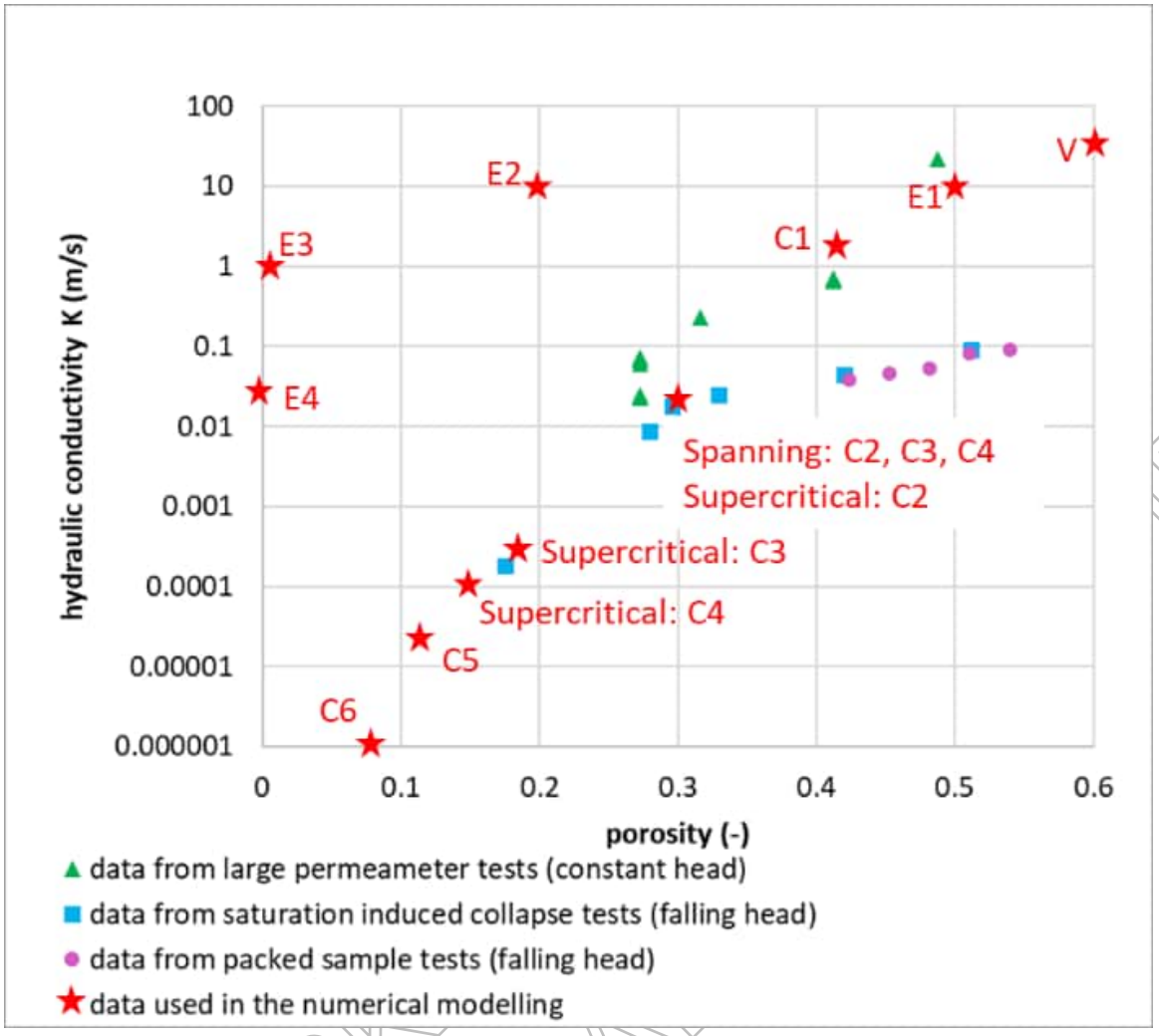

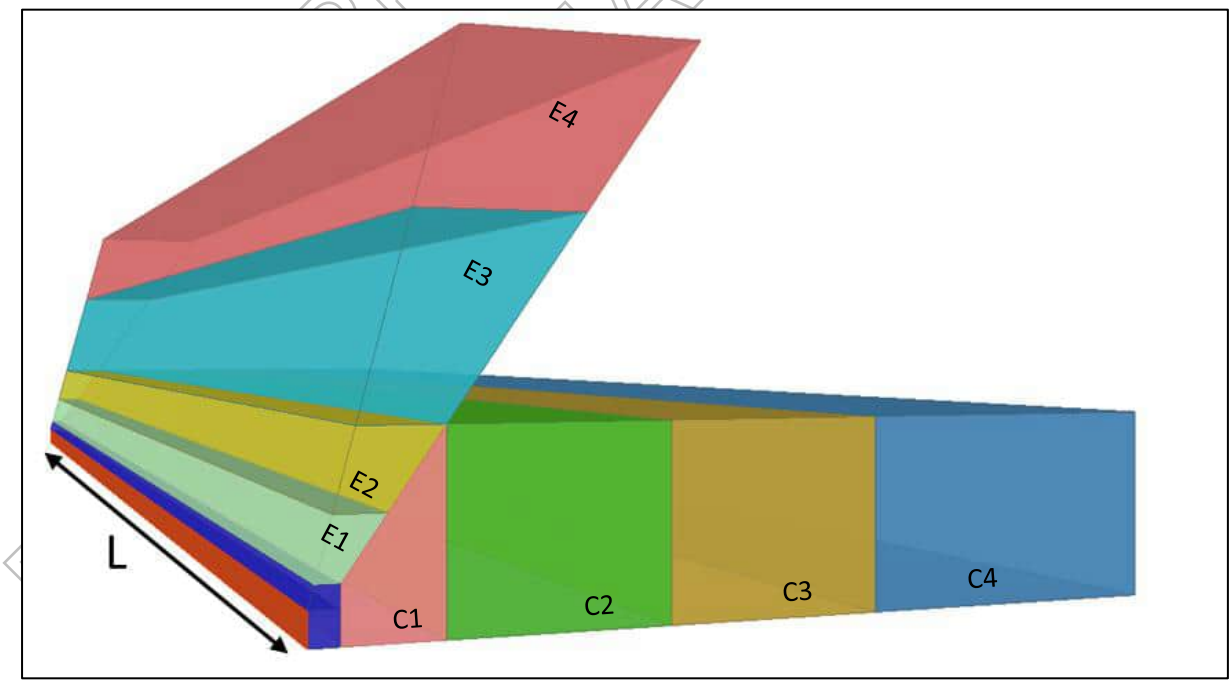

Figure 15 Estimates of the porosity and hydraulic conductivity of longwall goaf material (C1-C6 in the Potential Consolidation Zone, E1-E4 in the Enhanced Conductivity Zone, V is remnants of the initial access roadway).

6 PRCP PREDICTION

The Geotechnical model should be used as the basis for the prediction of hydraulic conductivity associated with the supercritical longwall geometry of BMA's longwall operations. It is important to note that there is no validation of the method available and it is difficult to imagine how it could be done as we are dealing with a large volume. Mine inflows are not useful in this context as they are most likely related to the ECZ and not the larger Disrupted zone and there is the problem of the low conductivity in the PCZ.

The only rock mass property used in the geotechnical model is the spacing of the joints – the rock mass is assumed to be a dilated fractured volume of rigid blocks. The geotechnical model is applicable to the Permian and Tertiary sequences but does not include the possible role of Quaternary and Recent alluvials at the surface.

The input variables to the geotechnical model are:

- Maximum vertical subsidence, or more precisely the difference in the maximum subsidence at /near the panel centreline relative to the subsidence above the chain pillars.
- The extraction width.
- The spacing of the cracks – these may be mining-induced or the natural geological joints. This is a highly uncertain parameter and its selection will require substantial judgement.

Output from the geotechnical Model includes the conductivity changes up to twice the excavation width – it can be sliced at any actual mining depth.

An example is presented in Figure 16 which also includes a sensitivity study on the choice of fracture spacing.

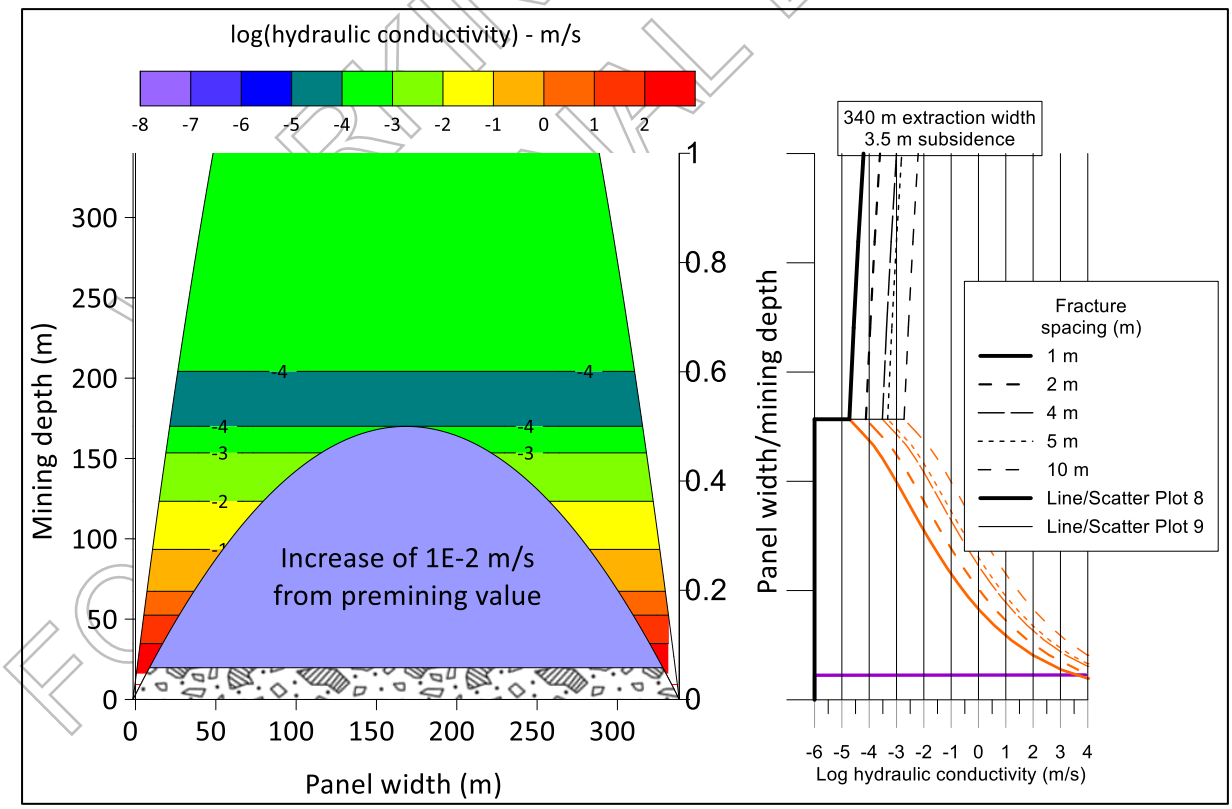

Figure 16 Example of hydraulic conductivity prediction for Broadmeadow with sensitivity to fracture spacing

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7 IMPLEMENTATION IN GROUNDWATER STUDIES

7.1 Overburden

It is noted that Byrnes Geotechnical have separately recommended intentional flooding of undergrounds to initiate any subsequent subsidence deformation as soon as possible in order to reduce geotechnical uncertainties.

The geotechnical model could be implemented in groundwater models as follows:

- The surface footprint of the mine should be the edge of the extraction – not the angle of draw that defines the extent of surface subsidence.
- The adopted hydraulic conductivities should be based on a crack spacing of 2 m. The horizontal and vertical conductivities should be equal.
- Porosity – Within in the Disrupted zone: at depths greater than half the panel width the porosity can be calculated as (seam thickness – maximum subsidence)/depth, At depth < half panel width – no mining-induced changes in porosity.
- Porosity – Within the ECZ

As mentioned in Section 6, there is no available validation of these suggestions.

7.2 Surface cracking

The technical literature consistently reports that there is no evidence that surface cracks are directly connected to the seam, but there will be an indirect connection via the disrupted zone. Site specific studies are recommended to provide data that can be used to confirm the currently available prediction tools.

Whether the cracks stay open will be a function of the surface lithology – sand, clay or rock. For soils the substrate will collapse over time, so the long term impact on the hydraulic conductivity is likely to be negligible.

There will be cracking at the surface where ever the induced tensile strains are in excess of about 5 mm/m. Figure 18 presents a typical subsidence cross line survey and shows how the tensile strains (positive values) develop near the edge of the extraction. The width of any rib side cracks is related to the induced tensile strains which themselves are related to the depth of mining and the extracted seam thickness. An upper bound estimate of the crack width can be derived from tensile strain and the peg spacing – all of the strain is accounted for by 1 crack. So for the example in Figure 18, the maximum tensile strain is 16.5 mm/m, indicating a crack width of 165 mm given that the survey pegs are at 10 m centres.

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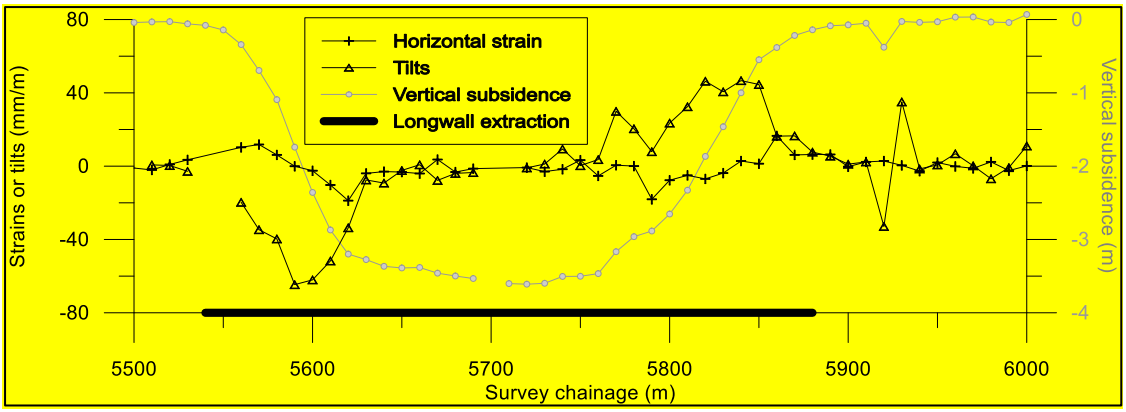

Figure 17 Typical subsidence survey cross line – survey pegs at 10 m centres.

The question of the depth of cracking has not been adequately studied or reported in the technical literature. For the USA mines studied, Kendowski suggested a surface zone that included temporary open fractures with a maximum thickness of 15 m (50 ft) but noted that the fractures did not extend through the full thickness of the zone and were only temporarily open; in 1993 he suggested the same depths and noted that the possibility of filling. It would appear that his case studies involved soils and friable materials at the surface – not rock.

Assuming rigid body movements, the survey data could be used to obtain an estimate of the depth of cracking – crack width/differential tilt either side of the crack. Referring to Figure 18, the maximum strain of 16.5 mm/m implies a crack width of 165 mm and this is associated with a differential tilt of 28 mm/m. The possible depth extent of the crack would be 5.9 m (0.165/0.028). Early application of this approach has given depths of up to 20 m for shallow longwall extraction.

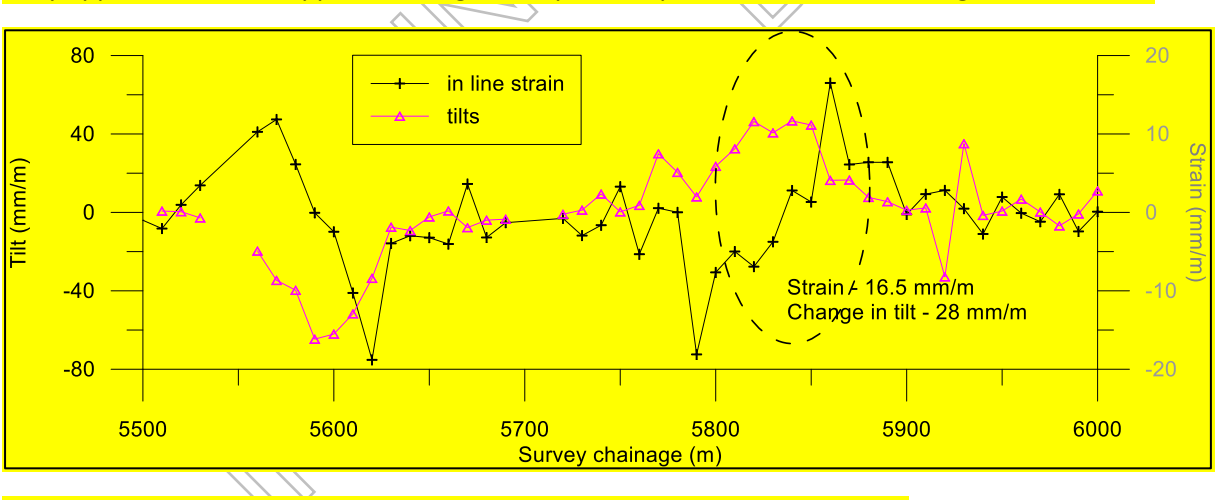

Figure 18 Detail of high strain and high tilt recorded on a subsidence cross line (180 m depth).

7.3 Risks and uncertainties

Any quantification will be challenged as nothing validated and not possible without case studies.

Can improve surface crack knowledge but unlikely to be material if there is a soil cover.

Inevitable that undergrounds will fill from the portal as bulkheads are not installed so surface infiltration may not be material.

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WORKING DRAFT
FOR INTERNAL BHP REVIEW

Appendix C

Calibration

Well	Easting	Northing	Obs (m)	Cal (m)	Obs_Cal	Res^2	Layer
DR-BH01	601292.419	7584122.067	226.6	2.22E+02	4.79	22.97285	4
DR-BH01	601292.419	7584122.067	226.9	2.22E+02	5.14	26.40932	4
DR-BH01	601292.419	7584122.067	226.9	2.22E+02	5.16	26.60496	4
DR-BH01	601292.419	7584122.067	226.9	2.22E+02	5.18	26.87386	4
DR-BH01	601292.419	7584122.067	226.8	2.22E+02	5.11	26.07124	4
DR-BH01	601292.419	7584122.067	226.8	2.22E+02	5.13	26.35796	4
DR-BH01	601292.419	7584122.067	226.7	2.22E+02	5.05	25.5126	4
DR-BH01	601292.419	7584122.067	226.4	2.22E+02	4.81	23.14572	4
DR-BH01	601292.419	7584122.067	226.3	2.22E+02	4.74	22.44864	4
DR-BH01	601292.419	7584122.067	226.2	2.22E+02	4.66	21.68765	4
DR-BH01	601292.419	7584122.067	226.1	2.22E+02	4.60	21.1416	4
DR-BH02	601301.669	7584005.468	226.6	2.24E+02	2.92	8.503056	4
DR-BH02	601301.669	7584005.468	226.8	2.24E+02	3.15	9.941409	4
DR-BH02	601301.669	7584005.468	226.8	2.24E+02	3.17	10.0489	4
DR-BH02	601301.669	7584005.468	226.9	2.24E+02	3.29	10.83726	4
DR-BH02	601301.669	7584005.468	226.8	2.24E+02	3.21	10.3041	4
DR-BH02	601301.669	7584005.468	226.7	2.24E+02	3.13	9.821956	4
DR-BH02	601301.669	7584005.468	226.6	2.24E+02	3.05	9.296401	4
DR-BH02	601301.669	7584005.468	226.4	2.23E+02	2.90	8.415801	4
DR-BH02	601301.669	7584005.468	226.2	2.23E+02	2.72	7.425625	4
DR-BH02	601301.669	7584005.468	226.1	2.23E+02	2.64	6.980164	4
DR-BH02	601301.669	7584005.468	225.9	2.23E+02	2.48	6.1504	4
DR-BH04	601335.479	7583739.129	174.6	1.85E+02	-10.12	102.3335	6
DR-BH04	601335.479	7583739.129	174.5	1.85E+02	-10.11	102.2728	6
DR-BH04	601335.479	7583739.129	174	1.84E+02	-10.19	103.8157	6
DR-BH04	601335.479	7583739.129	174.1	1.84E+02	-9.97	99.38096	6
DR-BH04	601335.479	7583739.129	174	1.84E+02	-10.00	99.90003	6
GN2480	603095.291	7607320.428	280.55	2.82E+02	-1.25	1.552516	1
GN2480	603095.291	7607320.428	280.54	2.82E+02	-1.21	1.466521	1
GN2481	603318.181	7607579.166	287.07	2.86E+02	1.24	1.545049	1
GN2481	603318.181	7607579.166	286.98	2.85E+02	1.61	2.601769	1
GN2482	603024.531	7608167.823	287.27	2.91E+02	-3.27	10.71253	1
GN2482	603024.531	7608167.823	287.09	2.89E+02	-1.85	3.433609	1
GRM_BH1	598515.474	7587336.538	249.5	2.48E+02	1.96	3.849444	1
GRM_BH1	598515.474	7587336.538	249	2.47E+02	1.81	3.286969	1
GRM_BH1	598515.474	7587336.538	248.9	2.47E+02	1.81	3.283344	1
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GRM_BH1A	598508.847	7587324.113	236.7	2.44E+02	-7.26	52.63503	4
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GRM_BH2	598384.785	7587059.009	246	2.45E+02	0.95	0.908209	1
GRM_BH2	598384.785	7587059.009	246	2.45E+02	1.05	1.096209	1
GRM_BH2	598384.785	7587059.009	246.2	2.45E+02	1.32	1.750329	1
GRM_BH3	598539.067	7586975.078	247.7	2.46E+02	1.99	3.976036	1
GRM_BH3	598539.067	7586975.078	247.2	2.45E+02	1.90	3.625216	1
GRM_BH3	598539.067	7586975.078	246.9	2.45E+02	1.71	2.934369	1
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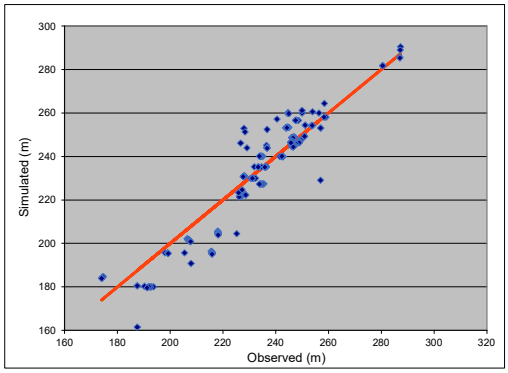
GRM_MB_120_01	598018.995	7587281.999	253.8	2.54E+02	-0.47	0.224676	1

Mean Error	0.73
RMSE	8.66
SD	8.65
Head range	113.27
Scaled ME	0.64%
Scaled RMSE	7.6%
Scaled SD	7.6%
R^2	0.89



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GRM_MB_122_02	598212.995	7586970	244.4	2.53E+02	-9.03	81.59509	1
GRM_MB_122_02	598212.995	7586970	244.4	2.53E+02	-9.03	81.59509	1
GRM_MB_122_02	598212.995	7586970	244.4	2.53E+02	-9.03	81.57702	1
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GRM_MB0402	606839.503	7599011.499	251.1	2.54E+02	-3.30	10.91642	1
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GRM_MB104	596513.999	7592622	256.3	2.60E+02	-3.80	14.46281	1
GW004A	604809	7590705	235	2.40E+02	-5.10	26.05082	1
GW004A	604809	7590705	234.5	2.40E+02	-5.62	31.55069	1
GW004A	604809	7590705	234.3	2.40E+02	-5.82	33.90733	1
GW004A	604809	7590705	234.2	2.40E+02	-5.93	35.21236	1
GW004A	604809	7590705	234.3	2.40E+02	-5.84	34.12896	1
GW004A	604809	7590705	234.2	2.40E+02	-5.95	35.3906	1
GW004A	604809	7590705	234	2.40E+02	-6.16	37.88403	1
GW004A	604809	7590705	233.8	2.40E+02	-6.36	40.43688	1
GW004B	604809	7590705	231.6	2.30E+02	1.60	2.56	2
GW004B	604809	7590705	230.5	2.30E+02	0.50	0.25	2
GW004B	604809	7590705	231.3	2.30E+02	1.30	1.69	2
GW004B	604809	7590705	231.3	2.30E+02	1.30	1.692601	2
GW004B	604809	7590705	232.3	2.30E+02	2.30	5.294601	2
GW004B	604809	7590705	231.2	2.30E+02	1.20	1.444804	2
GW004B	604809	7590705	231	2.30E+02	1.00	1.004004	2
GW004B	604809	7590705	231.1	2.30E+02	1.10	1.216609	2
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GW007A	604966	7596895	256.9	2.53E+02	3.77	14.22044	1
GW007B	604966	7596895	242.6	2.40E+02	2.60	6.754801	2
GW007B	604966	7596895	242.6	2.40E+02	2.59	6.723649	2
GW007B	604966	7596895	242.6	2.40E+02	2.59	6.702921	2
GW007B	604966	7596895	242.7	2.40E+02	2.68	7.193124	2
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GW007B	604966	7596895	241.6	2.40E+02	1.56	2.442969	2
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MB20GRM06A	599996.347	7582044.539	227.7	2.31E+02	-3.11	9.665881	1
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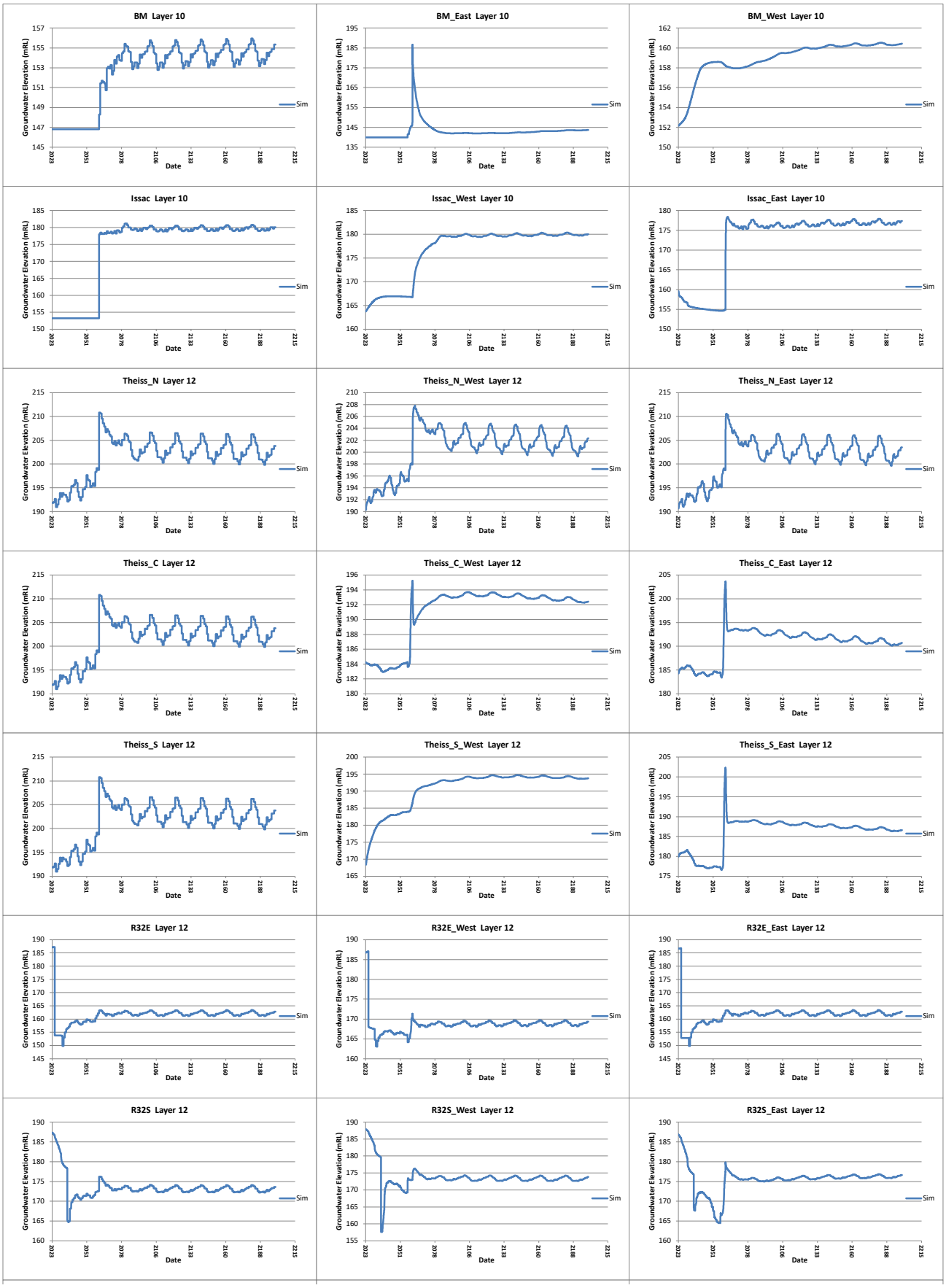
Appendix D

Hydrographs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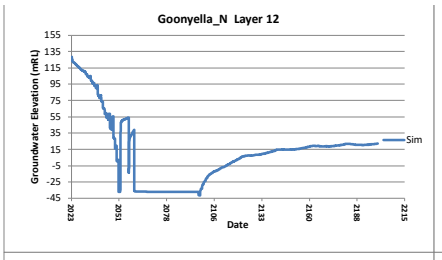
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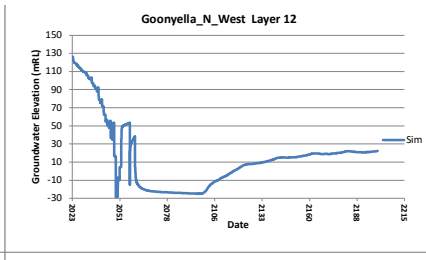
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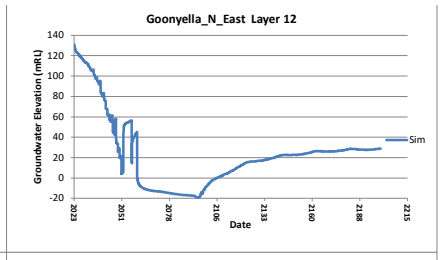
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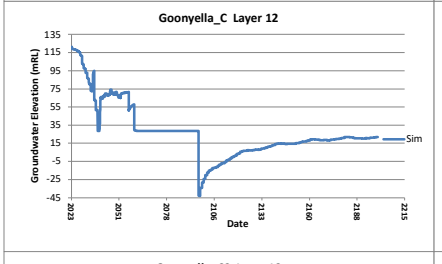
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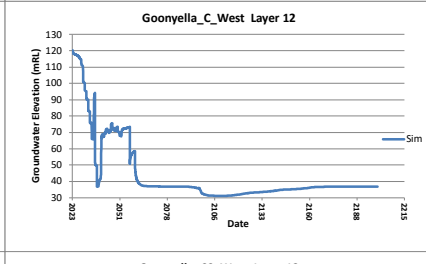
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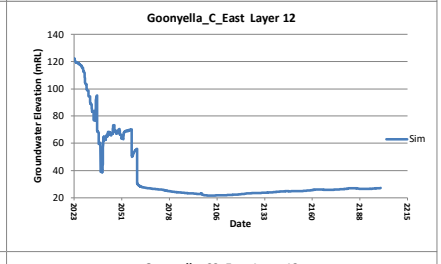
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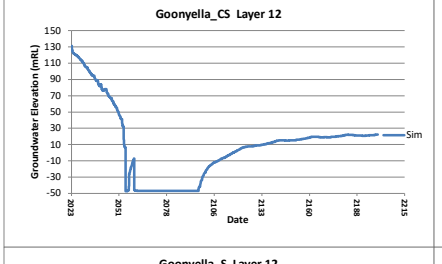
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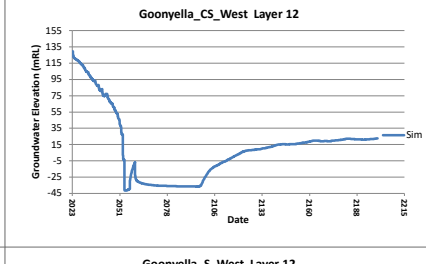
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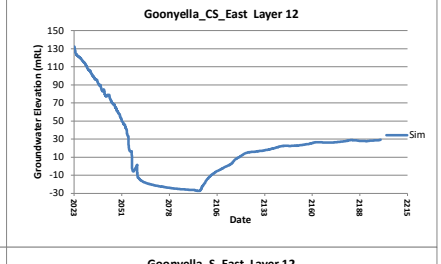
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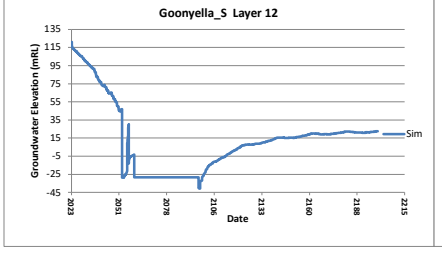
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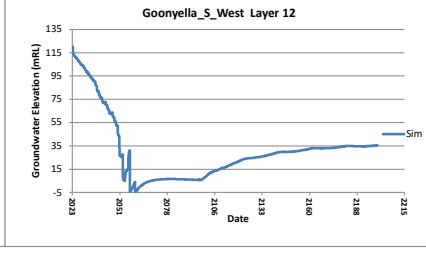
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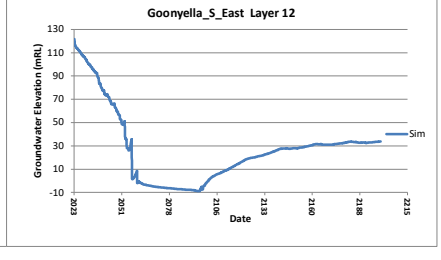
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Date
Sim

ENGENY

BHP MITSUBISH ALLIANCE

PRCP Concept Design Report

Eureka Creek Diversion

QC1000_051-REP-001-3

26 SEPTEMBER 2024

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1. INTRODUCTION

1.1 Context

The purpose of this report is to detail the concept design developed for the closure and ultimate relinquishment of the Eureka Creek Diversion which is an authorised watercourse diversion under the *Water Act 2000* located at Goonyella Riverside Mine (GRM). The watercourse diversion is required to achieve a state of dynamic equilibrium enabling its relinquishment in the post closure landform of the GRM. In addition, the GRM Environmental Authority (EA) (EPML00853413) requires all areas significantly disturbed by mining activities must be rehabilitated in accordance with specified rehabilitation requirements.

The long-term performance of the diversion under both operating and closure scenarios is assessed within the following objectives, based on requirements from relevant licences and approvals:

- The diversion demonstrates to be in a safe, stable, non-polluting, and self-sustaining state (As per Environmental Authority requirements outlined in Section 3.3).
- Rehabilitation requirements (acceptance criteria) include goals, objectives, and acceptance criteria for the post mining land use of the 'Watercourse' which is applicable for the watercourse diversion.
- Achieves the key outcomes identified in the Department of Natural Resources, Mines and Energy (DNRME) Guideline: Works that interfere with water in a watercourse for a resource activity – watercourse diversions authorised under the Water Act 2000 (DNRME, 2019).

This report details the design requirements for the rehabilitation of the diversion for incorporation into the Progressive Rehabilitation and Closure Plan (PRCP) for GRM as described in the Queensland Department of Environment, Science, and Innovation (DESI) Guideline: Progressive rehabilitation and closure plans (ESR/2019/4964, Version 3- 4 April 2023).

1.2 Purpose and Scope

The scope of work for each diversion is comprised of two stages:

- Stage 1: Options identification, assessment and selection.
- Stage 2: Concept Design on the preferred option outcome from Stage 1.

The purpose of this document is to outline the concept design developed for the preferred diversion option (outcome from Stage 1) to achieve a state of dynamic equilibrium resulting in a relinquishable state for the diversion. The following methodology was utilised:

- A desktop geomorphic assessment of the creek was undertaken using historical aerial imagery and survey to identify options for the closure alignment.
- Review of existing flood studies to determine peak flow rates for design flow events to assess hydraulic performance.
- Hydraulic assessment of the diversion option against the criteria in the *DNRME 2019 Guideline: Works that interfere with water in a watercourse for a resource activity – watercourse diversions authorised under the Water Act 2000 (DNRME, 2019)*.
- Develop concept design sketches and watercourse diversion spatial polygons for presentation in the PRCP.
- Develop concept design report summarising the design and key information required for inclusion in the PRCP.

1.3 Design Process

1.3.1 Concept Design Considerations

The design is concept only, and not at functional level which would be required for approval and construction. The concept design is developed exclusively for PRCP purposes within the limitations of the PRCP, with only permanent design options considered.

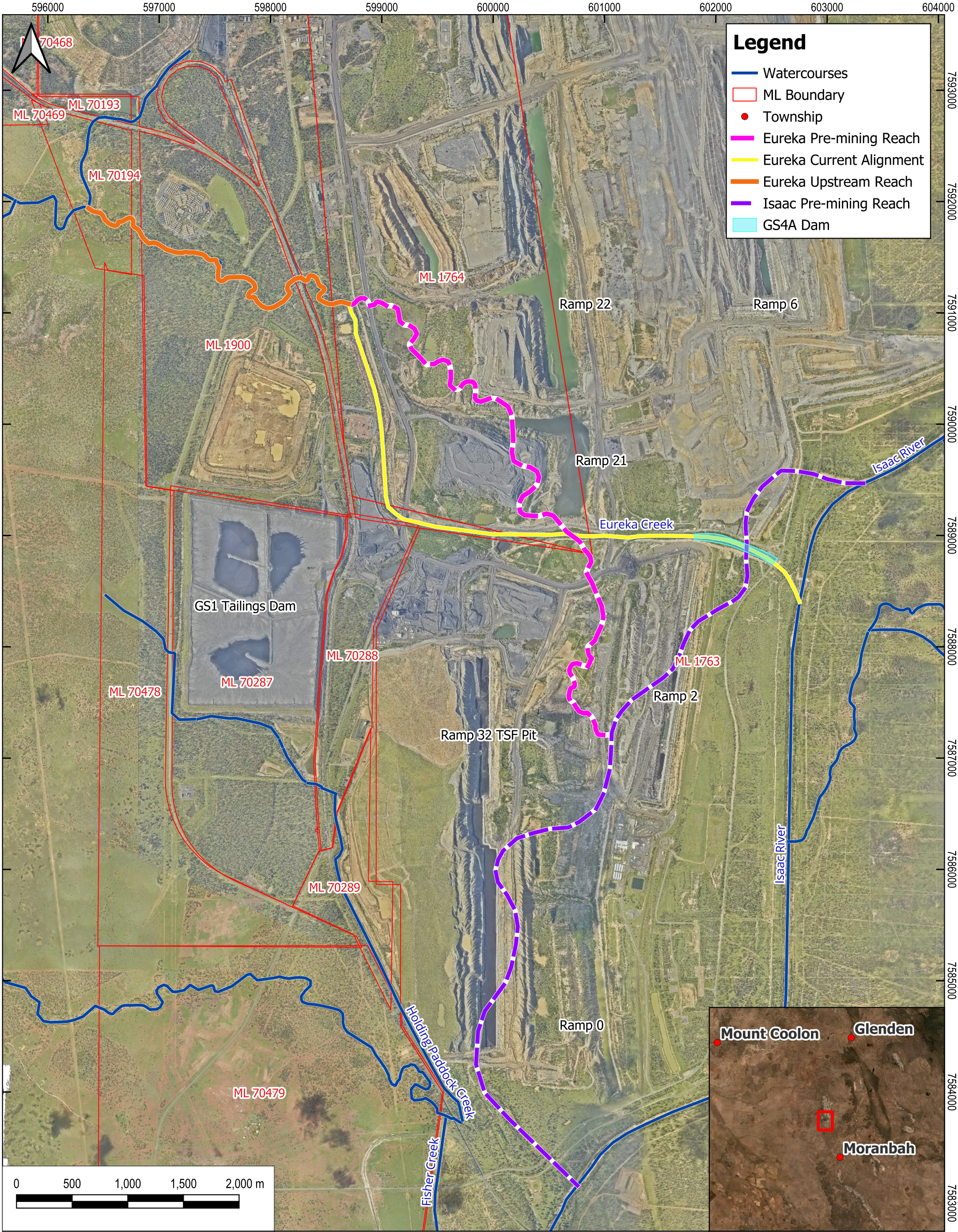
To progress the concept design to a functional design level, detailed site-specific information is required including:

- Soil surveys and geotechnical studies.
- Material characterisation for use in erosion protection cover (i.e. rock sizing and composition).
- Site specific revegetation studies.

2. OVERVIEW

2.1 Location

Eureka Creek is a tributary of the Isaac River, located in the Fitzroy River Basin. It is located 25 km north of Moranbah and 200 km southwest of Mackay QLD. The location within the Queensland region is shown in Figure 2.1. The catchment upstream covers an area of approximately 92 km^2 and flows through open woodlands across gently sloping plains for 19 km west of the GRM site. The watercourse was diverted in the late 1980's to facilitate mining activities with a redirection initially south on the western side of GRM then east towards the Isaac River. The GS4A dam at the downstream end of the diversion collects the mine affected water (MAW) from the channel and impounds it for storage and recirculation of MAW.



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ENGENY / BMA BHP Mitsubishi Alliance	1. Aerial imagery courtesy of ESRI.
	2. All unit measurements are provided in metres unless otherwise specified.
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BMA PRCP GRM Eureka Creek Diversion

Location of Eureka Creek Diversion

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2.2 Pre-Mining Conditions

Rehabilitation monitoring of the GRM and Eureka Creek diversion has been conducted since 1995 (Grigg, A. et al., 2001) and since 2015 under the new Department of Natural Resources and Mines (DNRM) model licence conditions (Engeny, 2016). Therefore, any pre-mining information of the area prior to this is limited. The pre-mining natural upstream, downstream and diversion reaches have been described as follows:

- **Upstream reach –** Based on the most recent monitoring report (Alluvium, 2022), Eureka Creek has four stream order one tributaries flowing into the Creek which flow southeast towards the GRM and Isaac River. Much of the catchment was cleared for grazing and is still grazed today. Upstream of the mine, Eureka Creek is a low capacity, moderately sinuous channel with a broad floodplain.
- **Downstream reach –** As the Eureka creek flows into the Isaac River, there is no specific downstream reach. Prior to the diversion, the reach entered the Isaac River further downstream where mining infrastructure is currently located. The pre-mining condition of the Isaac River diversion is reported separately.
- **Diversion reach (pre-mining) –** Utilising historical imagery from 1975 and sourced from the Queensland Open Data Portal, the pre-mining reach was approximately 6.5 km long and joined the Isaac River approximately 2 km downstream of the current confluence. The catchment area was approximately 93 km^2 prior to the construction of the diversion and is estimated to have been reduced by 10-15% post mining activity.

2.3 Current Conditions

Rehabilitation monitoring of the Eureka Creek diversion has been undertaken since 1995 and the last major monitoring was completed in 2021 by Alluvium. As part of the major monitoring, the latest condition of the Eureka Creek diversion has been described at the time of writing as follows (Alluvium, 2022):

- The upstream reach is in overall moderate to good condition with the occasional isolated bank erosion which is then offset by sediment build up. The riparian vegetation continuity is also generally good. Species diversity is conforming with biocondition benchmarks and provides a seed source for the diversion.
- The diversion reach remains in poor condition and requires significant management intervention to reduce the export of fine sediment from its batters. This is partly because of the GSA dam which was constructed immediately before Eureka Creek merges into the Isaac River and involves a weir and culvert structure. It forms part of the mine affected water (MAW) system and uses the GS4A dam impoundment and pumping however, it is not on a trajectory to achieve relinquishment. The riparian vegetation is typically limited to a narrow strip beside the channel and the lack of woody vegetation leads to reduced leaf litter, fallen logs, and hollow-bearing trees, resulting in poorer habitat value. Ground cover is often dense through the diversion and dominated by *Cenchrus ciliaris*, in particular upstream of the haul road.

Due to this current condition, it is considered unlikely that the existing diversion with the dam structure will achieve a state of dynamic equilibrium and be suitable for relinquishment following closure of the GRM. The upstream and current diversion reach of the Eureka diversion at the GRM are shown in Figure 2.1.

3. BASIS FOR CONCEPT DESIGN

There are currently two recognised guidelines for design of watercourse diversions within Queensland:

- *Guideline: Works that interfere with water in a watercourse for a resource activity – watercourse diversions authorised under the Water Act 2000 (Department of Natural Resources, Mines and Energy (DNRME), 2019).*
- *Criteria for functioning river landscape units in mining and post mining landscapes (Australian Coal Association Research Program (ACARP), 2014).*

Both the DNRME and ACARP Guidelines were developed based on previous research completed by ACARP in the early 2000s which included assessment of existing diversion performance and the development of design and rehabilitation criteria for watercourse diversions.

3.1 DNRME Guidelines

3.1.1 Diversion Design Outcome Requirements (Permanent Watercourse Diversions)

The diversion design outcome requirements are nominated by DNRME for permanent watercourse diversions and have been used to develop the design for Eureka Creek diversion:

- Outcome 1 – The permanent watercourse diversion incorporates natural features (including geomorphic and vegetation) present in the landscape and in local watercourses.
- Outcome 2 – The permanent watercourse diversion maintains the existing hydrologic characteristics of surface water and groundwater systems.
- Outcome 3 – The hydraulic characteristics of the permanent watercourse diversion are comparable with other local watercourses and suitable for the region in which the watercourse diversion is located.
- Outcome 4 – The permanent watercourse diversion maintains sediment transport and water quality regimes that allow the watercourse diversion to be self-sustaining, while minimising any impacts on upstream and downstream reaches.
- Outcome 5 – The permanent watercourse diversion and associated structures maintain equilibrium and functionality and are appropriate for all substrate conditions they encounter.

3.1.2 Design Criteria

DNRME recommend the following design criteria in development of permanent watercourse diversions and have been considered in development of the Eureka Creek diversion:

- The watercourse diversion should tie-in with the existing or receiving watercourse within the resource tenure boundary.
- The stability and performance of a watercourse diversion is assisted by vegetation within the watercourse diversion and adjoining floodplain and does not include artificial structures for grade control that requires ongoing maintenance.
- The channel capacity must be at least equivalent to the natural stream channel capacity existing in that vicinity.
- The length of the channel should be equivalent to the length of the watercourse it replaces.
- Bed grade/slope should be equivalent to the existing watercourse.
- Batter slopes should be designed to maintain stability through different substrates.

The DNRME Guideline also nominates a set of hydraulic design criteria which have been adapted from the original ACARP research. These hydraulic design criteria were developed based on assessment of existing Bowen Basin streams and watercourse diversions and are considered reflective of stable hydraulic conditions for ephemeral systems in central Queensland. The hydraulic design criteria are summarised in Table 3.1 and include the following:

- Shear stress which is a function of discharge, flow depth and hydraulic gradient and represents the tractive force acting on sediment particles and is used to determine the threshold of motion for sediment. High shear stress provides an indication of potential erosion in cohesive sediments or movement of non-cohesive sediments. It also provides a measure of the ability of vegetation to withstand flow.
- Stream power which is a function of hydraulic gradient, flow width and flow rate and represents the energy available to do work on the channel. High stream power values generally result in elevated erosion potential.

- Velocity which is a function of flow rate and cross-sectional area and is a simplified measure of erosion potential. Generally higher velocities result in higher erosion potential; however, stream power and shear stress are more reliable indicators of erosion and sediment transport potential.

TABLE 3.1: DNRME 2019 HYDRAULIC DESIGN CRITERIA

Design Flow Event	Stream Power (W/m^2)	Velocity (m/s)	Shear Stress (N/m^2)
39% AEP (previously 2-year ARI) - no vegetation	<35	<1.0	<40
39% AEP (previously 2-year ARI) - vegetated	<60	<1.5	<40
2% AEP (previously 50-year ARI)	<150	<2.5	<80[1]

[1] DNRME values are extracted from ACARP 2002, however the value reported for the 2% AEP shear stress (<50 N/m^2) in the DNRME 2014 is incorrect. The ACARP value of <80 N/m^2 has been adopted.

The DNRME hydraulic design criteria summarised in Table 3.1 were adopted as the basis for the concept design. The ACARP value described in Section 3.2 are provided for information only. The ACARP values were referenced when considering stable stream powers and shear stresses during the vegetation establishment phase of the construction.

3.2 ACARP Guidelines

ACARP (2014) outlined several approaches to the design of diversion channel dimensions, including:

- The analogous approach, where channel dimensions are selected from a reference reach.
- The hydraulic geometry approach, where dimensions are determined from regression relationships; and
- The analytical approach, where equations are used to calculate continuity, hydraulic resistance, and sediment transport and channel characteristics are determined from field inspection of a reference reach.

In addition to the analogous approach, ACARP (2014) also provides guidance on alluvial channel design parameters which were adapted from ACARP (2002). These hydraulic parameters are intended to be representative of stable watercourses within the Bowen Basin and are summarised in Table 3.2.

TABLE 3.2: ACARP 2014 ALLUVIAL CHANNEL DESIGN PARAMETERS

Stream Type	Sediment Scenario	Stream Power 39% AEP (W/m^2)	Stream Power 2% AEP (W/m^2)
Alluvial	Supply limited	15-35	50-100
	Transport limited	35-60	80-150
Bedrock controlled	n/a	50-100	100-350

ACARP (2014) also provides recommendations on shear stress thresholds for vegetation used as part of rehabilitation activities. These thresholds are summarised in Table 3.3.

TABLE 3.3: ACARP 2014 RECOMMENDED VEGETATION SHEAR STRESS THRESHOLDS

Vegetation Type	Design Shear Stress (N/m^2)
Buffel grass *(Cenchrus ciliaris)*	40
Structurally diverse suite of established native vegetation	120

4. OPTIONS IDENTIFICATION

Engeny identified two potential options for the Diversion as part of stage 1 (summarised below in Table 4.1). The following constraints were also considered during the development of the concept design:

- Geomorphic features of the pre mining drainage path.
- Upstream and downstream channel geometry and grade.
- Remaining within the ML boundary.
- Impacts to, and from, the final landform.
- Impacts to surrounding drainage paths and catchments.
- Permanent options only.

The objective was to identify suitable options for the rehabilitation of the Diversion, and select a preferred option informed by multi-criteria analysis (MCA) to progress to concept design.

Each option was defined with a concept cross section and longitudinal profile. Civil earthworks modelling was undertaken to confirm the following:

- Alignment of the diversion options.
- The need for potential flood levees (during operations).
- Final landform reconfiguration.
- Reinstatement of the floodplain.
- Proposed tie-in locations to the existing waterway.
- Development of a Class 5 capital cost estimate for construction.

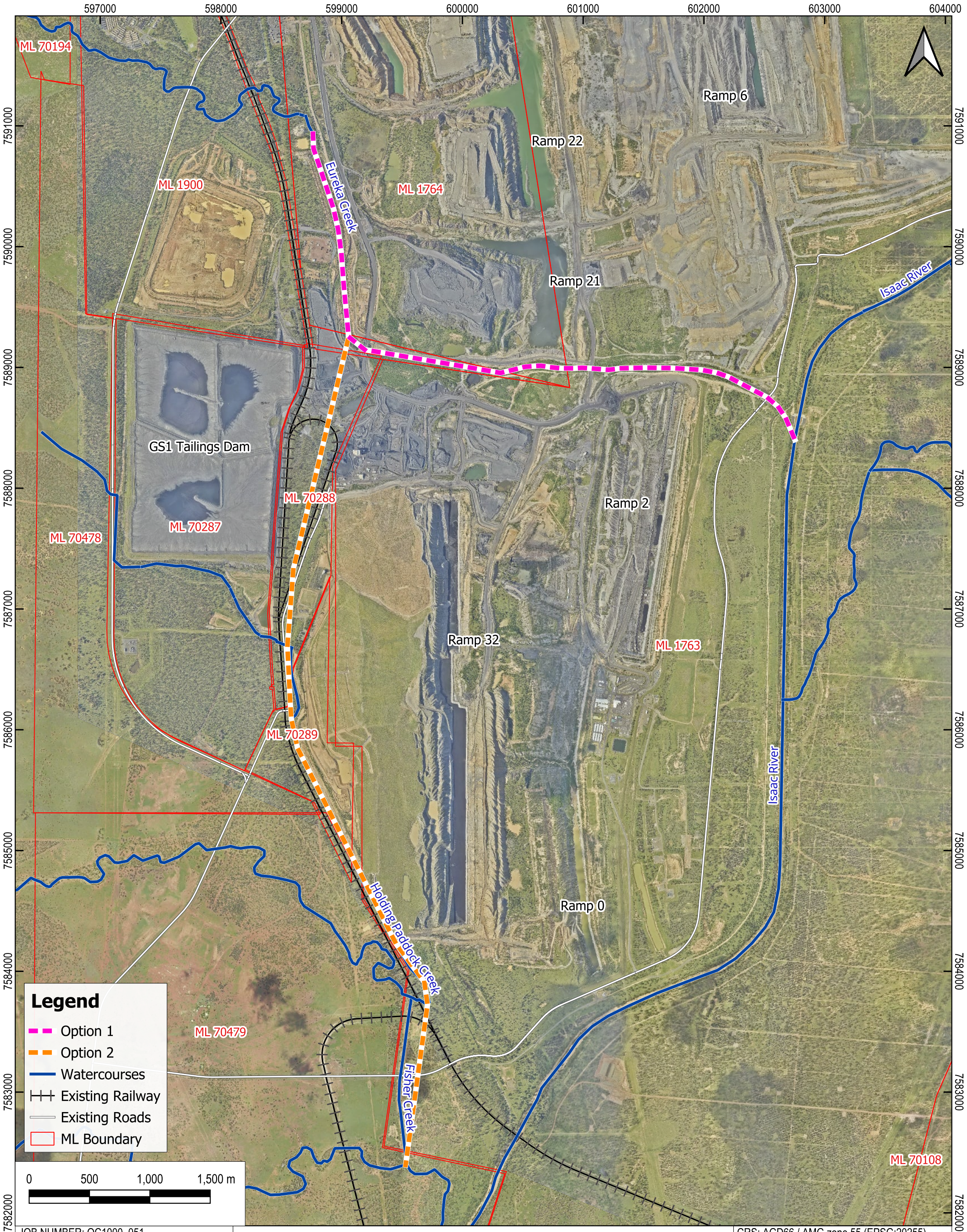
The options identification also included assessment of key risks and opportunities regarding construction staging, potential for impacts to downstream infrastructure and post mining land-use risks in the context of closure.

The three options assessed are shown in Figure 4.1 and summarised in Table 4.1.

TABLE 4.1: OPTIONS IDENTIFICATION DETAILS

Statistic	Option 1	Option 2
Description	Retain existing diversion alignment, GS4A to be desilted and weir removed. Total length is 5.7 km.	Divert to the east of GS1 tailings dam and connect to the Fisher Creek diversion. Alignment sits close to existing railway loop and will link up with the existing Holding Paddock Creek diversion. Total length is 8.8 km
Likelihood that diversion will achieve state of dynamic equilibrium	High – Similar grade to the pre-mining alignment (0.21%). There is no significant difference in geometry or appearance to the existing creek. The existing channel will be regraded and rehabilitated.	Low – Large difference in grade (0.15%) with potential risk with sediment transport regime. Large difference in length (8.8 km). Significant difference in geometry and could have impacts to Platypus Creek.
Order of magnitude cost estimate*	$12.4 M	$24 M
Ability to isolate diversion from flows during establishment period	No – it will be constructed on the existing diversion alignment so there is risk of inflows during construction	Yes – the majority of the diversion can be constructed offline from the existing diversion.

* Costs estimated based on average $10/m^3.



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REVISION: 1	Figure 4.1
AUTHOR: CH	Scale @A3 1:27,500
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DATE: 11/07/2024	GENERAL NOTES:

BMA PRCP GRM Eureka Creek Diversion

Eureka Creek Diversion Realignment Options

1. Aerial imagery courtesy of ESRI.
2. All unit measurements are provided in metres unless otherwise specified.
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5. OPTIONS ANALYSIS

5.1 Multi-Criteria Analysis Framework

A high-level multi-criteria analysis (MCA) was undertaken to rank the identified options for individual criteria as per Figure 5.1 below and determine a preferred option. The weighting of each criterion was determined and agreed upon with a BMA and Engeny collaborative decision group. The individual weightings are summarised in Table 5.1. Based on the score for each criterion against each option, a preferred option is identified.

-3	-2	-1	0	1	2
Fatal Flaw	Strongly Negative	Mildly Negative	Neutral	Mildly Positive	Strongly Positive

Figure 5.1: Ranking Scores for MCA

TABLE 5.1: WEIGHTING FOR INDIVIDUAL SCREENING CRITERIA

Criteria	Weight
Likelihood that diversion will achieve state of dynamic equilibrium	50%
Order of magnitude cost estimate	30%
Ability to isolate diversion from flows during establishment period	20%

5.2 Multi-Criteria Analysis

The MCA resulted in Option 1 to be carried forward into concept design as a preferred option, since it scored highest out of the two options and resulted in the lowest relative risk (see Table 5.2). Refer to Appendix A for the detailed MCA and scoring.

TABLE 5.2: MULTI-CRITERIA ANALYSIS OUTCOMES

Item	Option 1	Option 2
Overall Weighted Score	0.8	-0.2
Relative Risk	Lowest Risk	Neutral Risk
Fatal Flaw	No	No

6. CONCEPT DESIGN

6.1 Design Parameters and Plan

Table 6.1 details the parameters for each outcome in Section 3, forming the design plan for the permanent diversion, aligning with DNRME and ACARP Guideline requirements.

TABLE 6.1: DNRME AND ACARP PARAMETERS ADOPTED

DNRME Parameters (DNRME, 2019)		Equivalent ACARP Parameters (ACARP, 2014)	
Outcome 1 – The design plan should include a detailed description of: a) the location, function, and description of geomorphic features within the proposed watercourse diversion as well as a revegetation and vegetation management plan.	☒	*Outcome 1 –* Geomorphic and riparian vegetation features of the diverted watercourse and connecting reaches (minimum of 1 km upstream and downstream of proposed tie ins). Vegetation characteristics along the proposed optional watercourse diversions should also be noted.	☒
Outcome 2 – The design plan should include a detailed description of: a) the development and calibration, or sensitivity analysis, of the hydrologic model, including the referencing of methodologies used to generate flood frequency analysis.	☒	*Outcome 2 –* Summary of hydrological characteristics including surface water-groundwater interactions and water use. Flow changes along the reach should also be clearly noted.	☒
b) any design implications and construction processes that necessitate a lateral disconnectivity of sub-surface flow between the watercourse and an adjacent final void (if proposed).	☐		
Outcome 3 – The design plan should include hydraulic modelling results (benchmarked against guideline values for stream power, shear stress and velocity adopted from ACARP, 2002) and analysis identifying depth of inundation. The design plan should include a floodplain of sufficient capacity.	☒	*Outcome 3 –* Summary of hydraulic characteristics along the waterway length. Longitudinal section of stream power with standard cross section increments. A higher frequency of cross sections is required at stream junctions and bifurcations.	☒
		A table summarising stream powers (in channel and floodplain) at each cross section is also required, along with statistics for the reach. This specifically includes the reach minimum, low quartile, median, mean, upper quartile and maximum values[2]. [2] Only mean stream power values were calculated for comparison with the adopted criteria.	☐
Outcome 4 – The design plan should include a sediment transport analysis that identifies how the watercourse diversion will manage erosion or deposition events such that they are consistent with the existing sediment regime.	☒	*Outcome 4 –* Sedimentation characteristics. Where the existing reach is aggrading, degrading, or is in equilibrium. Note presence of sediment sources (e.g., main channel bed or bank instabilities, floodplain contributions) and sinks (e.g., flood outs or sediment splays along low gradient sections of the reach, and infilling pools).	☒
Outcome 5 – The design plan should include the specification of spoil placement and sequencing and the settlement process and timing of operation that will ensure the watercourse diversion, once constructed, operates in a stable manner.	☒	Outcome 5 – Interaction between watercourse diversion options and mine infrastructure (pipes, pits, culverts, access, etc.) and planning over the life of mine	☒

It is important to note only benchmark values for shear stress and velocity were adopted from DNRME (2019). Stream power benchmark values were adopted from ACARP (2014) due to it being a more contemporary standard that considers impacts of sediment transport.

6.2 Concept Design Diversion Alignment

The alignment of Option 1 was determined to be the preferred option using the MCA. The option was further refined to optimise the earthworks. The full concept drawing package for the permanent Eureka Creek diversion is included in Appendix E and the interaction of the design with the PRCP landform in Appendix F.

Typically, the works associated with the channel predominately involve flattening over-steep batters, cleaning out accumulated sediment and formalising the low flow channel. In addition, the GS4A weir and culvert structure will need to be removed to facilitate the works with future road crossing requirements for Eureka Creek to be determined during future phases of study.

6.3 Channel Geometry and Grade

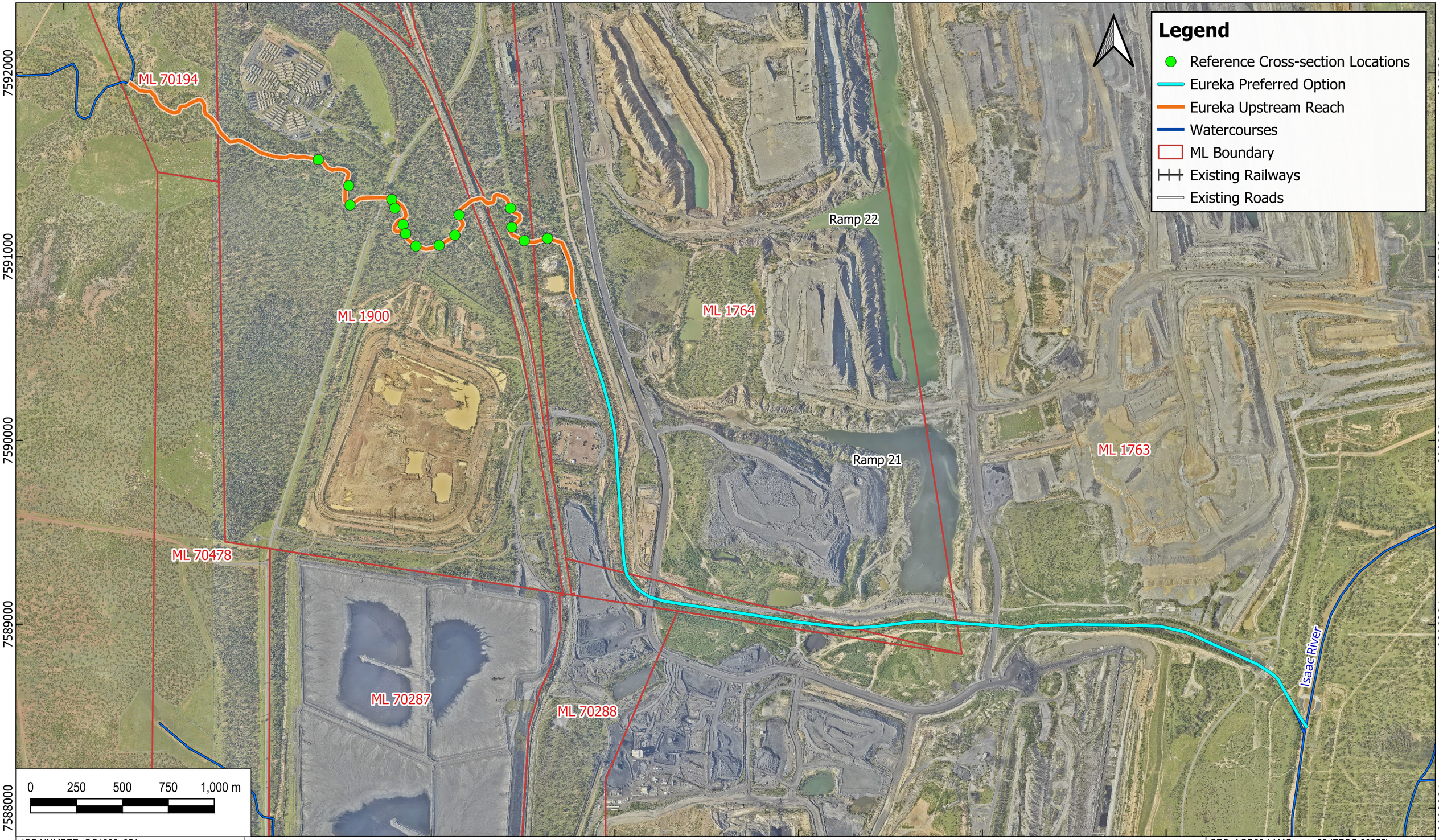
The reference cross-sections are shown in

Figure 6.1. The typical upstream channel cross-sections are presented in Figure 6.2. These dimensions were based on the average upstream channel geometry and grade.

Table 6.2 summarises the typical channel cross-section selected for the concept design. The concept design drawings in Appendix E show the typical cross sections, longitudinal profile, and footprint of the proposed channel works.

TABLE 6.2: DETAILED CHANNEL CROSS SECTION GEOMETRY FOR CONCEPT DESIGN

Channel Geometry	Quantity	Comments
Channel Bed Width	5 m	
Bench Width	6 m	
Channel Depth	2.5 m	Consistent depth of low flow channel at 2.5 m
Batter Slope	1V:3H	For both the low flow channel and high flow channel batters. As per Section 6.2, the diversion works only involve excavation of in-situ material through the following activities: - Flattening over-steep batters - Removing out accumulated sediment and formalising the low flow channel. The batters will be covered with topsoil, hydromulch and hydroseed (Appendix E) to ensure stability and prompt revegetation of the channel batters.



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Location of Reference Cross-Sectional Areas

CRS: AGD66 / AMG zone 55 (EPSG:20255)

Figure 6.1
Scale @ A3: 1:19,000

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1. Aerial imagery courtesy of Google.
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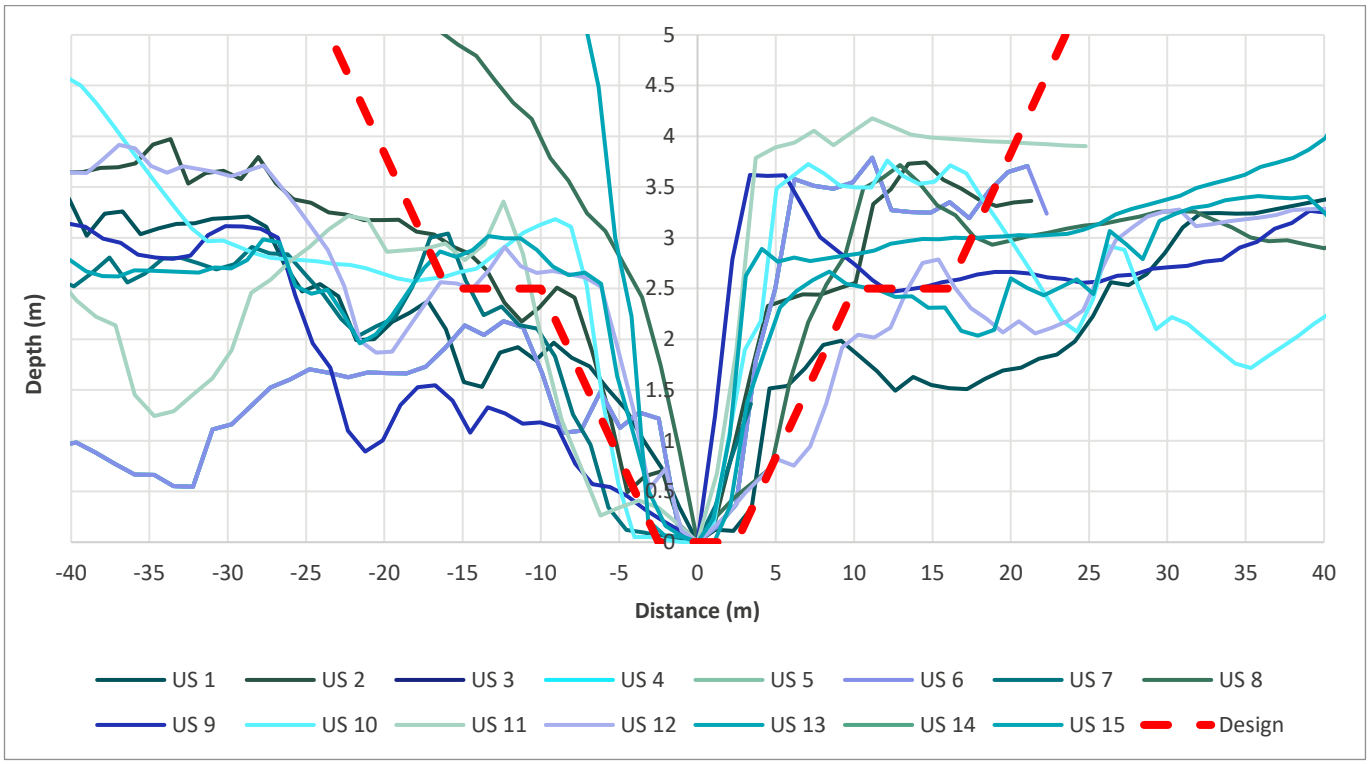
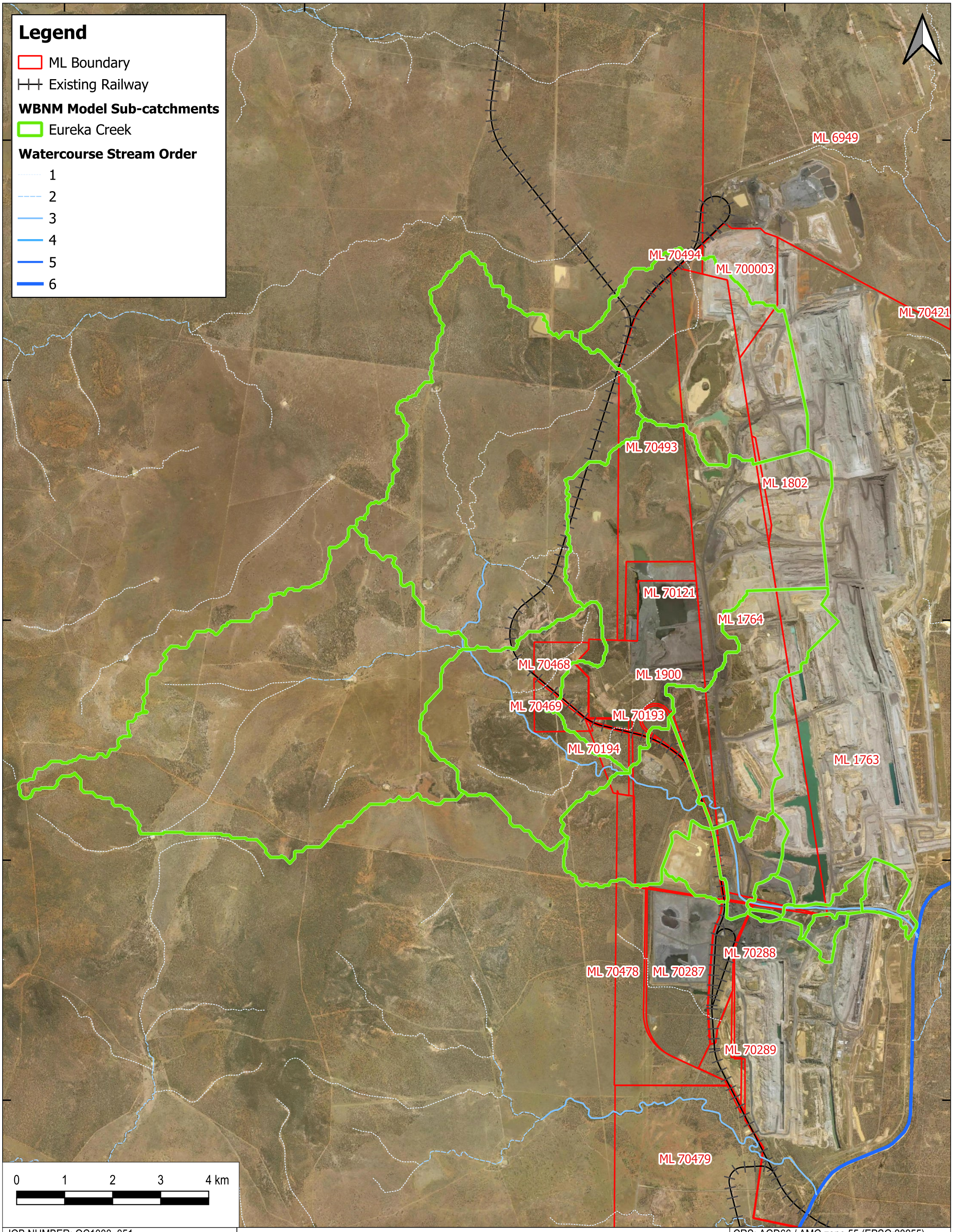


Figure 6.2: Typical Upstream Channel Cross Section of Eureka Creek

The concept design does not seek to add sinuosity to the channel. This is due to the spatial limitations and constraints of the surrounding environment. The current diversion closely approximates the pre-mining conditions for the creek. The current length of the diversion is approximately 5.7 km, the pre-mining length for the same reach was approximately 6.5 km. The existing grade of the diversion is 0.27%, while the design grade is 0.21%. The reduction in grade was implemented to ensure that it aligns with the future planned slope of the Isaac River bed. The reduced length (approximately 12%) in the channel is not expected to adversely impact sediment transport/deposition within the channel. A longitudinal section for the diversion alignment is included in the concept design drawings in Appendix E.

6.4 Hydrology

A hydrologic model of Eureka Creek (concept design) was developed using WBNM software. The model was used to estimate flows for the 1 in 1000-year flood event. The details of the hydrologic model development are presented in Appendix B. Peak flows for frequent events (39% AEP and 2% AEP) for the Eureka Creek diversion were estimated using the ACARP (2002) methods and are presented in Table 6.3. The Eureka Creek catchment is presented in Figure 6.3.



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Catchment Map

CRS: AGD66 / AMG zone 55 (EPSG:20255)

Figure 6.3
Scale @ A3: 1:70,000

GENERAL NOTES:
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6.4.1 Frequent Events

Peak flows for frequent events (39% AEP and 2% AEP) for the Eureka Creek diversion (concept design) were estimated using the ACARP (2002) methods and are presented in Table 6.3. The ACARP (2002) assessment included a regional flood frequency analysis for a selection of gauged catchments in the Bowen Basin region. From this, a method was developed to estimate flood magnitudes for ungauged catchments, based on catchment area and rainfall intensity. The calculated flood magnitudes for the 39% and 2% AEP events were then used to determine diversion design limits for shear stress, stream power and velocity. This approach has been adopted to determine the flows within the proposed Eureka Creek diversion concept design and has been compared to the ACARP (2002) diversion channel design parameters.

TABLE 6.3: EUREKA CREEK DIVERSION DESIGN FLOWS

Rainfall Event	Diversion Channel Design Flows (ACARP, 2002) m3/s
2% AEP (50-year ARI)	172
39% AEP (2-year ARI)	65

6.4.2 Rare Events

The interaction of a 0.1% AEP flood event and the PRCP closure landform was assessed to inform the interaction between the diversion and final voids landform. The 0.1% peak flow rate at the end of the diversion is 727.17 m3/s.

6.5 Hydraulics

A two-dimensional TUFLOW flood model was developed to assess the compliance with the DNRME and ACARP hydraulic performance criteria for the 39% and 2% AEP events.

Average values were derived from the TUFLOW model for the stream powers, stream velocity and shear stress in the 39% and 2% AEP events (refer to Table 6.4). The proposed diversion values have been compared to the DNRME (2019) diversion channel design parameters. The detailed results for the DNRME guideline design criteria (stream power, velocity, and shear stress) as they vary along the length of the channel are presented graphically in Appendix D.

TABLE 6.4: DIVERSION DESIGN CRITERIA COMPARED TO DNRME (2019) GUIDELINE PARAMETERS

	39% AEP (2-year ARI)		2% AEP (50-year ARI)	
Design Criteria	Diversion	DNRME Design Parameter (2019)	Diversion	DNRME Design Parameter (2019)
Stream Power (W/m^2)	39.09	<60	76.59	<150
Stream Velocity (m/s)	1.04	<1.5	1.44	<2.5
Shear Stress (N/m^2)	34.39	<40	51.56	<80[1]

[1] DNRME values are extracted from ACARP 2002, however the value reported for the 2% AEP shear stress (<50 N/m^2) in the DNRME 2014 is incorrect. The ACARP value of <80 N/m^2 has been adopted.

It can be seen from Table 6.4 that all the average diversion hydraulic results are below the design parameters for both the 39% AEP and 2% AEP storm events.

It is noted that the 39% AEP (2yr ARI) stream power and velocities exceed the DNRME design criteria for stability if the channel remains unvegetated. Given that the alignment is unable to be taken offline during construction, it will be critical that vegetation of the channel be established following construction to minimise erosion risk during frequent events. The concept design could be optimised in detailed design to further reduce the stream power and shear stress in conjunction with a planned diversion revegetation strategy.

The extents and depths of the 0.1% flooding are depicted in Figure 6.4. The result shows that there is no risk of flood ingress to any final voids.

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0.1% AEP Flood Event with PRCP Landform 2

CRS: AGD66 / AMG zone 55 (EPSG:20255)

Figure 6.4
Scale @ A3: 1:15,000

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6.6 Risks and Mitigation Measures

Table 6.5 summarises the main risks for the diversion design and its ability to achieve a state of dynamic equilibrium suitable for relinquishment. The consequence and likelihood matrix utilised for this risk assessment align with BHP Global Standard – Risk Management.

TABLE 6.5: DIVERSION RISKS AND MITIGATION MEASURES

Risks	Likelihood	Consequences	Risk Rating and Score	Mitigation Measures	Residual Likelihood	Residual Consequences	Residual Risk Rating and Score
Damage to new diversion channel due to frequent (up to 20% AEP / 5 year ARI) flood events. Diversion alignment unable to be taken offline.	Likely	2	30	Diversion channel constructed during dry season. Detailed revegetation plan to be implemented to promote rapid establishment. Seed mix to include fast establishing species to rapidly stabilise diversion.	Probable	1	3
Damage to the new diversion channel due to extreme/rare (0.1% AEP / 1000 year ARI) flood event (mainly overland flow and bank erosion)	Highly Unlikely	2	0.9	Revegetation plan to include large species capable of withstanding shear stresses associated with rare events.	Highly Unlikely	2	0.9
Construction program impacted by frequent flow event (up to 20% AEP / 5 year ARI). Diversion unable to be taken offline	Unlikely	1	1	Diversion construction to be timed to minimise risk of large flows while still maintaining enough watering to promote vegetation establishment and growth. Potential to construct upstream detention to minimise the peak flows if allowed by existing water licence.	Probable	1	3
Constructability of diversion channel – encountering bedrock, material availability and access	Highly Unlikely	2	0.9	Geotechnical and soil investigations as part of functional design.	Highly Unlikely	1	0.3
Flood ingress into final voids	Highly Unlikely	2	0.9	Final landform design to provide flood protection to ensure no flooding ingress in 0.1% AEP flood with 1.0 m freeboard	Highly Unlikely	2	0.9
Upstream rehabilitation of mining areas unsatisfactory leading to increase sediment loads to the final diversion channel	Likely	2	30	Additional upstream controls could be considered during functional design. Offline flow through sediment basins during vegetation establishment phase of rehabilitated catchments reporting to the Eureka Diversion	Unlikely	2	9

6.7 Additional Design and Construction Considerations

6.7.1 Surface Water Infrastructure

The GS4A weir and culvert structure will need to be removed to facilitate the works.

6.7.2 Soils

The channel bed and banks are expected to be comprised largely of the surrounding soils, which potentially include dispersive sandy to loamy duplex soils. Erosion of the diversion channel is a key risk to the diversion not achieving a state of dynamic equilibrium. Key actions which should be undertaken in detailed design and construction to further quantify and mitigate this risk include:

- A detailed soil survey should be conducted in the functional design stage to determine characteristics of topsoil and subsoil within the diversion alignment.
- The detailed engineering in functional design should specify requirements for cover materials, including rock and rock mulch, to protect diversion batters from erosion.
- Temporary erosion sediment controls should be designed to minimise risk of erosion until vegetation establishment. This plan should be developed and approved by an appropriately qualified person informed by site specific soils data.
- An appropriately qualified person to assess the growth media for the diversion banks and recommend required ameliorants, fertilisers and surface treatments.
- Excess supply of sediment from upstream and adjacent mining activities (spoil dumps, haul roads, coal stockpiles etc.) can impact vegetation establishment within the new diversion. Controls should be established to reduce sediment influx from surrounding landforms during the establishment of the diversion channel.

6.7.3 Revegetation

Hydraulic modelling has demonstrated that the 39% AEP average shear stress of 39.09 N/m2 is slightly above the DNRME guideline value of 35 N/m^2 for a stable channel with no vegetation (refer Table 3.2). Effective revegetation will be crucial for the long-term stability of the diversion reach. A detailed revegetation plan should be developed as part of the function design for Eureka Creek as it will be critical to prevent uncontrolled erosion in the early years following construction.

The revegetation for the diversion should be done in accordance with the revegetation plan informed by baseline vegetation surveys. The plan should:

- Specify the method for revegetation considering direct seeding, mulch blanket, direct planting etc. and be informed by the erosion potential, expected velocities of flows and the cover material in selecting the appropriate method.

The watercourse revegetation species should be based on selecting key framework trees, woody understory and groundcover species associated with the predominant natural watercourse regional ecosystems occurring upstream and/or downstream of the site as prescribed in the Goonyella Riverside Mine Progressive Rehabilitation and Closure Plan.

- Revegetation design should focus on re-establishing riparian vegetation for upper banks, mid banks and lower bank (including bank toe) revegetation zones.
- Include Geomorphic and vegetation features like those in the local landscape.
- Consider irrigation and other controls required to promote vegetation establishment in response to changing climatic conditions.
- Achieve sufficient ground cover to mitigate erosion risk on beds and banks.
- Maintain a sediment transport regime that does not directly impact on upstream and downstream reaches.
- Not require ongoing maintenance.

6.7.4 Monitoring and Maintenance

Monitoring and maintenance of the diversion during the operational phase should be conducted in accordance with BMAs watercourse diversion monitoring program and during the closure phases of the mine is required to be conducted in accordance with the PRCP. The monitoring and maintenance of the diversion during the establishment phase should be done routinely and consider the following (at least):

- Identifying introduced species and weeds for control.
- Success of vegetation establishment and identifying the need for subsequent seeding or planting.
- Climatic conditions which may impact the success of vegetation establishment (i.e., drought).
- Unplanned events which may impact the success of vegetation establishment (i.e., bushfire).
- Monitoring for erosion of beds and banks.
- Sediment transport under low flow conditions to ensure no excess sedimentation.
- Success of temporary erosion and sediment control measures.

The frequency of inspections should be aligned to risk (i.e. increase where control implementation is not suitable), and also following periods of high flow in the diversion.

7. CONCLUSION

The existing diversion is experiencing increasing bank erosion, lack of geomorphic and vegetation features like those in the local landscape, sediment aggradation and sediment deposition downstream.

The concept design has been developed to meet the requirements of the PRCP and achieve a state of dynamic equilibrium enabling its relinquishment in the post closure landform of GRM.

Two options for rehabilitation of the Diversion were identified and assessed using the BMA Multi-Criteria Analysis outlined in Section 5. Option 1 was selected to proceed as the preferred concept design as it retains the existing diversion alignment with maintenance efforts to regrade and rehabilitate along the channel and removes mining infrastructure such as the GS4A dam to achieve the closure objectives. The final concept design, typical cross sections and longitudinal section are presented in Appendix E.

The highest risk to successful performance of the diversion is vegetation failure and subsequent erosion of the banks and bed of the diversion. It is noted that the 39% AEP (2yr ARI) stream power and velocities exceed the DNRME design criteria for stability if the channel remains unvegetated. Given that the alignment is unable to be taken offline during construction, it will be critical that vegetation of the channel be established following construction to minimise erosion risk during frequent events. The concept design could be optimised in detailed design to further reduce the stream power and velocities in conjunction with a planned diversion revegetation strategy.

The concept design demonstrates that the watercourse diversion will satisfy the closure objectives identified in the guidelines, for PRCP purposes.

8. QUALIFICATIONS

(a) In preparing this document, including all relevant calculation and modelling, Engeny Australia Pty Ltd (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

(b) Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

(c) Engeny reserves the right to review and amend any aspect of the works performed including any opinions and recommendations from the works included or referred to in the works if:

   (i) Additional sources of information not presently available (for whatever reason) are provided or become known to Engeny; or

   (ii) Engeny considers it prudent to revise any aspect of the works in light of any information which becomes known to it after the date of submission.

(d) Engeny does not give any warranty nor accept any liability in relation to the completeness or accuracy of the works, which may be inherently reliant upon the completeness and accuracy of the input data and the agreed scope of works. All limitations of liability shall apply for the benefit of the employees, agents and representatives of Engeny to the same extent that they apply for the benefit of Engeny.

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(f) If any claim or demand is made by any person against Engeny on the basis of detriment sustained or alleged to have been sustained as a result of reliance upon the Report or information therein, Engeny will rely upon this provision as a defence to any such claim or demand.

(g) This Report does not provide legal advice.

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APPENDIX A: MULTI-CRITERIA ANALYSIS DETAILS

Multi-Criteria Analysis - Eureka Creek Diversion

Project: PRCP GRM Diversions
Workshop Date:

-3	-2	-1	0	1	2
Fatal Flaw	Strongly Negative	Mildly Negative	Neutral	Mildly Positive	Strongly Positive

Criteria	Assumptions/Considerations	Weight	Option 1	Option 2	Comments
Likelihood that diversion will achieve state of dynamic equilibrium	Considers the difference between diversion length and grade to natural stream length and grade. Ideally diversion length/grade = natural stream length/grade.	50%	1	0	Option 1: Has an alignment with a length (5.7km) and grade (0.21%) similar to the pre-mining alignment. Works will include removing the GS4A dam and regrading and rehabilitating the current diversion. Option 2: Substantial difference in length (8.8 km) and grade (0.15%). Potential impacts to Platypus Creek.
Order of magnitude cost estimate	Assumes $10/m3 of cut.	30%	1	-2	Option 1: Utilises existing diversion corridor. Approximately 1.2MBCM of cut. Option 2: Crosses Existing Rail Loop and there might be interaction with Tailings Dam for the closure.
Ability to isolate diversion from flows during establishment period	Diversion can be isolated from flows if it is constructed offline of the existing diversion.	20%	0	2	Option 1: Will be constructed on the existing diversion alignment. Option 2: The majority of the diversion can be constructed offline from the existing diversion.
		Overall Weighted Score	0.8	-0.2	

Is there a Fatal Flaw?	**No**	**No**
Relative Risk	**Lowest Risk**	**Neutral Risk**

APPENDIX B: HYDROLOGIC MODEL DEVELOPMENT

HYDROLOGIC MODEL SETUP

The WBNM (Watershed Bound Network Model) runoff routing software (2021 version) was used to develop the hydrology model. WBNM automatically calculates catchment routing based on the sub-catchment area, pervious/impervious areas and parameters, and the sub-catchment flow paths.

Catchment Inputs

Sub-catchment delineation for GRM was developed using the PRCP landform (Version 2) topography displayed in **FIGURE F.1**. The hydrological model includes the total catchment for the Isaac River (inclusive of Eureka, HPC, and Fisher creeks) extending downstream past the Goonyella mine, covering a total area of approximately 1180 km^2.

Three open water bodies are located in the upper catchment: Lake Elphinstone, Teviot Dam and Burton Gorge Dam. Lake Elphinstone is a natural lake formed behind the Carborough Range whereas Teviot Dam and Burton Gorge Dam are man-made structures that supply water to Burton and North Goonyella mines in the upper catchment.

The design life of the Teviot Creek Dam and Burton Gorge Dam, as part of mining closure operations, could impact design flow estimates. For this study, the WBNM model did not include the Burton Gorge Dam, Teviot Dam, and Lake Elphinstone located upstream of the study area, considering a worst-case scenario.

FIGURE B.1 provides the sub-catchment extents used for the WBNM.

Model Parameters

The final landform is proposed to be rehabilitated; therefore, the hydrology model has assumed no impervious surfaces remain and a 0% impervious fraction (Fi) for all catchments including the remaining spoil areas and voids.

The default routing parameter of 1, pervious lag parameter of 1.8 and impervious lag parameter of 0.1 have been adopted for the WBNM.

Design Rainfall

The 0.1% AEP (1000yr) was sourced using the Australian Rainfall and Runoff 2019 IFD generation tool available on the Bureau of Meteorology (BoM) website (www.bom.gov.au), at Latitude 21.6652 (S), Longitude 148.0792 (E). Aerial Reduction Factors (ARFs) have been used for all design events to convert point rainfall estimates to areal rainfall estimates.

Temporal Patterns

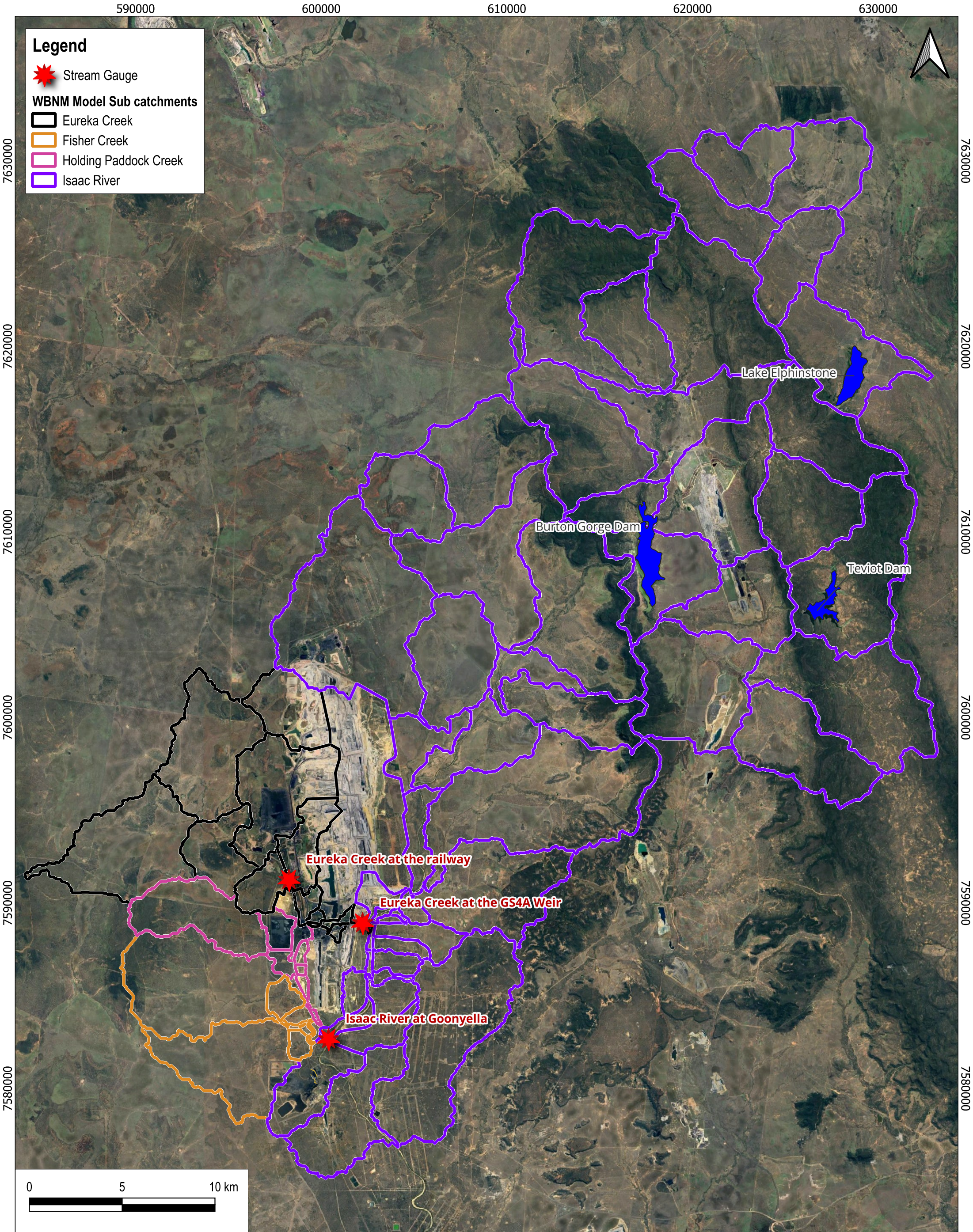
Design events (1% - 0.1% AEP) have utilised the 'East Coast North' areal temporal patterns, as the total catchment area for the model exceeds 75 km^2. All ten temporal patterns were simulated for storm durations ranging from the 3 hours to 168 hours.

Design Rainfall Losses

The initial and continuing losses obtained from the ARR Datahub for Isaac River catchment to Goonyella gauge are 36 mm and 2.7 mm/h, respectively.

The adopted design rainfall losses were selected to achieve the best match between the XP-RAFTS design discharges with the design discharges estimated by the FFA at the Isaac River Goonyella gauge. The following is of note:

- For the 50%, 20%, 10%, 5%, 2% and 1% AEP events, the default ARR initial losses of 36 mm and continuing losses of 2.7 mm/h were adopted, respectively. The initial loss will decrease for larger events as the catchment is likely to be more saturated prior to the design rainfall burst.
- For the 0.1% AEP design event, a conservative 0 mm initial loss was adopted. A continuing loss of 2.5 mm/h was adopted as per the flood assessment done by WRM in 2019 (WRM, 2019).



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REVISION: 0	Figure B1
AUTHOR: CH	Scale @ A3: 1:180,000
CHECKED: BK	
DATE: 25/06/2024	GENERAL NOTES:
ENGENY / BMA BHP Mitsubishi Alliance	1. Aerial imagery courtesy of Google.
	2. All unit measurements are provided in metres unless otherwise specified.
	3. Figure has been designed and exported to A3 page size.

BMA PRCP GRM Eureka Creek Diversion

WBNM Hydrologic Model Layout

MODEL VALIDATION

The 50%, 20%, 10%, 5%, 2% and 1% AEP peak flows estimated from the hydrology model were validated using the following methods:

- **Regional Flood Frequency Estimation Model (RFFE)** - is a recommended peak flow validation method from the ARR 2019 guidelines (Ball, et al., 2019). The RFFE provides peak flow estimations based on the catchment area and a catchment shaping factor, determined using the catchment centroid and outlet coordinates. The RFFE peak flow estimates were calculated using the ARR RFFE Model online tool (http://rffe.arr-software.org/).

- **Flood Frequency Analysis (FFA)** - provides peak flow estimates for different AEPs by developing a fitted distribution from recorded peak flows from historical flood events.

  The Eureka Creek gauges (Eureka Creek at the railway and GS4A) had an insufficient monitoring duration to conduct a reliable Flood Frequency Analysis (FFA). As a result, the FFA for the nearby Isaac River at the Goonyella gauge, located 7 km downstream of Eureka, was used for validation purposes. This analysis was completed as part of the Isaac River Flood Model by Engeny in March 2021.

  Isaac River FFA was undertaken on the peak annual (water year from October to September) discharges recorded at Isaac River at Goonyella (130414A) streamflow gauge by Queensland Department of Natural Resources Mines and Energy (DNRME) between 1982 and 2020. A Log Pearson Type 3 (LPIII) distribution was fitted to an annual maximum series of peak flows from the gauge (Engeny, 2021). To adapt the Isaac River FFA to Eureka Creek, peak flows were scaled based on the catchment area using the QRT method. The formula used for this adjustment is:

$$Q_u = \left(\frac{A_u}{A_g}\right)^n Q_g$$

  Where,

  Q_u is the estimated peak flow for the ungauged catchment.

  A_u is the area for the ungauged catchment.

  A_g is the catchment area for the stream gauging station.

  Q_g is the peak flow for the gauging station determined from the flood frequency analysis.

  The exponent n has been determined from the regional flood frequency regression analysis (RFFE) undertaken by the Queensland Department of Transport and Main Roads (Palmen & Weeks, 2008).

- **Peak flow estimates from previous flood studies** –

  - A hydrologic modelling of the Isaac River catchment including the Grosvenor Mine (GRV) and Moranbah North Mine (MNM) using the XPRAFTS runoff-routing model was developed to estimate the 39%, 10%, 5%, 2%, 1%, 0.2% and 0.1% annual exceedance probability (AEP) and probable maximum flood (PMF) design discharges for the Isaac River and its tributaries (Engeny, 2021). The estimated peak flows at the Isaac River at Goonyella Streamflow Gauge were compared to the WBNM and RFFE peak flows (refer toFigure B.2). It is to be noted that The Burton Gorge Dam, Teviot Dam and Lake Elphinstone upstream of the study area were modelled as detention basins in the XPRAFTS model.

  - Design peak discharges in the Isaac River at Goonyella, Eureka Creek upstream of the railway and Eureka Creek at the GS4A for the 10%, 5%, 2%, 1%, 0.1% were estimated using the XP-RAFTS model by WRM in 2019. These flows were compared to the WBNM model design peak discharges at these three gauge locations.

Model Validation Results

Table B.1 shows the WBNM estimated design discharges at the Isaac River at Goonyella, Eureka Ck at the Railway and Eureka Ck at the GS4A for design events between 10% to 0.1% AEP, and the comparison to the WRM design discharges. A visual comparison of the WBNM design peak discharges at the Isaac River streamflow gauge (130414A) against the flood frequency distribution curve, XP-RAFTS estimated peak flows by Engeny in 2021 and RFFE is provided in Figure B.2.

Validation of the design hydrology peak flow estimates indicates the following.

- **Isaac River Gauge**
  - Modelled peak flows for all design events are higher (3%-26%) than the LPIII expected quantile from the FFA. This is expected considering the exclusion of Burton Gorge Dam, Teviot Dam and Lake Elphinstone (Figure B.2).
  - Modelled peak flows compared to the RFFE method were higher for events rarer than the 10% AEP and lower for events more frequent than the 10% AEP. This irregularity is not concerning as the RFFE can provide irregular results if catchment characteristics are mostly different from the nearby gauged waterways used to derive the RFFE. Additionally, the Issac gauge catchment (1071.21 km^2) is outside the RFFE recommended catchment size of 0.5-1000 km^2, hence results have lower accuracy (Figure B.2).
  - WBNM estimated peak flows for all design events are higher (11%-28%) than the WRM 2019 flood modelling report (Table B.1).
- **Eureka Ck Gauge**
  - WBNM estimated peak flows for all design events are higher (10%-37%) than the WRM 2019 flood modelling report. This is expected considering the 37% increase of the Eureka catchment (Table B.1).

TABLE B.1: COMPARISON OF WBNM DESIGN DISCHARGES TO THE WRM 2019 FLOWS

		WRM (2019) Peak Discharge (m3/s)	WRM (2019) Critical duration (hours)	WBNM Peak Discharge (m3/s)	WBNM Critical duration (hours)	Difference (%)
Isaac River at Goonyella	Catchment Area (km^2)	-		1071.12 km^2		-
	Design event (AEP%)					
	10	830	18 hr	932	18 hr	11%
	5	1167	18 hr	1363	18 hr	14%
	2	1707	18 hr	2061	18 hr	17%
	1	2079	24 hr	2616	18 hr	21%
	0.1	3808	24 hr	5291	18 hr	28%
Eureka Creek at the railway	Catchment Area (km^2)	76.4 km^2		113.78 km^2		33%
	Design event (AEP%)					
	10	140	6 hr	159	18 hr	12%
	5	180	6 hr	217	18 hr	17%
	2	256	6 hr	299	18 hr	14%
	1	299	6 hr	374	18 hr	20%
	0.1	499	6 hr	692	12 hr	28%
Eureka Creek at the GS4A	Catchment Area (km^2)	80.7 km^2		129.05 km^2		37%
	Design event (AEP%)					
	10	147	6 hr	163	18 hr	10%
	5	189	6 hr	225	18 hr	16%
	2	267	6 hr	320	18 hr	17%
	1	311	6 hr	400	18 hr	22%
	0.1	521	6 hr	728	18 hr	28%

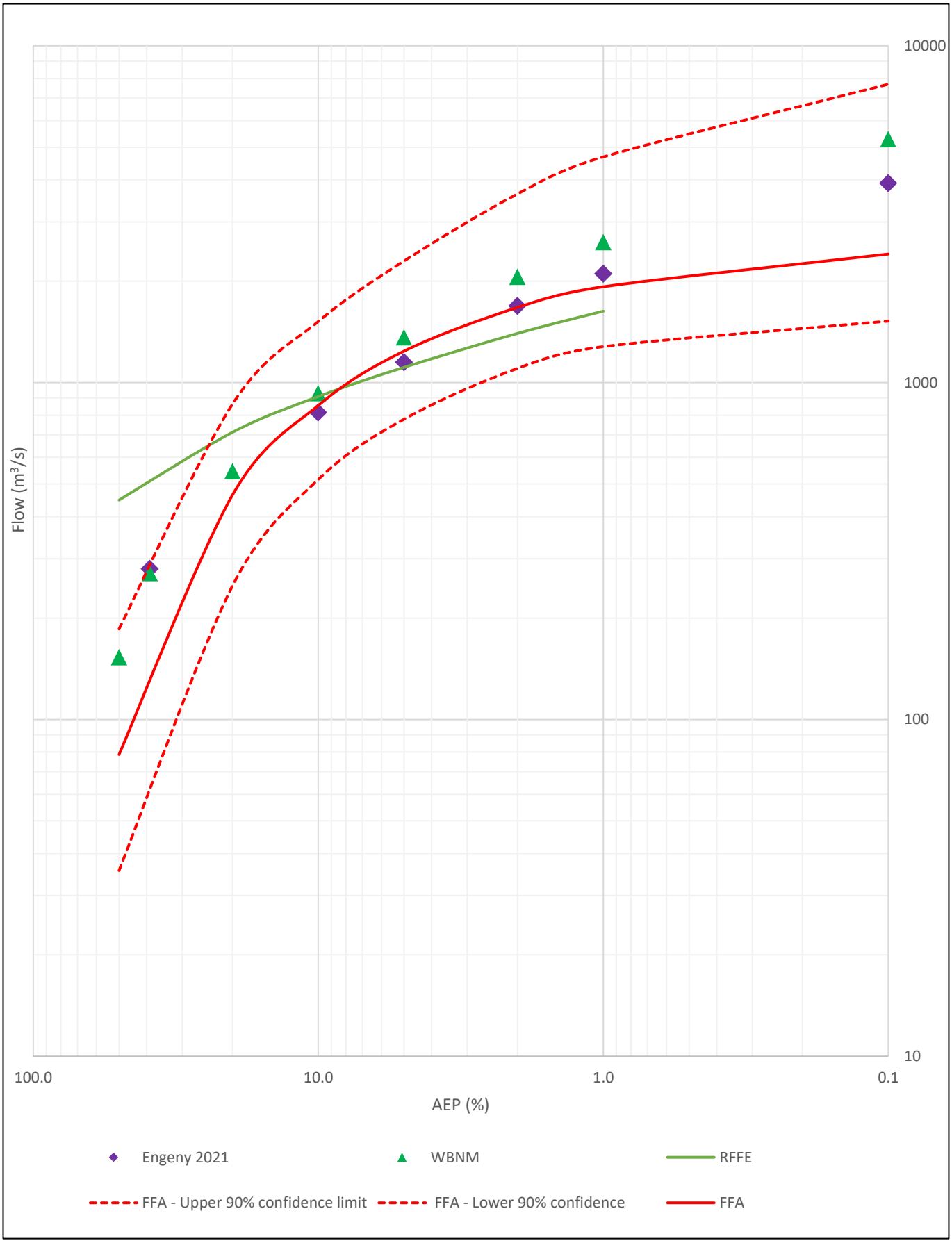


FIGURE B.2: COMPARISON OF WBNM DESIGN DISCHARGES TO THE FFA AND RFFE DESIGN DISCHARGES TO THE ISAAC RIVER GAUGE

APPENDIX C: HYDRAULIC MODEL DEVELOPMENT

MODEL EXTENT AND TOPOGRAPHY

The hydraulic model utilised the TUFLOW HPC solver. The Digital Elevation Model (DEM) used in the hydraulic model was based on the most recent PRCP landform (Version 2) provided by BHP.

A grid cell size of 4 m was selected for the TUFLOW model, which is suitable for representing the width of the diversion across multiple modelling cells. To enhance the resolution of sub-grid scale features, an SGS (Sub-Grid Scale) sample distance of 2 m was implemented.

The selected extent for the model is from upstream of where Eureka design starts to downstream of Isaac River in the extent of the ML Goonyella Riverside. The modelling layout is shown in FIGURE C.1 and FIGURE C.2.

The proposed diversion design option was included in the model using design tins produced by 12D and merging it to the PRCP landform (Version 2).

HYDRAULIC ROUGHNESS

The hydraulic roughness has been selected based on the inspection of aerial imagery and expected treatments within the diversion. As per the MCA workshop, roads and the GS4A dam will be removed as part of the closure and the GS1 tailings dam will be rehabilitated. The rail, which is not owned by BMA and goes to Moranbah North, was considered in the base land use mapping of the site. The adopted Manning's 'n' roughness values are summarized in TABLE C.1 below.

TABLE C.1: ADOPTED MANNING'S N ROUGHNESS

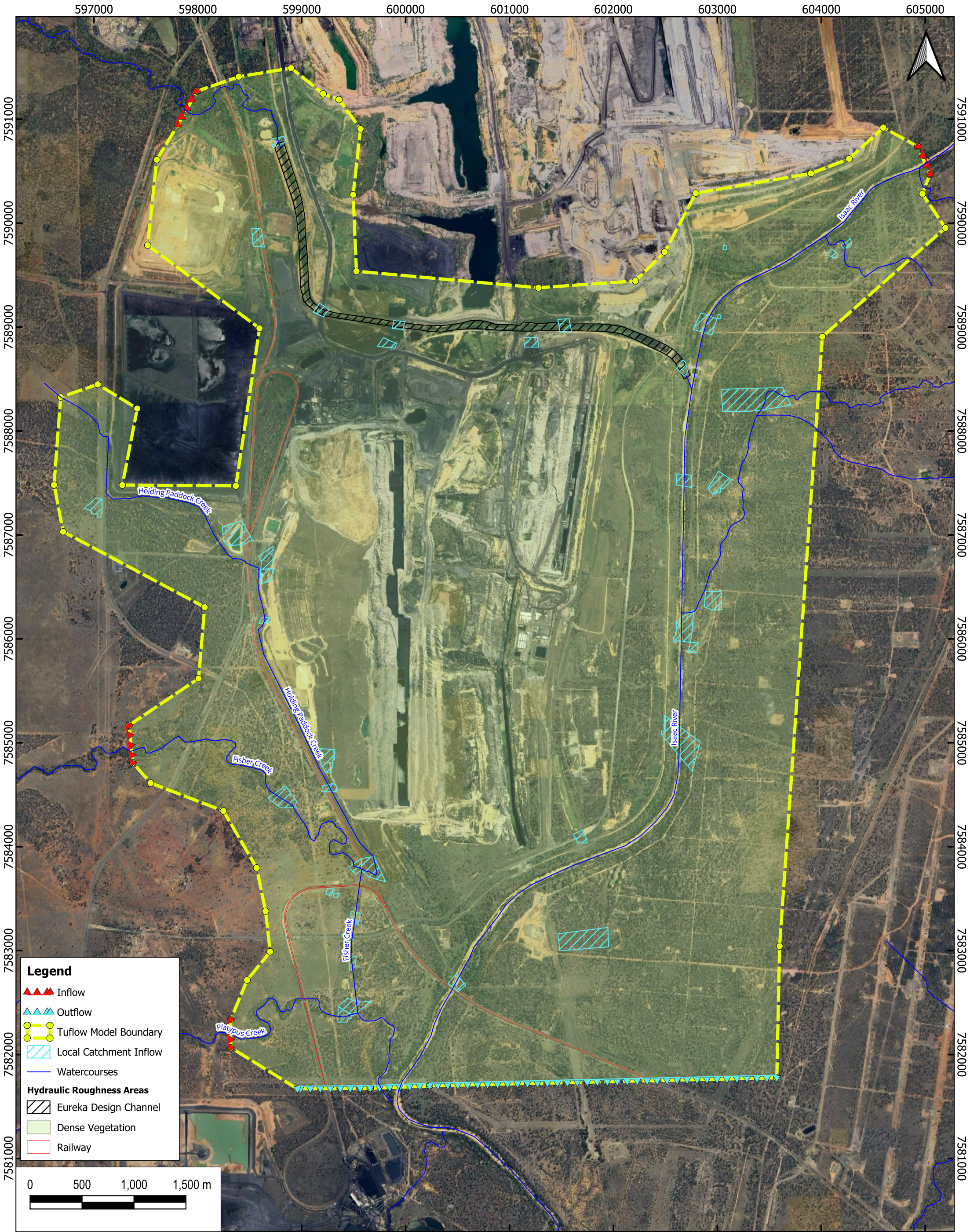
Land Use	Manning's' 'n'
Railway	0.015
Constructed Channel	0.050
Dense Vegetation	0.080

MODEL INFLOWS AND BOUNDARY CONDITIONS

Boundary conditions are required in the model to define hydrology inflows, flow leaving the model domain and interfaces between the one dimensional and two-dimensional model domains. The following boundary conditions used in the models are:

- Upstream: The upstream boundary condition used a combination of 'SA' and 'BC' type boundaries, allocating flow to the defined model grid cells based on the design hydrograph from the hydrologic model (flow per unit of time) input. Total inflow hydrographs were applied to Eureka Ck at the upstream boundary.
- Downstream: A normal depth outflow boundary was adopted with a hydraulic grade based on the Isaac River channel grade at the downstream extent of the model. The boundary was located a sufficient distance downstream to not influence the flood behaviour near the areas of interest.

Peak flows as estimated by the WBNM hydrologic model (only for 0.1% AEP event) have been applied at various locations dependent on the diversion being assessed. The location of the model inflows (0.1% AEP) can also be seen in Figure C.1**.** As mentioned in section 6.4.1, for the 39% and 2% AEP event, constant ACARP flows were applied throughout the diversion as shown in Figure C.2**.**



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AUTHOR: CH	Scale @ A3: 1:32,000
CHECKED: BK	
DATE: 26/07/2024	GENERAL NOTES:

BMA PRCP GRM Eureka Creek Diversion

Hydraulic Model Layout - 0.1% AEP

GENERAL NOTES:
1. Aerial imagery courtesy of Google.
2. All unit measurements are provided in metres unless otherwise specified.
3. Figure has been designed and exported to A3 page size.

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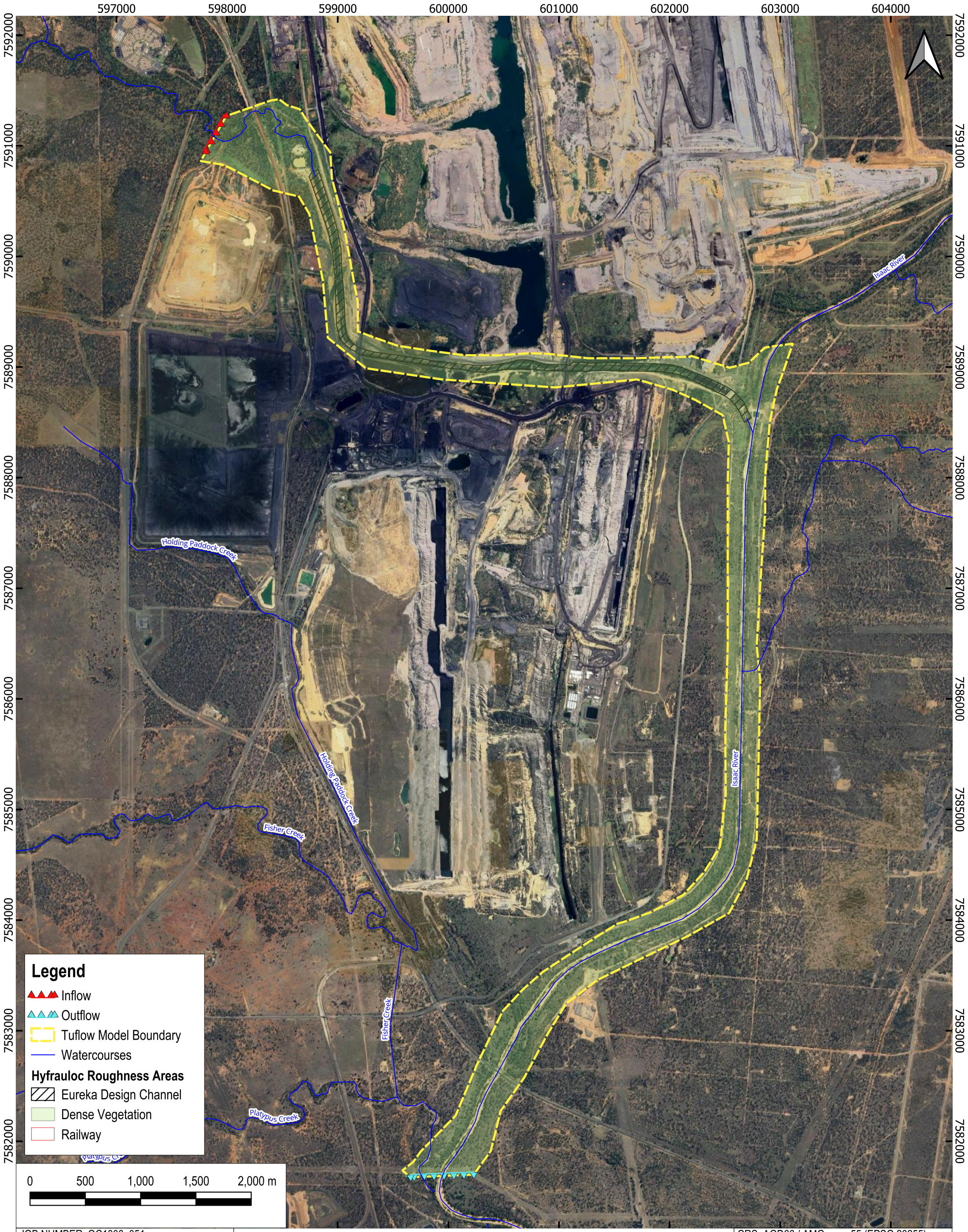

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CHECKED: BK	
DATE: 26/06/2024	GENERAL NOTES:

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BMA PRCP GRM Eureka Creek Diversion

Hydraulic Model Layout - 39% and 2% AEP

GENERAL NOTES:
1. Aerial imagery courtesy of Google.
2. All unit measurements are provided in metres unless otherwise specified.
3. Figure has been designed and exported to A3 page size.

APPENDIX D: HYDRAULIC PARAMETER MODELLING RESULT

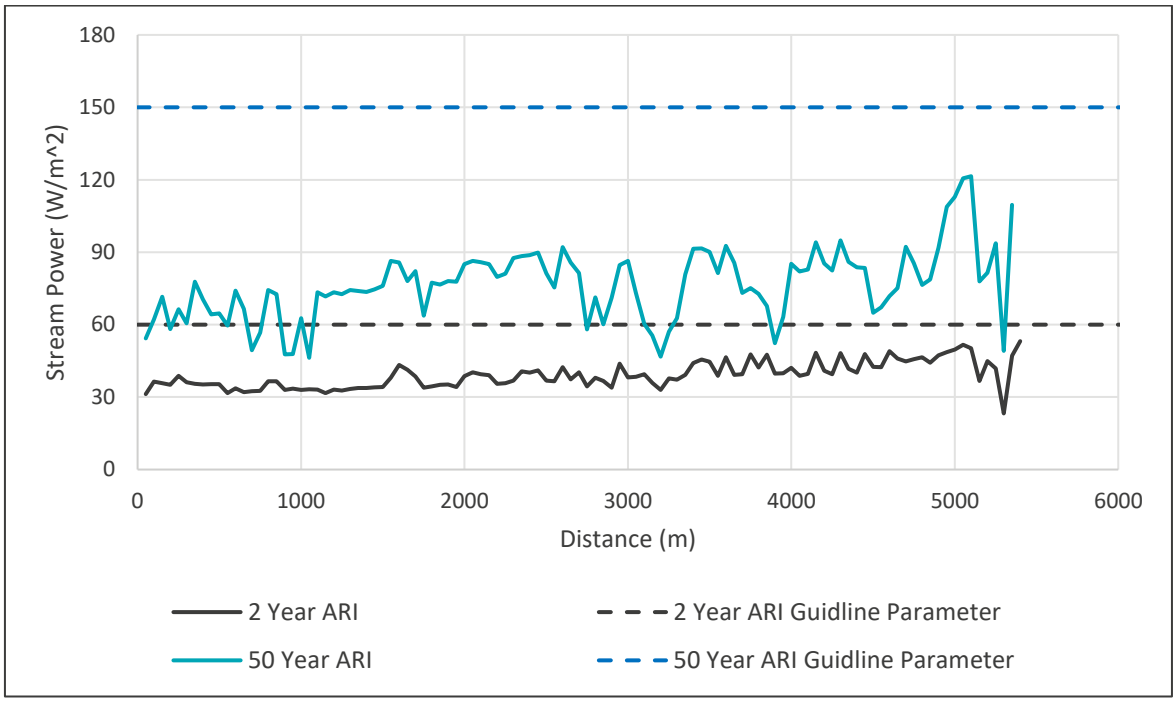

FIGURE D.1: STREAM POWER TUFLOW MODEL RESULTS

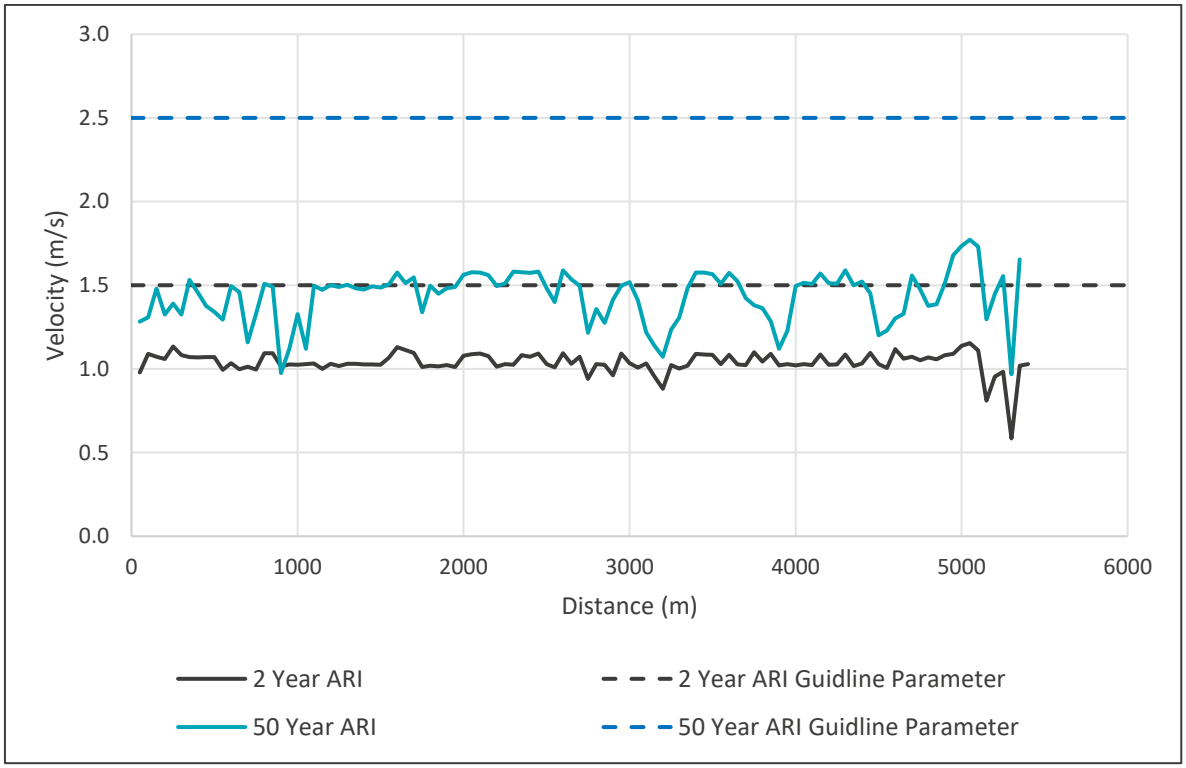

FIGURE D.2: VELOCITY TUFLOW MODEL RESULTS

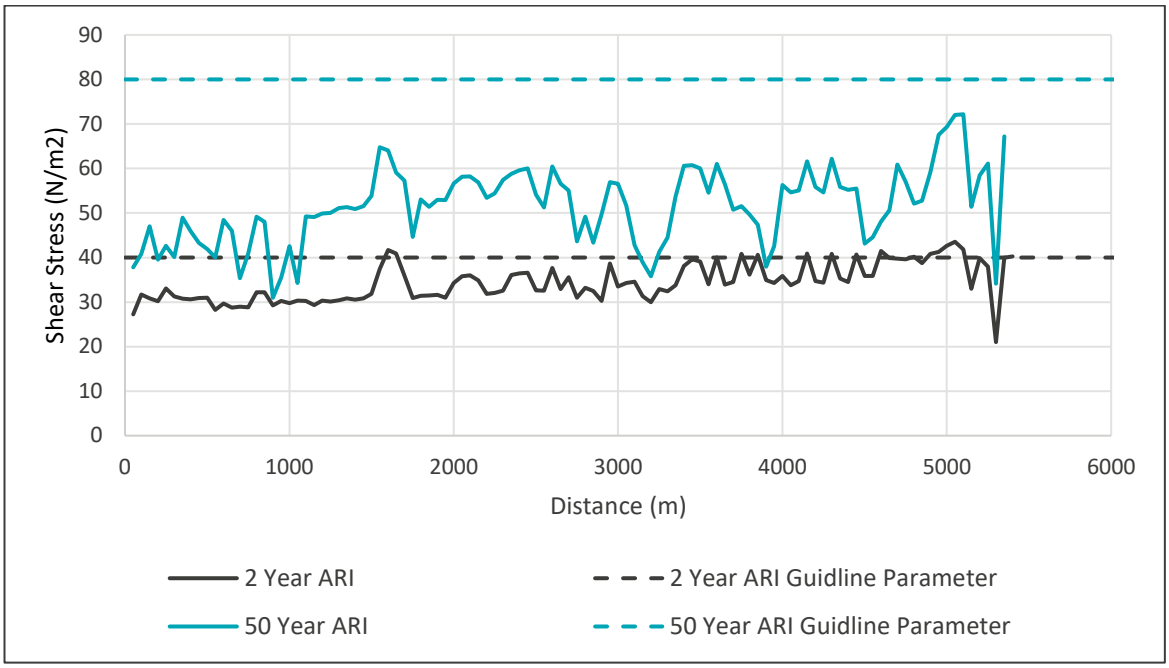

FIGURE D.3: SHEAR STRESS TUFLOW MODEL RESULTS

APPENDIX E: PREFERRED OPTION CONCEPT DESIGN DRAWINGS

NOT FOR CONSTRUCTION

EUREKA CREEK

RAMP 6

ISAAC RIVER

CONTROL LINE MCD01
(EUREKA CREEK DIVERSION)

RAMP 21/22

A
0201

GS4A WEIR TO BE DECOMMISSIONED. ROAD CROSSING DETAILS TO BE CONFIRMED DURING FUTURE PHASES OF STUDY

GS1 TSF
(GS1 TAILINGS DAM TO BE REHABILITATED)

RAMP 2

0.000 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000 3250 3500 3750 4000 4250 4500 4750 5000 5250 5500 5574.000

LEGEND

EXISTING WATERCOURSE

EUREKA CREEK DIVERSION EXTENTS

0 100 200 300 400 500m
SCALE 1:10,000 (A1)
SCALE BEFORE REDUCTION

VENDOR DRG NUMBER	REV	DATE	DESCRIPTION	DRN	ENG	APP	DRAWING No.	TITLE
QC1000-051-DWG-0101	A							

VENDOR LOGO

ENGENY

REVISION

REFERENCE DRAWINGS

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VENDOR APPROVALS	SIGNATURE	DATE
DRAWN		
DRN. CHK		
ENGINEER		
ENG. CHK (QA)		
APPROVED		

RPEQ APPROVAL
RPEQ ENGINEER
RPEQ No. DATE
PROJECT No.
EQUIPMENT TAG

BMA REVIEW
SIGNATURE
DATE

GOONYELLA MINE
PRCP EUREKA CREEK DIVERSION
GENERAL ARRANGEMENT PLAN

DRG. No.
LEGACY DRG No.
STATUS: NOT FOR CONSTRUCTION - FOR REVIEW
DATE:

Sht
Sht Size A1
Scale –
Rev. No. A

CAD FILE: QC1000-051-DWG-0101.dwg

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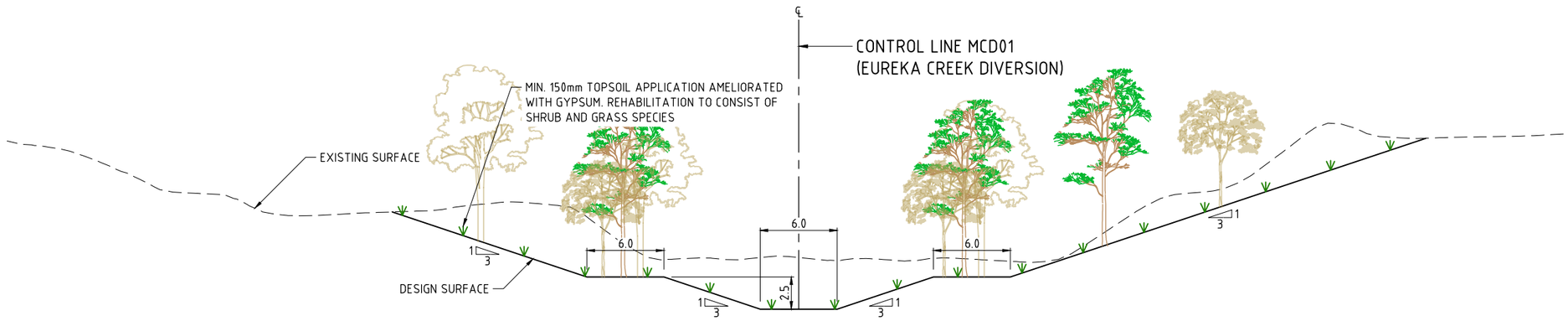

SECTION A 0101
SCALE 1:200

LEGEND

- EXISTING SURFACE
- DESIGN SURFACE

SCALE 1:200 (A1)
SCALE BEFORE REDUCTION

VENDOR DRG NUMBER QC1000-051-DWG-0201	A							
VENDOR LOGO ENGENY	REV	DATE	DESCRIPTION	DRN	ENG	APP	DRAWING No.	TITLE
	REVISION						REFERENCE DRAWINGS	

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VENDOR APPROVALS	SIGNATURE	DATE
DRAWN		
DRN. CHK		
ENGINEER		
ENG. CHK (QA)		
APPROVED		

RPEQ APPROVAL	BMA REVIEW
RPEQ ENGINEER	SIGNATURE
RPEQ No. DATE	
PROJECT No.	DATE
EQUIPMENT TAG	

GOONYELLA MINE
PRCP EUREKA CREEK DIVERSION
TYPICAL SECTIONS AND DETAILS

DRG. No.
LEGACY DRG No.
STATUS: NOT FOR CONSTRUCTION - FOR REVIEW
DATE:

Sht
Sht Size A1
Scale –
Rev. No. A

CAD FILE: QC1000-051-DWG-0201.dwg

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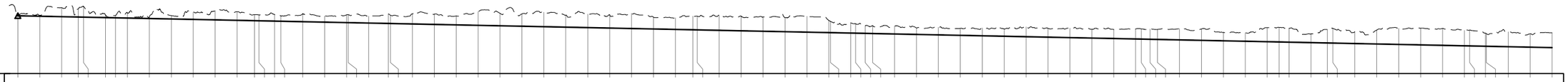

DATUM 238.0

VERT. DETAILS	-0.21%
HORIZ. DETAILS	L=137.673 R=-500.0; L=317.301 R=500.0; L=167.943 R=500.0; L=694.414 R=-250.0; L=57.094 R=-250.0; L=630.031 R=-500.0; L=293.946 R=-500.0; L=324.638 R=200.0; L=287.285

CHAINAGES	NORTHING	EASTING	DEPTHS	DESIGN LEVELS	EXISTING LEVELS
0.000	7590865.839	598775.063	0.030	251.214	251.244
50.000	7590816.598	598783.745	0.175	251.110	251.284
100.000	7590767.358	598792.427	2.057	251.006	253.062
137.673	7590730.258	598798.969	1.831	250.927	252.759
150.000	7590718.145	598801.259	2.430	250.902	253.332
200.000	7590669.710	598813.585	0.561	250.798	251.358
222.670	7590648.206	598820.755	0.511	250.750	251.262
250.000	7590622.482	598829.986	1.154	250.694	251.848
300.000	7590575.420	598846.874	0.401	250.590	250.990
350.000	7590528.358	598863.761	0.751	250.486	251.236
400.000	7590481.296	598880.649	1.639	250.382	252.021
450.000	7590434.235	598897.536	2.097	250.278	252.375
500.000	7590387.173	598914.424	1.969	250.174	252.143
539.970	7590349.551	598927.924	1.365	250.091	251.456
550.000	7590340.078	598931.217	1.322	250.070	251.392
585.668	7590305.894	598941.373	1.510	249.996	251.506
600.000	7590292.019	598944.962	1.207	249.966	251.173
650.000	7590243.612	598957.484	1.790	249.862	251.652
700.000	7590195.205	598970.006	1.341	249.758	251.099
750.000	7590146.799	598982.528	1.756	249.654	251.410
753.611	7590143.303	598983.432	1.791	249.646	251.437
800.000	7590097.918	598992.951	1.560	249.550	251.109
845.270	7590052.963	598998.148	2.176	249.456	251.632
850.000	7590048.244	598998.477	1.883	249.446	251.329
900.000	7589998.366	599001.965	2.262	249.342	251.604
950.000	7589948.488	599005.453	2.331	249.238	251.569
1000.000	7589898.610	599008.941	2.013	249.134	251.147
1050.000	7589848.732	599012.429	3.155	249.030	252.185
1100.000	7589798.853	599015.917	2.835	248.926	251.761
1150.000	7589748.975	599019.404	2.786	248.822	251.608
1200.000	7589699.097	599022.892	3.272	248.718	251.990
1250.000	7589649.219	599026.380	2.736	248.614	251.350
1300.000	7589599.341	599029.868	3.065	248.510	251.575
1350.000	7589549.462	599033.356	3.013	248.406	251.419
1400.000	7589499.584	599036.844	3.465	248.302	251.767
1450.000	7589449.706	599040.331	2.704	248.198	250.902
1500.000	7589399.828	599043.819	2.634	248.094	250.728
1539.684	7589360.240	599046.587	3.099	248.011	251.110
1550.000	7589349.967	599047.519	3.110	247.990	251.100
1600.000	7589301.158	599057.977	3.399	247.886	251.285
1650.000	7589255.400	599077.924	3.340	247.782	251.122
1700.000	7589214.517	599106.564	3.258	247.678	250.936
1750.000	7589180.138	599142.755	3.216	247.574	250.790
1800.000	7589153.635	599185.054	3.582	247.470	251.052
1850.000	7589136.064	599231.776	2.756	247.366	250.122
1853.843	7589135.106	599235.498	2.555	247.358	249.913
1900.000	7589123.939	599280.284	2.343	247.262	249.605
1910.937	7589121.293	599290.896	2.346	247.239	249.385
1933.194	7589116.877	599312.703	2.766	247.193	248.959
1950.000	7589114.277	599329.306	1.779	247.158	248.937
2000.000	7589106.542	599378.705	1.833	247.054	248.887
2050.000	7589098.808	599428.103	1.470	246.950	248.420
2100.000	7589091.073	599477.501	1.714	246.846	248.560
2150.000	7589083.338	599526.899	1.573	246.742	248.315
2200.000	7589075.604	599576.297	1.761	246.638	248.400
2250.000	7589067.869	599625.695	1.646	246.534	248.180
2300.000	7589060.134	599675.093	2.216	246.430	248.646
2350.000	7589052.399	599724.491	1.986	246.326	248.312
2400.000	7589044.665	599773.890	2.135	246.222	248.358
2450.000	7589036.930	599823.288	1.987	246.118	248.105
2500.000	7589029.195	599872.686	2.069	246.014	248.083
2550.000	7589021.461	599922.084	2.286	245.910	248.196
2563.225	7589019.415	599935.150	2.295	245.883	248.178
2583.098	7589016.732	599954.839	2.302	245.841	248.143
2600.000	7589014.782	599971.629	2.279	245.806	248.085
2650.000	7589009.017	600021.295	2.535	245.702	248.237
2700.000	7589003.251	600070.962	2.576	245.598	248.174
2750.000	7588997.485	600120.628	1.914	245.494	247.408
2800.000	7588991.720	600170.294	1.900	245.390	247.291
2850.000	7588985.954	600219.961	3.216	245.286	248.502
2877.043	7588982.835	600246.824	3.318	245.230	248.548
2900.000	7588980.712	600269.680	3.129	245.182	248.311
2950.000	7588979.730	600319.650	1.979	245.078	247.057
2987.108	7588982.230	600356.664	3.070	245.001	248.071
3000.000	7588983.576	600369.486	3.334	244.974	248.308
3050.000	7588988.794	600419.213	2.718	244.870	247.588
3100.000	7588994.012	600468.940	3.161	244.766	247.927
3150.000	7588999.231	600518.667	3.652	244.662	248.315
3200.000	7589004.449	600568.394	3.783	244.558	248.342
3250.000	7589009.667	600618.121	3.855	244.454	248.310
3300.000	7589014.886	600667.848	3.507	244.350	247.858
3311.745	7589016.112	600679.529	3.600	244.326	247.926
3348.053	7589016.611	600715.783	2.970	244.250	247.221
3350.000	7589016.462	600717.725	2.860	244.246	247.106
3400.000	7589012.616	600767.577	3.391	244.142	247.534
3450.000	7589008.771	600817.429	3.021	244.038	247.060
3500.000	7589004.926	600867.281	3.368	243.934	247.302

CONTROL LINE MCD03 (EUREKA CREEK DIVERSION)

SCALE 1:5000 HORZ.
SCALE 1:500 VERT.

LEGEND

- EXISTING SURFACE
- DESIGN SURFACE

0 10 20 30 40 50m
SCALE 1:1000 (A1)
SCALE BEFORE REDUCTION

0 50 100 150 200 250m
SCALE 1:5000 (A1)
SCALE BEFORE REDUCTION

VENDOR DRG NUMBER
QC1000-051-DWG-0301

VENDOR LOGO
ENGENY

REV	DATE	DESCRIPTION	DRN	ENG	APP
A					

REVISION

DRAWING No.	TITLE

REFERENCE DRAWINGS

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VENDOR APPROVALS	SIGNATURE	DATE
DRAWN		
DRN. CHK		
ENGINEER		
ENG. CHK (QA)		
APPROVED		

RPEQ APPROVAL
RPEQ ENGINEER
RPEQ No. DATE
PROJECT No.
EQUIPMENT TAG

BMA REVIEW
SIGNATURE
DATE

GOONYELLA MINE
PRCP EUREKA CREEK DIVERSION
LONGITUDINAL SECTIONS

DRG. No.
LEGACY DRG No.
STATUS: NOT FOR CONSTRUCTION - FOR REVIEW
DISCIPLINE:

Sht
Sht Size A1
Scale -
Rev. No. A

CAD FILE: QC1000-051-DWG-0301.dwg

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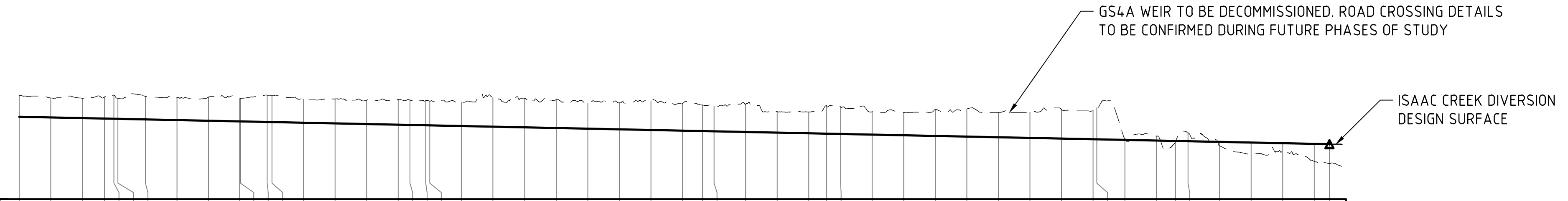

VERT. DETAILS: -0.21%

HORIZ. DETAILS: L=287.285, R=-500.0, L=192.344, R=-500.0, L=226.064, R=300.0, L=437.983, R=500.0, L=427.348, R=200.0, L=243.982

CHAINAGES	NORTHING	EASTING	DEPTHS	DESIGN LEVELS	EXISTING LEVELS
3500.000	7589004.926	600867.281	3.368	243.934	247.302
3550.000	7589001.081	600917.132	3.097	243.830	246.928
3600.000	7588997.235	600966.984	3.154	243.726	246.881
3635.337	7588994.518	601002.217	3.425	243.653	247.078
3650.000	7588993.605	601016.851	3.731	243.622	247.353
3656.375	7588993.341	601023.220	3.239	243.609	246.848
3700.000	7588991.819	601066.819	3.645	243.518	247.163
3750.000	7588990.074	601116.788	3.580	243.414	246.994
3800.000	7588988.329	601166.758	3.753	243.310	247.063
3848.719	7588986.629	601215.447	3.619	243.209	246.828
3850.000	7588986.586	601216.727	3.628	243.206	246.834
3892.352	7588987.009	601259.065	4.235	243.118	247.353
3900.000	7588987.410	601266.702	4.218	243.102	247.320
3950.000	7588990.026	601316.634	3.753	242.999	246.752
4000.000	7588992.643	601366.565	3.858	242.895	246.753
4050.000	7588995.260	601416.497	3.778	242.791	246.568
4100.000	7588997.877	601466.428	3.985	242.687	246.671
4118.417	7588998.841	601484.819	3.945	242.648	246.594
4143.724	7588999.098	601510.118	3.885	242.596	246.481
4150.000	7588998.897	601516.391	3.817	242.583	246.400
4200.000	7588997.298	601566.365	3.775	242.479	246.253
4250.000	7588995.698	601616.340	4.607	242.375	246.982
4300.000	7588994.099	601666.314	4.611	242.271	246.882
4350.000	7588992.499	601716.288	4.543	242.167	246.709
4400.000	7588990.899	601766.263	4.044	242.063	246.107
4450.000	7588989.300	601816.237	4.187	241.959	246.146
4500.000	7588987.700	601866.212	4.596	241.855	246.450
4550.000	7588986.101	601916.186	4.290	241.751	246.041
4581.707	7588985.086	601947.877	4.108	241.685	245.793
4600.000	7588984.167	601966.146	3.976	241.647	245.623
4650.000	7588978.254	602015.774	4.385	241.543	245.928
4700.000	7588967.416	602064.564	3.313	241.439	244.752
4750.000	7588951.761	602112.028	3.362	241.335	244.697
4778.247	7588940.846	602138.076	4.336	241.276	245.612
4800.000	7588931.875	602157.894	4.305	241.231	245.536
4850.000	7588911.255	602203.444	3.615	241.127	244.742
4900.000	7588890.635	602248.994	3.587	241.023	244.610
4950.000	7588870.016	602294.545	4.225	240.919	245.143
5000.000	7588849.396	602340.095	4.344	240.815	245.158
5050.000	7588828.777	602385.645	3.897	240.711	244.608
5100.000	7588808.157	602431.196	4.091	240.607	244.698
5150.000	7588787.538	602476.746	4.591	240.503	245.094
5200.000	7588766.918	602522.296	4.616	240.399	245.015
5205.594	7588764.611	602527.393	5.000	240.387	245.387
5250.000	7588741.976	602565.490	0.207	240.295	240.502
5300.000	7588707.184	602601.219	0.714	240.191	240.905
5330.018	7588682.410	602618.119	-0.152	240.128	239.976
5350.000	7588665.105	602628.110	1.318	240.087	241.404
5400.000	7588621.804	602653.110	-0.640	239.983	239.343
5450.000	7588578.502	602678.110	-1.576	239.879	238.303
5500.000	7588535.201	602703.110	-1.344	239.775	238.431
5550.000	7588491.900	602728.110	-2.767	239.671	236.904
5574.000	7588471.115	602740.110	-3.070	239.621	236.551

CONTROL LINE MCD03 (EUREKA CREEK DIVERSION)

SCALE 1:5000 HORZ.
SCALE 1:500 VERT.

LEGEND

— — — — EXISTING SURFACE
———— DESIGN SURFACE

0 10 20 30 40 50m
SCALE 1:1000 (A1)
SCALE BEFORE REDUCTION

0 50 100 150 200 250m
SCALE 1:5000 (A1)
SCALE BEFORE REDUCTION

VENDOR DRG NUMBER: QC1000-051-DWG-0302

VENDOR LOGO: ENGENY

REV	DATE	DESCRIPTION	DRN	ENG	APP
A					

REVISION

DRAWING No.	TITLE

REFERENCE DRAWINGS

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BMA BHP Mitsubishi Alliance

VENDOR APPROVALS	SIGNATURE	DATE
DRAWN		
DRN. CHK		
ENGINEER		
ENG. CHK (QA)		
APPROVED		

RPEQ APPROVAL
RPEQ ENGINEER
RPEQ No. DATE
PROJECT No.
EQUIPMENT TAG

BMA REVIEW
SIGNATURE
DATE

GOONYELLA MINE
PRCP EUREKA CREEK DIVERSION
LONGITUDINAL SECTIONS

DRG. No.
LEGACY DRG No.
STATUS: NOT FOR CONSTRUCTION - FOR REVIEW
DISCIPLINE:

Sht
Sht Size A1
Scale -
Rev. No. A

CAD FILE: QC1000-051-DWG-0302.dwg

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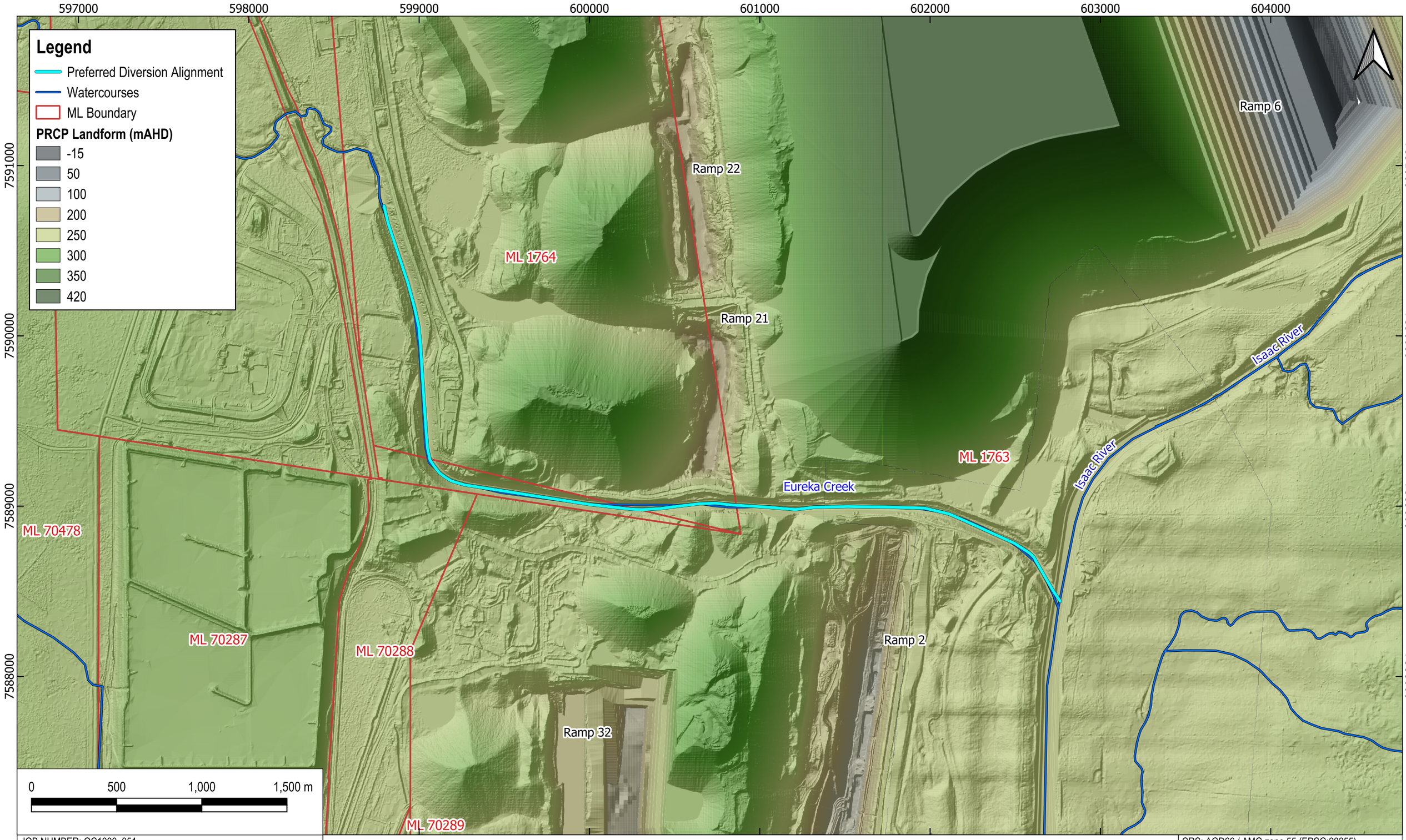
APPENDIX F: CONCEPT DESIGN WITH PRCP LANDFORM INTERACTION



JOB NUMBER: QC1000_051	
REVISION: 2	
AUTHOR: CH	
CHECKED: BK	
DATE: 24/09/2024	

ENGENY

BMA
BHP Mitsubishi Alliance

BMA PRCP GRM Eureka Creek Diversion

Eureka Creek Concept Design with PRCP Landform 2

CRS: AGD66 / AMG zone 55 (EPSG:20255)

Figure F.1
Scale @ A3: 1:20,000

GENERAL NOTES:
1. All unit measurements are provided in metres unless otherwise specified.
2. Figure has been designed and exported to A3 page size.