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Moranbah North Extension

Underground Water Impact Report

FINAL

ISO 9001 14001 45001

D10167A03

September 2020

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1 INTRODUCTION

KCB Australia Pty Ltd (KCB) was commissioned by Hansen Bailey on behalf of Anglo Coal (Moranbah North Management) Pty Ltd (Anglo) to prepare an Underground Water Impact Report (UWIR) for the Moranbah North Extension Project (the project) operations within Mining Lease (ML) 700042.

This section provides a description of the project and its approval status, the background to the UWIR and the scope and structure of the UWIR. It also provides an overview of approved facilities and operations at the existing Moranbah North Mine, to the extent that they are relevant to the UWIR.

1.1 Moranbah North Mine

Moranbah North Mine (MNM) is an operating underground coal mine located approximately 7 km north of Moranbah township in Central Queensland (Figure 1). The MNM site comprises Mining Lease (ML) 70108 and ML700042.

MNM commenced operations in 1998 on ML70108. The commencement of operations on ML70108 was prior to establishment of the underground water management provisions of the *Water Act 2000* (Water Act), and Anglo has advised that MNM operations on ML70108 falls under the Water Act provisions for pre-existing mining activities.

Moranbah North Mine has an Environmental Authority (EA) (EPML00738813) under the *Environmental Protection Act 1994* (EP Act). The MNM EA prescribes a maximum production rate of 13.5 Million tonnes per annum (Mtpa) of Run of Mine (ROM) coal. Coal is extracted from the Goonyella Middle Seam (GM Seam) using longwall mining methods.

The Moranbah North Mine surface infrastructure is shown in Figure 2 and includes the following key facilities:

- The underground mine access drifts/portals;
- The coal handling and preparation plant (CHPP) and associated infrastructure, including conveyors and stockpiles;
- Rejects co-disposal area (CDA);
- Surface facilities, which include administration buildings, employee facilities, warehouse, workshop and vehicle washdown, servicing and refuelling facilities, security, first aid and rescue facilities and sewage and potable water treatment facilities;
- Water management system including mine water storages, CHPP return water system and licensed mine water discharge system; and,
- An onsite rail loop and train loading facility for the transport of coal from site.

In addition to these permanent facilities, temporary surface facilities are progressively constructed above the underground mining area to create a safe working environment for underground mining activities. These facilities include infrastructure associated with the pre-drainage of gas (e.g. gas wells, pipelines), ventilation shafts, underground communication cables, mine dewatering boreholes and other access boreholes. This infrastructure is developed above areas currently being mined (or soon to be mined) and then decommissioned progressively once mining is completed.

1.2 Project Overview

The project involves the extension of longwall mining into an adjoining area east of ML70108. In October 2018, Anglo applied for a new ML for the project site (ML700042) which was granted on 22 September 2020 for a period of 25 years.

The project site corresponds to the ML700042 area (i.e. the proposed new ML) and is shown in Figure 2. The project mining operations will be integrated with the existing mine and Moranbah North's mining operations will ultimately move into the project site.

Mining will be undertaken using Moranbah North's mining equipment and the existing Moranbah North Mine portals and drifts will provide underground access to the project longwall panels. As is the case for Moranbah North Mine, the project will target the Goonyella Middle (GM) seam and mining will be at a maximum coal production rate of 13.5 Mtpa ROM. The project will also make use of the existing surface infrastructure at Moranbah North Mine and no upgrades of the infrastructure are required for the project. The existing workforce will be used for the project. The project will extend the life of the Moranbah North Mine by approximately 16 years.

The project involves the use of conventional gas drainage activities to remove residual gas from the GM seam within the project site where conditions allow. Hydraulic stimulation activities may be used to remove residual gas from the GM seam in areas of the project site that are not conducive to the use of conventional gas drainage methods.

1.3 Background to the UWIR

The *Mineral Resources Act 1989* (MR Act) entitles the holder of a ML to take or interfere with underground water (i.e. groundwater) as part of approved mining operations. This entitlement is termed the ML holder's 'underground water rights'.

Groundwater that is taken or interfered with while exercising the underground water rights is termed 'associated water'. The holder of the ML is entitled to use associated water for any purpose. In order to exercise the underground water rights for the project, the ML holder must:

- Obtain an Environmental Authority (EA) under the *Environmental Protection Act 1994* (EP Act); and,
- Comply with its reporting obligations under Chapter 3 of the *Water Act 2000* (Water Act). The administering authority for Chapter 3 of the Water Act is the Department of Environment and Science (DES). Lease holder obligations under Chapter 3 of the Water Act include undertaking baseline assessments of the groundwater regime and water supply bores, preparing UWIRs to provide for ongoing assessment and reporting of groundwater take and (where necessary) entering into make good agreements with owners of affected water supply bores.

In November 2019, an amendment to the Moranbah North Mine EA was granted by the DES for the project. The current EA (EPML00738813) therefore authorises the project activities and the associated groundwater impacts described in the EA amendment application.

In order to obtain approval for the EA amendment, Anglo was required to meet the information requirements of Sections 126A and 227AA of the EP Act for the exercise of underground water rights.

The required information was provided in the Environmental Assessment Report (EAR) that supported the EA amendment application. The EAR was prepared by Hansen Bailey on behalf of Anglo. KCB completed a groundwater study as part of the EAR. The scope of work and methodology for the EAR groundwater assessment included:

- Conceptualising the groundwater regime of the project site and its surrounds through:
  - Reviewing various groundwater, geotechnical and environmental reports related to Moranbah North Mine and adjacent mines and projects in order to develop an appreciation of the hydrogeological setting of the project;
  - Reviewing relevant geological data including 3D geology models, databases and exploration drilling logs developed by the proponent for the project site, the existing Moranbah North Mine and surrounding areas;
  - Reviewing hydrogeological data from the Department of Natural Resources, Mines and Energy's (DNRME's) groundwater database of existing groundwater bores;
  - Reviewing records of coal seam gas (CSG) wells and extraction within the project site and its surrounds;
  - Undertaking a census of groundwater supply bores within a 5 km radius of the project site to confirm bore locations, usage and water quality;
  - Undertaking a groundwater site investigation at the project site. The site investigation included the installation of dedicated monitoring bores to measure groundwater levels, groundwater quality and hydraulic parameters in the key strata. The groundwater bores used in the site investigation are shown in Figure 12;
  - Compiling a groundwater monitoring dataset from over 100 bores within the project site and its surrounds. The bores are predominantly groundwater monitoring bores, vibrating wire piezometers, exploration bores and bores associated with coal seam gas (CSG) operations. Data was collected for a range of hydraulic parameters including water levels, yield and permeability;
  - Compiling a groundwater quality dataset from monthly field testing and laboratory analysis of groundwater samples. Data was collected for an extensive suite of groundwater quality parameters including physical chemistry, metals and metalloids, major ions, nutrients and petroleum hydrocarbons; and,
  - Analysing the above listed data and using it to develop a conceptual model of the groundwater regime that includes a description of the recharge, flow and discharge of groundwater. The data was also used to gain an understanding of the environmental values of the groundwater.

- Developing a 3D numerical groundwater flow model for the project to simulate the existing conditions of the groundwater regime and provide predictions of the potential impacts of the proposed mining activities. The model represented the hydrogeology of the project site and its surrounds (based on the conceptual groundwater model described above) and the proposed mine plan and mining schedule.
- Undertaking predictive modelling for the project to determine the effects of mining on groundwater levels in the surrounding aquifers, and to inform the assessment of groundwater impacts during mine operations and post- closure. The groundwater modelling used conservative parameters and values and is considered to represent the worst-case scenario for potential groundwater impacts resulting from the project.
- Assessing the groundwater impacts and developing feasible mitigation and management strategies in the event of potential adverse impacts being identified. Impacts assessed included:
  - Potential groundwater drawdown impacts on groundwater supply bores;
  - Potential groundwater drawdown impacts on Teviot Brook and other surface water features;
  - Potential groundwater drawdown impacts on Groundwater Dependent Ecosystems;
  - Potential cumulative drawdown impacts with local resource activities, including existing mines and coal seam gas activities;
  - Potential impacts on existing groundwater quality pre-mining as a result of the project's hydraulic stimulation activities, during and post-mining; and,
  - Potential impacts on stygofauna.
- Developing a groundwater monitoring program for the project.

In approving the EA amendment for the project, the DES accepted that the EAR groundwater study was suitable supporting information for the EA amendment application for the project.

1.4 UWIR Scope and Structure

Chapter 3 of the Water Act requires that the proponent prepare an initial UWIR for the project. The main purpose of the UWIR is to describe the groundwater take due to mining (and any associated impacts) over a three-year period (the UWIR period).

This UWIR addresses the initial three years of the project from the date that Anglo exercises its underground water rights on the project site. Anglo's exercise of its underground water rights on the project site is currently scheduled to commence in late 2020. The planned mining activities during this UWIR period include mining longwall panels in the northwest of the project site and the associated drainage of coal seam gas. Anglo has not produced any groundwater or exercised its rights to take groundwater prior to this UWIR period.

The UWIR has been prepared in accordance with the UWIR content requirements described in Section 376 of the Water Act and the DES guideline Underground water impact reports and final reports (the UWIR guideline), where relevant. The requirements Section 376 of the Water Act are complimentary to the information requirements of the Section 126A and 227AA of the EP Act.

Consistent with Section 2.3 of the UWIR guideline, this UWIR is based on the information provided in the EAR groundwater study described in Section 1.3. DES has reviewed and approved this information as part of the EA amendment approval process, including the groundwater data, conceptual groundwater model and numerical groundwater modelling. This information has been reproduced in the UWIR, where relevant. The specific scope of the UWIR includes:

- Presenting the relevant groundwater, geology and environmental information from the EAR groundwater study;
- Undertaking an updated review of the DNRME's Groundwater Database to identify relevant water supply bores within ML700042 and its surrounds;
- Gathering updated information on the relevant water supply bores from bore owners in order to confirm the extent of groundwater use in the area;
- Presenting the conceptual groundwater regime within the project site and its surrounds, based on the EAR groundwater study and any updated data collected from the DNRME database and bore owners;
- Presenting the EAR groundwater modelling predictions for the life of the project;
- Using the EAR groundwater model to produce predictions of the project groundwater effects during the UWIR period, including drawdown predictions and predictions of groundwater take for years 1, 2 and 3 of the UWIR period;
- Presenting the predicted groundwater impacts from the EAR, updated as necessary to reflect the updated data collected from the DNRME database and bore owners; and,
- Confirmation of the existing approved EA groundwater monitoring program and management measures.

The UWIR comprises the following sections:

- Section 1 – Introduction
- Section 2 – Regulatory Requirements
- Section 3 – Project Setting
- Section 4 – Assessment Methodology
- Section 5 – Groundwater Regime
- Section 6 – Groundwater Impact Assessment
- Section 7 – Groundwater Monitoring Program
- Section 8 – UWIR Updates and Review
- Section 9 – Conclusions

Appendix I presents summary details of all groundwater monitoring bores within 5 km of the project site. Appendix II provides a description of the numerical modelling undertaken for the project, including details on model construction, calibration, predictive simulation and sensitivity analysis.

2 REGULATORY REQUIREMENTS

Section 376 of the Water Act specifies the UWIR content requirements. Table 2.1 lists the specific content requirements and provides an explanation of where each requirement is addressed in this UWIR.

Table 2.1 UWIR Content Requirements

Water Act Section No.	Water Act Section Content	UWIR Cross Reference
376(1)(a)	An underground water impact report must include each of the following — for the area to which the report relates: (i) the quantity of water produced or taken from the area because of the exercise of any previous relevant underground water rights; and (ii) an estimate of the quantity of water to be produced or taken because of the exercise of the relevant underground water rights for a 3-year period starting on the consultation day for the report.	(i) To date, Anglo has not produced or taken groundwater due to the exercise of underground water rights on the project site. (ii) Section 6.2 describes the estimated groundwater take over the UWIR period.
376(1)(b)	For each aquifer affected, or likely to be affected, by the exercise of the relevant underground water rights: (i) a description of the aquifer; (ii) an analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and (iii) an analysis of the trends in water level change for the aquifer because of the exercise of the rights mentioned in paragraph (a)(i); (iv) a map showing the area of the aquifer where the water level is predicted to decline, because of the taking of the quantities of water mentioned in paragraph (a), by more than the bore trigger threshold within 3 years after the consultation day for the report; and, (v) a map showing the area of the aquifer where the water level is predicted to decline, because of the exercise of relevant underground water rights, by more than the bore trigger threshold at any time.	(i) and (ii) Section 5 describes the groundwater regime in the relevant aquifers. (iii) To date, Anglo has not produced or taken groundwater due to the exercise of underground water rights on the project site. (iv) Figure 23 Salinity Hydrograph (as Total Dissolved Solids) Figure 24 to Figure 26 show the areas where depressurisation due to the project activities is predicted to exceed the bore trigger threshold during the UWIR period. (v) Figure 27 shows the areas where depressurisation due to the project activities is predicted to exceed the bore trigger threshold during the life of the project.
376(1)(c)	A description of the methods and techniques used to obtain the information and predictions under paragraph (b).	Section 4 describes the UWIR methodology.
376(1)(d)	A summary of information about all water bores in the area shown on a map mentioned in paragraph (b)(iv), including the number of bores, and the location and authorised use or purpose of each bore.	Section 4.1 and Section 4.2 describe the water bores identified during the UWIR bore census. Section 6.5.2 confirms that there are no water bores within the affected aquifers.

Water Act Section No.	Water Act Section Content	UWIR Cross Reference
376(1)(da)	A description of the impacts on environmental values that have occurred, or are likely to occur, because of any previous exercise of underground water rights.	To date, Anglo has not produced or taken groundwater due to the exercise of underground water rights on the project site.
376(1)(db)	An assessment of the likely impacts on environmental values that will occur, or are likely to occur, because of the exercise of underground water rights: i. during the period mentioned in paragraph (a)(ii); and, ii. over the projected life of the resource tenure.	Section 6.5 presents an assessment of potential groundwater impacts due to groundwater take.
376(1)(e)	A program for: i. conducting an annual review of the accuracy of each map prepared under paragraph (b)(iv) and (v); and, ii. giving the chief executive a summary of the outcome of each review, including a statement of whether there has been a material change in the information or predictions used to prepare the maps.	Section 8 describes the UWIR review and reporting process for the affected aquifers.
376(1)(f)	A water monitoring strategy.	Section 7 describes the groundwater monitoring program.
376(1)(g)	A spring impact management strategy.	There are no springs within the mine site or its surrounds. Hence, a strategy for spring management is not required.
376(1)(h)	If the responsible entity is the office: i. a proposed responsible tenure holder for each report obligation mentioned in the report; and, ii. for each immediately affected area—the proposed responsible tenure holder or holders who must comply with any make good obligations for water bores within the immediately affected area.	Not applicable.
376(1)(i)	The information or matters prescribed under a regulation.	No other relevant information or matters have been prescribed under a regulation.
376(2)	However, if the underground water impact report does not show any predicted water level decline in any area of an affected aquifer by more than the bore trigger threshold during the period mentioned in subsection (1)(b)(iv) or at any time as mentioned in subsection (1)(b)(v), the report does not have to include the program mentioned in subsection (1)(e).	Section 8 describes the UWIR review and reporting process for the affected aquifers.

Section 378 of the Water Act lists the content requirements for the water monitoring strategy. Table 2.2 lists the specific content requirements and provides an explanation of where each requirement is addressed in this UWIR.

Table 2.2 UWIR Water Monitoring Strategy Content Requirements

Water Act Section No.	Water Act Section Content	UWIR Cross Reference
378(1)	A responsible entity's water monitoring strategy must include the following for each immediately affected area and long-term affected area identified in its underground water impact report or final report: a) a strategy for monitoring— (i) the quantity of water produced or taken from the area because of the exercise of relevant underground water rights; and (ii) changes in the water level of, and the quality of water in, aquifers in the area because of the exercise of the rights; b) the rationale for the strategy; c) a timetable for implementing the strategy; d) a program for reporting to the office about the implementation of the strategy.	Section 7 describes the groundwater monitoring program.
378(2)	The strategy for monitoring mentioned in subsection (1)(a) must include: a) the parameters to be measured; b) the locations for taking the measurements; and, c) the frequency of the measurements.	Section 7 describes the groundwater monitoring program.
378(3)	If the strategy is prepared for an underground water impact report, the strategy must also include a program for the responsible tenure holder or holders under the report to undertake a baseline assessment for each water bore that is: a) outside the area of a resource tenure; but b) within the area shown on the map prepared under section 376(b)(v).	Section 4.1 and Section 4.2 describe the water bores identified during the UWIR bore census. Section 6.5.2 confirms that there are no water bores within the affected aquifers.
378(4)	If the strategy is prepared for a final report, the strategy must also include a statement about any matters under a previous strategy that have not yet been complied with.	Not applicable.

3 PROJECT SETTING

3.1 Project Location and Land Use

The dominant land uses within the vicinity of the project site are coal mining, CSG production and cattle grazing.

The existing and approved future mines in the vicinity of the project site are shown on Figure 3 and include:

- MNM and the approved Grosvenor mining area adjoining the project site;
- The Goonyella Riverside and Broadmeadow Mine complex (GRBM) located north of MNM and the adjacent Red Hill Project;
- The Isaac Plains Mine located east of the approved Grosvenor mining area;
- The undeveloped Moranbah South Project located south of the approved Grosvenor mining area; and,
- The inactive Burton and Broadlea Mines located east of the project site.

The project site is located within a gas field that forms part of the Moranbah Gas Project, one of Australia's largest CSG operations. The Moranbah Gas Project extends over the project site and the surrounding area (Figure 13). The Moranbah Gas Project is a joint venture between Arrow Energy and AGL. The Moranbah Gas Project comprises 689 production and production testing coal seam gas wells that are used to extract coal seam gas from the P, Q and GM seams of the Moranbah Coal Measures. Coal seam gas production across the Moranbah Gas Project commenced in 2003 and is anticipated to be completed in 2025. Cumulative water production from the Moranbah Gas Project area, to 2015, is 4,652 ML, while the cumulative forecast water production from 2016 to 2025 is 2,018 ML (Arrow Energy 2016).

The Moranbah Gas Project involves the use of conventional gas drainage and hydraulic stimulation methods to extract CSG. Arrow Energy has approval to undertake hydraulic stimulation as a part of its CSG activities. Arrow Energy has undertaken hydraulic stimulation in 22 wells in the project site and areas immediately adjacent to the project site.

Historical clearing for cattle grazing has been undertaken within the project site and the surrounding area.

The potential for groundwater impacts due to the project and the surrounding land uses is assessed in Section 6.5.

3.2 Topography and Drainage

The project site is located in the Isaac River catchment, a sub-basin of the upper Fitzroy Basin. The Isaac River catchment covers an area of approximately 22,000 km^2, it discharges to the Connors River approximately 130 km to the southeast of the project site, and subsequently into the Fitzroy River a further 170 km southeast. The Isaac River traverses MNM from northwest to southeast, located approximately 4 km west of the project site.

The project site is traversed by Teviot Brook and Skeleton Gully. Teviot Brook is a substantive tributary of the Isaac River with a catchment area of approximately 259 km^2. It is an ephemeral creek with highly variable flows characterised by short duration flows driven by tropical low-pressure systems.

Skeleton Gully is a minor tributary of the Isaac River with a catchment area of approximately 47 km^2. Skeleton Gully is also ephemeral and flows are highly variable, but smaller than those of Teviot Brook due to the smaller contributing catchment area.

Topography across the project site is dominated by Teviot Brook and the associated floodplain adjacent to the creek (Figure 4). Two elevated ridgelines occur in the northwest and east of the project site. The topography gently slopes from these elevated ridges towards the Teviot Brook floodplain, which is oriented along a north-northeast to south-southwest axis, parallel with the flow direction of the creek.

In the northwest corner of the project site the terrain is an elevated plateau that is incised by Skeleton Gully.

There are no known springs or groundwater seeps in the vicinity of the project site.

3.3 Climate

The climate at the project site is sub-tropical continental, characterised by high variability in rainfall, temperature and evaporation, typical of Central Queensland.

Climate data has been collected from two Bureau of Meteorology (BoM) weather stations within the vicinity of the project site. These weather stations are:

- Moranbah Water Treatment Plant (Station 034038) – now decommissioned, operating from 1972 to March 2012. This monitoring station is located approximately 12 km southwest of the project site (Figure 4).
- Moranbah Airport (Station 034035) – operational, operating from March 2012 to present. This monitoring station is located approximately 19 km south of the project site (Figure 4).

A summary of average temperatures, rainfall and evaporation from the Moranbah Water Treatment Plant station is presented in Table 3.1, while a summary of average temperatures and rainfall from the Moranbah Airport station is presented in **Error! Reference source not found.**.

Table 3.1 Climate Averages – Moranbah Water Treatment Plant (Station 034038)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean max temp (^{0}C)**	33.8	33.1	32.1	29.5	26.5	23.7	23.7	25.5	29.2	32.3	33.1	34.0	29.7
Mean min temp (^{0}C)**	21.9	21.8	20.2	17.6	14.2	11.2	9.9	11.1	14.1	17.6	19.4	21.1	16.7
Mean rainfall (mm)*	103.8	100.7	55.4	36.4	34.5	22.1	18.0	25.0	9.1	35.7	69.3	103.9	613.0
Mean daily evaporation (mm)**	8.0	7.4	6.8	5.7	4.3	3.5	3.7	4.9	6.6	8.0	8.5	8.5	6.3

* Data record from 1972 to 2012
** Data record from 1986 to 2012

Table 3.2 Climate Averages – Moranbah Airport (Station 034035)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean max temp (ºC)	35.1	33.6	32.2	30.2	26.9	24.1	24.7	26.9	30.5	33.0	34.9	35.5	30.8
Mean min temp (ºC)	21.5	21.3	20.2	16.7	12.8	9.7	8.6	8.5	12.3	15.9	18.8	20.5	15.7
Mean rainfall (mm)	88.0	100.6	92.7	23.8	30.2	16.7	28.0	8.3	7.4	24.7	42.5	56.5	529.3

Data record from 2012 to June 2020

The available climate data shows distinct cycles of above average and below average rainfall. The Moranbah area has experienced below average rainfall between 2001 and 2006, and 2008 to 2010; with above average rainfall in 2007, and between 2010 and 2012. Rainfall from 2012 to present day has been varied with the long-term average, with years 2013/2014 and 2016/2017 where above average rainfall occurred and years 2018/2019 where below average rainfall occurred.

Evaporation rates have been recorded at the Moranbah Water Treatment Plant station between 1986 and 2012. Monthly evaporation rates exceed monthly rainfall for all months of the year, highlighting a net evaporative loss over a year.

3.4 Geology

The project is located on the north-western flank of the Bowen Basin, a sedimentary basin comprising Permian to Triassic age geology. The regional geology in the vicinity of the project site is shown in Figure 5. A veneer of more recent Tertiary and Quaternary age basalts and sediments typically overlie the Bowen Basin strata. The solid Bowen Basin geology is shown in Figure 6. The thickness and distribution of Tertiary basalt is shown in Figure 7. A detailed stratigraphic profile is shown in Figure 8.

As shown in Figure 5, the relevant geology in the vicinity of the project site includes:

- Cenozoic (i.e. Quaternary and Tertiary age) alluvium associated with the Isaac River and its tributary Teviot Brook;
- A veneer of Cenozoic (predominantly Tertiary) sediments comprising the Suttor Formation and associated colluvium, and weathered sediments;
- A highly variable and heterogeneous Tertiary basalt flow; and,
- Permian coal measures including the Rangal Coal Measures, the Fort Cooper Coal Measures (FCCM), the Moranbah Coal Measures (MCM) and the Back Creek Group. The Goonyella Middle Seam (GM seam) is included in the MCM target coal seam.

The distribution of alluvium is limited to localised deposits associated with Teviot Brook and its floodplain in the central and southern parts of the project site (Figure 9). In these areas, the creek channel is incised into the landscape and there is typically less than 3 m of alluvium present in the creek bed. Floodplain alluvial deposits are highly variable, typically ranging from a few centimetres to approximately 10 m thick on creek banks and older flood terraces, and locally thickening to 20 m. Alluvium is not present outside this localised area of creek and floodplain deposits. The Isaac River alluvium is located approximately 3 km south of the project site.

The Tertiary sediments comprise a heterogeneous profile of semi-consolidated sandstone, mudstone and other minor sediments associated with the Tertiary Suttor Formation, duricrusted palaeosols at the top of deep weathering profiles, colluvium and regolith (Figure 5). Published geological mapping confirms that the colluvium deposits transition to Suttor Formation sediments, indicating that these materials are frequently indistinguishable due to lithological similarities between these materials. These materials are therefore considered to form a single unit, hereafter referred to as the Tertiary sediments. The Tertiary sediments are widely distributed over the project site and its surrounds (Figure 10). The Tertiary sediments are thin (i.e. typically less than 20 m thick) over the Teviot Brook floodplain, thickening to approximately 100 m in the elevated northern part of the project site (Figure 10).

The Tertiary basalt comprises a heterogeneous profile of vesicular and massive basaltic lavas, with minor tuff and ash. The upper basalt profile is highly weathered forming a basaltic clay. The distribution of Tertiary basalt is confined to a paleochannel that is incised into the Permian coal measures and traverses the project site and north-east to south-west (Figure 7). The basalt reaches a maximum thickness of approximately 100 m within the project site (Figure 7). The Tertiary basalt is underlain by highly localised deposits of Tertiary alluvium that were present within the paleo-channels at the time the basalt flows occurred. The Tertiary alluvium comprises medium to coarse grained sand and is informally referred to as Tertiary basal sand due to its association with the base of the basalt unit. Where present, the Tertiary basal sand is less than 5 m thick and laterally discontinuous, forming discrete sandy lenses below the basalt. Previous investigations have confirmed that these materials are not extensive across the mapped Tertiary basalt extent and they have not been identified at the project site.

The Rewan Group is a thinly interbedded sequence of siltstone, claystone, fine grained sandstone and minor volcano-lithic pebble conglomerate. The Rewan Group sub-crops beneath the overlying alluvium, Tertiary sediments and basalt to the east of the project site and dips to the east (Figure 5).

The Permian coal measures include the Rangal Coal Measures, the FCCM, the MCM and the underlying Back Creek Group. The coal measures comprise a sedimentary sequence with interbedded coal seams, including the target GM seam. The upper profile of the sub-cropping coal measures have been extensively weathered forming a clay.

The coal measures typically sub-crop under the Tertiary sediments and basalt and dip towards the east. As the coal measures dip to the east, the depth of cover above the project longwall panels increases from approximately 370 m in the western part of the project mining area to more than 540 m in the east (Figure 11).

No significant or extensive faults have been detected within the project site or its surrounds.

Approximately 11 km to the east of the project site (Figure 6), the north-south trending Isaac Thrust Fault system can be traced over 30 km. The Isaac Thrust Fault is typically steeply dipping and with a vertical displacement of 600 m to 800 m. This vertical displacement has resulted in contact between significantly different geological units, specifically the Triassic formations on the downthrown (western) side of the fault and the Permian formations on the upthrown (eastern) side of the fault.

Approximately 7 km east of the project site a fault splays from the main Isaac Thrust Fault (Figure 6). This fault splay is orientated on a north-northwest to south-southeast axis and is steeply dipping. The fault splay has resulted in approximately 50 m to 100 m of vertical displacement within the Permian coal measures. Fault displacement has resulted in truncation of the Rangal Coal Measures and the lower seams of the MCM (including the GM seam) at the Isaac Thrust Fault, and associated splay, causing the coal seams to be juxtaposed with Permian interburden.

4 ASSESSMENT METHODOLOGY

This section describes the UWIR methodology, including the desktop study of relevant groundwater bores, geological and environmental information, and groundwater monitoring data. It also provides an overview of the numerical groundwater modelling method. A detailed description of the numerical groundwater modelling method is provided in Appendix II.

4.1 Desktop Study

4.1.1 Database Searches for Groundwater Bores

A search of relevant Queensland databases was undertaken for the EAR groundwater study and updated for the UWIR. The purpose of this search was to:

- Identify the presence of current and historical 'water bores' and groundwater monitoring bores; and,
- Collate drilling records and groundwater level, yield and quality data from relevant bores.

The database search area included the project site and its surrounds within a radius of 5 km. The database search area was considered suitably representative of the geological and hydrogeological setting of the project and includes the maximum extent of groundwater level drawdown as a result of the project activities.

The following databases and mapping were searched:

- The DNRME Groundwater Database of registered water bore data from private water bores and Queensland Government groundwater investigation and monitoring bores. This database provided information on bore location, groundwater levels, bore construction details, stratigraphic logs, hydrogeological testing and groundwater quality.
- The Queensland Spatial Catalogue (QSpatial), via Queensland Globe. Records of registered petroleum and coal seam gas (CSG) exploration, production and monitoring wells are contained within this database.

These searches identified the following registered bores:

- There are 56 registered groundwater monitoring bores within 5 km of the project site (Figure 12). These bores are all associated with the surrounding mining operations. Bore installation records are available for 52 of these bores. A total of 16 bores are installed in the Permian coal measures, 29 bores are installed in the Tertiary sediments and basalt and seven bores are screened in alluvium. The DNRME Groundwater Database information on these bores has been tabulated in Appendix I.
- There are 113 registered CSG production wells within the project site and an additional 361 registered CSG production wells within 5 km of the project site (Figure 13).
- There is one registered groundwater supply bore (RN 81696, also known as 'Skeleton Bore') located within 5 km of the project site (Figure 12). Skeleton Bore is located approximately 0.65 km north of the project site boundary. The database records indicate that this bore was drilled in 1992, although the landholder has indicated that the bore is approximately 50 years old. Information provided by the landholder indicates that this

bore is approximately 30 m deep. At this depth, the bore would be screened in the Tertiary sediments. The bore is currently equipped with a pump and groundwater from this bore is used as a stock watering supply.

4.1.2 Database Searches for Sensitive Environmental Features

The EAR presented a detailed assessment of the potential for Groundwater Dependent Ecosystems (GDEs) to be present within the project site and its surrounds. The GDE assessment involved Identifying potential GDEs within the project site from a search of the Queensland Springs Database and a search of the BoM's GDE Atlas.

The desktop GDE database searches identified the following potential aquatic and terrestrial GDEs within the project site:

- Areas of the channel of Teviot Brook and its anabranch;
- Areas of the floodplain of Teviot Brook and its anabranch;
- Two farm dams in the headwaters of Skeleton Gully and Skeleton Gully Tributary;
- A farm dam in the south-east of the project site along a minor tributary of Teviot Brook; and,
- An area in the south-west of the project site.

A search of the Queensland Springs Database indicated that no spring wetlands are located within the project site. Springs are therefore not discussed further in this section.

There are no subterranean GDEs mapped within the project site and there are no known caves or aquifer ecosystems in the region. Hence there are no likely subterranean GDE's within the project site.

The potential GDEs within the project site identified from desktop searches with field data were rationalised. This included consideration of potential GDE locations in relation to groundwater distribution, depth and quality as described in Section 5 and the distribution and types of vegetation to confirm the likely presence of any GDEs.

The GDE assessment confirmed that there are no aquatic GDEs within the project site due to the lack of any shallow surface water and surface expression of groundwater.

Based on a reconciliation of the potential GDE mapping, the groundwater assessment, the surface water assessment and the terrestrial vegetation assessment, the only potential terrestrial GDEs within the project site are the channels and areas of the floodplain associated with Teviot Brook and its anabranch.

4.1.3 Previous Groundwater Studies

A review of relevant groundwater studies was undertaken for the EAR groundwater study to collect local and regional hydrogeological data. This was undertaken to support the development and validation of the hydrogeological setting of the project site (described in Section 4.3). The review included the following groundwater studies undertaken within the vicinity of the project site and within comparable geological and environmental settings:

- G200s Project EAR Groundwater Report (AGE 2016). This report provided groundwater level data from 42 bores and 41 vibrating-wire piezometers (VWPs), while groundwater quality data was sourced from 61 bores. A summary of the groundwater monitoring facilities that provided water level and quality data are provided in Appendix I and II. This report also demonstrated that the characteristics of the main geological units at the G200 project are comparable to those of the project site. A numerical groundwater model was developed during the undertaking of this assessment to assess the potential impacts to groundwater from the G200s project. This groundwater model supported the development of the groundwater model for this project.
- Grosvenor Coal Project EIS Groundwater Impact Assessment (JBT Consulting 2010). This report demonstrated that the characteristics of the main geological units at the Grosvenor Mine are comparable to those of the project site.
- Moranbah North Mine groundwater monitoring program annual results for the period 2010 to 2017. These groundwater monitoring records supported the calibration of the numerical groundwater model.
- Red Hill Project EIS Groundwater Report (URS 2013). This report provided a groundwater investigation and impact assessment for the Red Hill EIS. Mine scheduling for the Red Hill project was summarised in this report; and was used in the groundwater model for this project to simulate potential cumulative drawdown impacts on the groundwater system.
- Moranbah South Project EIS Groundwater Report (AGE 2013). This report provided a summary of the groundwater investigation and impact assessment as part of the Moranbah South EIS. The proposed project development schedule supported the impact assessment of the project, while, the hydrogeological conceptualisation demonstrated that the characteristics of the main geological units at the Moranbah South project are comparable to those of the project site.
- Moranbah Gas Project Underground Water Impact Report (Arrow Energy 2016). This report provided information on the potential decline in water levels in aquifers due to the removal of associated water during CSG extraction and production testing. Water production forecasting from the various petroleum leases and the groundwater monitoring records from the project monitoring network were used to support the development and calibration of the groundwater model for this project.
- Integrated Isaac Plains Project Environmental Impact Statement (Matrix Plus Consulting 2009). This report summarises the hydrogeological investigation and impact assessment of the Integrated Isaac Plains Project. Characteristics of the proposed mine development were incorporated into numerical model for the project to support the cumulative impact assessment. This report also demonstrated that the characteristics of the main geological units at the Integrated Isaac Plain Project are comparable to those of the project site.

4.1.4 Anglo American Regional Groundwater Monitoring Network

Anglo maintains an integrated regional groundwater monitoring network that comprises a total of 82 groundwater monitoring locations (note: of the 82 monitoring locations, five monitoring bore screen intervals are unknown), and includes 24 VWPs in 12 holes across the project site and surrounding areas including MNM, Grosvenor Mine and the Moranbah South Project site (Figure 15). These monitoring facilities are distributed amongst the following units:

- Permian coal measures – 20 groundwater monitoring bores, 21 VWPs;
- Tertiary sediments and basalt – 52 groundwater monitoring bores, three VWPs; and,
- Alluvium – five groundwater monitoring bores.

Historical groundwater monitoring has also been completed at an additional 15 locations from open exploration holes. A summary of details (e.g. screen interval / sensor depth, target unit etc) of groundwater monitoring sites within 5 km of the project site is provided in Appendix I.

Groundwater sampling records from the monitoring network is available from July 2010. Collected samples were analysed for physico-chemical parameters [pH, Electrical Conductivity (EC), total dissolved solids (TDS)], major ionic constituents, trace metals and total petroleum hydrocarbons (TPH).

Hydraulic conductivity was measured in each of the major stratigraphic units from 34 bores.

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

The regional groundwater monitoring network and monitoring program incorporates the dedicated groundwater investigation of the project site that was undertaken by Anglo between 2014 and 2018. The project site groundwater investigation network/program involved:

- Drilling and constructing a groundwater monitoring network comprising 14 groundwater monitoring bores (Figure 14). The monitoring bores were installed within the interpreted key hydrogeological units, including the four bores in the alluvium, one bore in the Tertiary sediments, five bores in the Tertiary basalt, and four bores in the Permian coal measures;
- Measuring depth of groundwater strike and airlift yields in each groundwater monitoring bore during drilling to approximate the water table elevation and formation transmissivity during drilling;
- Measuring static groundwater levels following bore completion and development;
- Installing automatic water level loggers in each groundwater monitoring bore following bore completion and development;
- Permeability testing in eight groundwater monitoring bores where sufficient groundwater was present to measure the hydraulic conductivity of the screened hydrostratigraphic unit in each monitoring bore; and,
- Field measurement and laboratory analysis of six groundwater samples from alluvial, Tertiary and Permian formations to characterise and compare the existing groundwater quality within key formations.

4.1.5 Arrow Energy Groundwater Monitoring Network

Arrow Energy maintains a groundwater monitoring network as part of the Moranbah Gas Project that comprises seven shallow groundwater monitoring bores, six deep groundwater monitoring bores and eight VWPs (within five holes) within the vicinity of the project site (Figure 16). A summary of the groundwater data from this network comprises:

- Groundwater levels collected from shallow groundwater monitoring bores from June 2012 to January 2016 and deep groundwater monitoring bores from July 2014 to January 2016;
- Groundwater quality data was collected from seven shallow groundwater monitoring bores between June 2012 and January 2016; and, six deep groundwater monitoring bores between July 2014 (for four monitoring bores) and November 2015 (for two monitoring bores), and January 2016. Collected groundwater samples were analysed for physico-chemical parameters [pH, Electrical Conductivity (EC), total dissolved solids (TDS)], major ionic constituents, trace metals and nutrients; and,
- Hydraulic conductivity data collected from 42 hydraulic tests completed on 21 bores screened across the Quaternary alluvium, Tertiary sediment, weathered Tertiary basalt, and weathered Fort Cooper Coal Measures within the vicinity of the project site.

4.1.6 Bore Census

A water supply bore census was undertaken by Anglo as part of the EAR groundwater study and updated for the UWIR. The purpose of the bore census was to confirm existing groundwater use at the project site and its surrounds.

The bore census confirmed the presence of two water supply bores within 5 km of the project site (as shown in Figure 12), namely:

- Registered bore RN81696 (i.e. Skeleton Bore) located approximately 0.65 km north of the project site boundary; and
- An unregistered bore (i.e. Flohr Bore) in the eastern part of the project site.

Skeleton Bore is currently installed with pumping equipment and groundwater from this bore is currently used as a stock watering supply. The database records indicate that this bore was drilled in 1992, although the landholder has indicated that the bore is approximately 50 years old. Information provided by the landholder indicates that this bore is approximately 30 m deep. At this depth, the bore would be screened in the Tertiary sediments.

The Flohr Bore is not equipped with pumping infrastructure; and based on the condition of the bore casing it is interpreted that the bore has not been used for water supply for some time. The landholder confirmed that the bore is inactive. The bore is approximately 42.8 m deep. The depth to groundwater in this bore is approximately 18 m below ground level. At this depth, the bore would be screened in the Tertiary basalt.

Anglo has agreed to purchase land within the project site from the bore owner. As part of the land purchase agreement, ownership of the Flohr Bore will transfer to Anglo. Anglo has advised that the land purchase (and bore acquisition) will be completed upon grant of ML700042. Anglo has advised that it will decommission the Flohr Bore prior to commencement of any groundwater take on the project site, following the finalization of the land purchase agreement. Hence, there will be no groundwater supply bores present within the project site at the time Anglo first exercises its underground water rights in the project site.

4.2 Data Collation and Analysis

All relevant data was collated and analysed to develop a conceptual understanding of the groundwater regime, including the key geology, groundwater flow and groundwater quality characteristics.

The collated groundwater dataset includes the following relevant measurements:

- Geological data collected from the Anglo's geological block model of the project site and projects within the vicinity of the project site; and 14 drill holes completed as part of the hydrogeological field program for the project site.
- Groundwater level data collected from 109 bores and 32 VWPs within the main stratigraphic units across the project site and its surrounds. This includes manual groundwater level data and water level logger data collected from the Anglo established integrated regional groundwater monitoring program, the Moranbah Gas Project groundwater monitoring network and monitoring records from the project field investigation.
- Hydraulic data collected from a total of 55 bores, which rising/falling head tests were conducted. This includes hydraulic data for each of the main stratigraphic units within the project site and its surrounds.
- Groundwater quality data collected from 1,164 samples of 61 bores from within the vicinity of the project site.

4.3 Numerical Groundwater Modelling

A 3D numerical groundwater flow model was developed to predict the extents of depressurisation and the associated impacts on the groundwater regime and the surrounding environment. The groundwater model for the project was developed using MODFLOW software. MODFLOW is the most widely used groundwater modelling software in Australia and is considered to be the industry standard. A detailed description of the groundwater model is provided in Appendix II.

The groundwater model was constructed using a detailed geological model developed by the proponent from exploration data. It was further enhanced by inclusion of bore logs from groundwater monitoring bores and CSG production wells installed within the project site and its surrounds, and all published lithological logs within the model extents. The model was calibrated to existing groundwater levels using reliable measurements from all representative local and regional bores within the model domain.

Once calibrated, the model was used to predict the groundwater response to the project, including changes in groundwater levels and inflows to the proposed mining area. The groundwater model allowed the impacts of the existing approved mining and CSG operations to be distinguished from those of the project.

Conservative values were used to model the effects of subsidence cracking on the hydraulic properties of the overlying geology and the local groundwater regime. Overburden within the subsidence cracking profile was represented as highly permeable material to the top of the uppermost cracked unit. This approach is a realistic worst case representation of the effects of subsidence cracking and depressurisation on the groundwater regime.

The sensitivity of the model predictions to the input parameters was tested and analysed. The sensitivity analysis included varying model parameters and design features that could most influence the model predictions. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters. Overall, the sensitivity analysis confirmed that there is a high degree of confidence in the model's calibration and predictions, and that the model is not likely to have under-predicted any significant impacts.

The groundwater model has specifically been used to predict groundwater take and resulting groundwater depressurisation; and these predictions have been used to identify the Immediately Affected Areas (IAA) and Long Term Affected Areas (LTAA) for the UWIR. These predictions have also been used to assess the impacts of the project on groundwater users and the sensitive environmental features.

5 GROUNDWATER REGIME

The relevant hydrogeological units of the project site and its surrounds broadly comprise:

- Localised deposits of alluvium associated with the Isaac River and larger creeks including Teviot Brook;
- A shallow, highly weathered and heterogeneous veneer of low permeability Tertiary sediments;
- Tertiary basalt;
- Triassic Rewan Group; and,
- Permian coal measures including coal seams and interburden sediments.

The main groundwater-bearing formations are the Tertiary basalt and the coal seams of the Permian coal measures. These formations have been significantly depressurised and impacted by mining and gas production activities at nearby operations. The Rewan Group is a low permeability formation that is a regionally recognised aquitard. The alluvium and Tertiary sediments do not form permanent, saturated aquifers, and persistent groundwater occurs only where these sediments extend below the regional water table.

Recharge predominantly occurs via direct and diffuse rainfall to the weathered Tertiary sediments and Permian coal measures, or the localised alluvium. A portion of the rainfall moves downwards to the groundwater table, then moves through the system following the hydraulic gradient. Minor localised recharge also occurs via leakage from the alluvium during flow events in the larger creeks such as Teviot Brook. Recharge to the Tertiary sediments and Permian coal measures will occur where these units sub-crop below the alluvium.

Figure 17 and Figure 18 presents the interpolated groundwater surface elevation for the two main groundwater bearing formations (i.e. the Tertiary basalt and the GM seam). The regional groundwater flow is from elevated areas to the east of the project to lower lying areas to the west of the project. The calculated regional hydraulic gradient is approximately 0.01 and 0.03, respectively (i.e. very shallow). The available data for the Tertiary basalt and the Permian coal measures indicates a similar flow direction and gradient in each formation.

The groundwater table has been significantly altered by mining operations near the project site. Figure 18 shows the zone of depressurisation that exists above and around the surrounding mines and gas production bores. This zone locally influences groundwater flow directions and results in groundwater flowing towards these mines and gas production activities.

The alluvium and Tertiary sediments are predominantly unsaturated in the vicinity of the project site, therefore, interpolated groundwater surfaces for these units are unable to be produced. Saturated extents within these units have been developed and presented in Figure 19 and Figure 20, respectively.

The depth to groundwater and the elevation of the water table based upon the available data are presented in Figure 21.

With the exception of the localised alluvium, all units have a relatively low hydraulic conductivity.

Groundwater quality within the project site and its surround ranges from saline to highly saline. Regionally, groundwater is moderately saline to highly saline. Local and regional groundwater is therefore generally unsuitable for potable, irrigation or stock watering uses. Where water quality is suitable, yields are generally very low. There are no current groundwater users in the project site or its surrounds.

Figure 22 shows a conceptual cross-section of the geology and groundwater regime within the project site and its surrounds.

The hydrogeology of each unit is described in the following sections (KCB 2018a).

5.1 Alluvium

5.1.1 Distribution

The alluvium comprises clay, silt, sand and gravel associated with stream channels and flood deposits.

The distribution of alluvium is limited to Teviot Brook and its floodplain in the central and southern part of the project site (Figure 9).

Observations made during the field surveys undertaken as part of the EAR ecology assessment indicate that the Teviot Brook channel is incised into the floodplain and there is typically 1.5 to 3 m of alluvium present in the creek bed. This is consistent with observations made during the field surveys undertaken in the Isaac River at MNM. Project site drilling investigations and previous investigations in the Isaac River and its local tributaries show that floodplain alluvial deposits are highly variable, typically ranging from a few centimetres to 10 m thick, locally thickening to approximately 20 m on riverbanks and older flood terraces (Figure 9). Project site investigations encountered alluvium to a depth of 11 m below ground level. Alluvium is not present outside this localised area of river and floodplain deposits.

The regional groundwater table is typically located several metres below the base of the alluvium. The significant separating depth means that the alluvium is typically dry and unsaturated.

In small, discrete areas, where the alluvium is thickest and the groundwater table is shallowest, the base of the alluvium may intersect the regional water table at depths of approximately 15 m or deeper. In these localised areas, the base of the alluvium is likely to be partially saturated (Figure 19). High points in the underlying geology will act to separate any localised zones of saturated alluvium and limit any potential direct connection between the zones of saturated alluvium.

The regional water table does not saturate the shallow alluvium or intersect the ground surface (either in the riverbed or on the floodplain) in the vicinity of the project site. There is therefore no expression of the regional water table at the ground surface and no direct groundwater – surface water interconnection within the vicinity of the project. Groundwater does not provide baseflow to a watercourse in the vicinity of the project site. This is supported by the highly ephemeral nature of Isaac River flows (i.e. no baseflow) and absence of recorded springs in the vicinity of the project site.

5.1.2 Hydraulic Parameters

The hydraulic conductivity of the alluvium is highly variable; and is a function of the relative proportions of sand and fine clay and silt. Hydraulic conductivity of the bed sands ranges from 8.9 m/d to 45 m/d (mean of 17 m/d). The floodplain deposits exhibit lower hydraulic conductivity in the range 0.01 m/d and 5.4 m/d (mean of 0.3 m/d). These values are moderately high to high for unconsolidated sediments, respectively.

The higher permeability bed sands are localised to the creek channel and form a small proportion of the alluvium. The lower permeability flood deposits are more extensive and comprise the majority of the alluvium. The average hydraulic conductivity of the alluvium will therefore reflect this composition and by in the lower end of the measured range.

5.1.3 Potentiometric Surface, Recharge, Flow and Discharge

Recharge to the alluvium occurs via:

- Direct rainfall infiltration to the alluvium;
- Seepage of surface water into the creek bed during seasonal flow events in the river and larger creeks. Stream gauging data collected from the Isaac River downstream of the project site, and observations of Teviot Brook at the Grosvenor Mine, indicate that surface water flows are limited to short-duration events during and immediately following sustained seasonal rainfall. These flow events result in discrete, short duration recharge events through the alluvium that will dissipate to the surrounding groundwater regime; and,
- Localised seepage from the underlying groundwater regime in the Tertiary and Permian sediments during periods of no surface water flow (where the alluvium is thicker and the base of the alluvium extends below the regional groundwater table).

Regionally, the piezometric surface and groundwater flows within in the alluvium is a compartmentalised reflection of surface topography. Within the project site, groundwater flow in the alluvium is from northeast to southwest and follows the gradient and alignment of Teviot Brook.

Any alluvial groundwater accumulated during discrete, short-duration surface water flow events will subsequently dissipate to the groundwater regime associated with the underlying and adjacent Permian coal measures and Tertiary sediments and basalts.

All creeks near the site are ephemeral, with no measurable baseflow and therefore there is no significant groundwater contribution to surface water baseflow.

5.1.4 Groundwater Quality

Groundwater monitoring data shows that the quality of groundwater in the alluvium reflects the natural recharge and discharge processes described above.

Groundwater quality in the alluvium within the vicinity of the project site is brackish to moderately saline.

Brackish water quality data relates to areas where the alluvial groundwater is ephemeral and recharged by surface water flows. In these areas, evaporative concentration of surface water recharge over a short residence time has resulted in a slight increase in the salinity. More saline groundwater has been recorded in areas where the alluvium is inferred to be recharged by the underlying regional groundwater regime.

5.1.5 Yield and Use

No groundwater supply bores are located in the alluvium within 5 km of the project site due to the general lack of saturation or reliable water supply in these sediments.

5.2 Tertiary Sediments

5.2.1 Distribution

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

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

These sediments are widely distributed over the project site and its surrounds (Figure 10). Where present they generally form a thin veneer less than 40 m thick over the Tertiary basalt and Permian coal measures, thickening to approximately 90 m where it forms elevated plateaus and ridgelines (Figure 10). The Tertiary sediments do not store significant groundwater due to their generally limited thickness.

As with the alluvium, the Tertiary sediments are typically located above the regional groundwater table and are therefore generally dry and unsaturated in the vicinity of the project site.

The Tertiary sediments are saturated where they extend below the regional groundwater table, up to a maximum thickness of approximately 50 m (Figure 20) within the project site. In these instances, the groundwater within the Tertiary sediments is in direct hydraulic connection with the underlying Tertiary basalt and Permian coal measures. The limited saturated thickness means that these sediments do not store significant groundwater and are not considered a significant aquifer.

5.2.2 Hydraulic Parameters

Hydraulic testing data indicates that the Tertiary sediments have a low hydraulic conductivity ranging from 7×10^{-4} m/d to 1.22 m/d. The Tertiary sediments therefore have a lower average hydraulic conductivity than either the alluvium or the basalt; and is comparable to the Permian interburden sediments. This supports the assessment that this unit is not a significant aquifer.

5.2.3 Potentiometric Surface, Recharge, Flow and Discharge

The Tertiary sediments are recharged by direct infiltration from rainfall where these sediments are present at the surface. Short-duration recharge also occurs via seepage from the alluvium (where present) for short periods following surface water flow events. The Tertiary sediments are also recharged by the underlying groundwater regime where they are hydraulically connected.

Groundwater flow in the Tertiary sediments reflects the topography and is continuous only where this unit is saturated.

Groundwater flow in the Tertiary sediments is to the southwest, reflecting the topography of the Teviot Brook and Skeleton Gully catchments. Groundwater flows in the Tertiary sediments have also been influenced by the presence of mining and CSG production. The influence of these activities is observed in groundwater levels west of the project site, where coal seams are located at relatively shallow depths.

Discharge of the Tertiary sediments groundwater predominantly occurs as seepage to the underlying Permian sediments and Tertiary basalt (where present).

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

5.2.4 Groundwater Quality

Groundwater in the Tertiary sediments at the project site is saline (EC = 14,500 µS/cm). Regionally, groundwater in the Tertiary sediments vary from brackish to highly saline (EC = 1,300 to 29,100 µS/cm). The elevated salinity is a reflection of the degree of connectivity with the underlying Permian coal measures and the the long groundwater residency times and low permeability of groundwater in this unit.

5.2.5 Yield and Use

Groundwater yields are expected to be low (less than 1 L/s).

A single inactive water supply bore has been identified within 5 km of the project site. The bore is located on the Flohr property at the eastern boundary of the project site (Figure 12). This bore is inferred to be screened in the Tertiary sediments. The impact of the project on this bore are addressed in Section 6.5.

5.3 Tertiary Basalt

5.3.1 Distribution

The Tertiary basalt underlies the Tertiary sediments and overlies weathered Permian strata at the project site and typically occurs as a single composite unit comprising massive and vesicular lava, tuff and ash flows. Within the project site, the basalt flows are thickest towards the northeast where they are up to 100 m thick (Figure 7). The upper basalt profile is highly weathered to a depth of up to 55 m and comprises a basaltic clay. The weathered Tertiary basalt outcrops to the northeast and south of the project site. The maximum thickness of fresh basalt within the project site is 41 m.

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

The groundwater flow regime in the saturated Tertiary basalt is shown on Figure 17.

The depth of the groundwater table within the Tertiary basalt is more than 10 m within the project site and its surrounds; and is typically more than 50 m below ground level (Figure 21).

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

5.3.2 Hydraulic Parameters

The weathered basalt has a hydraulic conductivity ranging from 0.002 m/d to 2.6 m/d, while the hydraulic conductivity of the fresh basalt ranges from 0.03 m/d to 6.5 m/d. The large range in hydraulic conductivity values highlights the heterogeneous nature of the basalt.

On average the hydraulic conductivity of the weathered basalt is an order of magnitude lower than that of the fresh basalt.

The storage coefficient of the Tertiary basalt is between 0.01 and 0.0003 which also highlights the heterogeneous nature of the basalt and the variability of this unit between semi-confined and confined conditions.

5.3.3 Potentiometric Surface, Recharge, Flow and Discharge

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

Groundwater flow in the Tertiary basalt is typically parallel with the orientation of the palaeo-channel (Figure 7). Within the project site and its surrounds the paleo channel and groundwater flow are towards the southwest (Figure 17). Groundwater flows in the basalt are locally influenced by mining, particularly to the west of the project site where groundwater flows are towards MNM (Figure 17).

Groundwater discharge from the Tertiary basalt occurs as seepage to the underlying Permian coal measures and the underground workings at MNM. Depressurisation of the underlying Permian coal measures has increased the vertical gradient and seepage from the Tertiary basalt.

Due to the depth of groundwater in the Tertiary basalt (i.e. more than 50 m), there is no significant interaction with surface water or alluviual groundwater in the vicinity of the project site.

5.3.4 Groundwater Quality

Groundwater in the Tertiary basalt at the project site ranges from brackish to saline (EC = 2,310 to 17,300 µS/cm). The range in salinity reflects the highly heterogeneous characteristics of the basalt.

5.3.5 Yield and Use

Yields from the Tertiary basalt are variable due to its heterogeneous nature. Air-lift flow rates from the Tertiary basalt aquifer within the project site are between 0.14 L/s and 0.8 L/s. In the surrounding area air-lift flow rates encountered during exploration drilling are between 0.45 L/s in the basalt and 12.9 L/s in the basal sands, with a mean of 3 L/s and median of 1.5 L/s.

There are no water supply bores in the Tertiary basalt within 5 km of the project site.

5.4 Triassic Rewan Group

5.4.1 Distribution

The Rewan Group is a thinly interbedded sequence of siltstone, claystone and minor fine grained sandstone. This unit sub-crops and outcrops approximately 3 km east of the project site where it overlies the Permian coal measures (Figure 5). The Rewan Group is absent from the project site.

The Rewan Group is uniformly saturated at depth; and may become unsaturated where it outcrops or subcrops above the regional groundwater table east of the project site.

5.4.2 Hydraulic Parameters

The measured hydraulic conductivity of the Rewan Group ranges from 1×10^{-3} m/d to 1 m/d.

The Rewan Group is recognised as a regional aquitard and acts as a confining unit overlying the Permian coal measures. This unit is characterised by low primary porosity and as a result, groundwater movement is controlled by local fracture sets. Where fractures are intersected, this unit shows slightly higher permeability, and conversely, where limited fractures are intersected this unit shows lower permeability associated with the primary porosity. Bulk permeability of this unit is therefore constrained by the degree of connection between any localised fractures. This means that at the regional scale the representative average hydraulic conductivity is expected to be towards the lower end of the values measured by field testing.

5.4.3 Potentiometric Surface, Recharge, Flow and Discharge

The Rewan Group is recharged via direct rainfall infiltration in outcropping areas and via seepage from overlying units (including the Tertiary sediments, Tertiary basalt, and alluvium).

Groundwater levels in the Rewan Group are more than 20 m below ground level, and typically up to 40 m, in the vicinity of the project site.

Groundwater flow is towards the southwest and is a subdued reflection of the topography and surface water catchments. Discharge into the underlying Permian coal measures is the main discharge mechanism. However, discharge volumes are very low due to the very low rates of groundwater recharge.

5.4.4 Groundwater Quality

Groundwater in the Rewan Group is typically saline (KCB 2016). This is due to the low hydraulic conductivity and long groundwater residence times of this unit, which results in solute contribution from the rock mass to the groundwater. Groundwater within highly weathered zones of outcropping Rewan Group sediments can be slightly less saline due to enhanced direct recharge in these areas.

5.4.5 Yield and Use

Groundwater yields from the Rewan Group are typically very low (approximately 1 L/s). Slightly higher yields can occur where localised fractures are intersected by drilling.

There are no known groundwater supply bores in the Rewan Group within 5 km of the project site.

5.5 Permian Coal Measures

5.5.1 Distribution

The Permian coal measures include the Rangal Coal Measures, the Fort Cooper Coal Measures, the Moranbah Coal Measures, and the underlying Back Creek Group (Figure 8). They comprise alternating layers of fine to medium grained sandstone, siltstone and coal, including the target GM seam.

The coal measures sub-crop under the Tertiary sediments and basalt and dip towards the east. The GM seam reaches a maximum depth of approximately 540 m at the eastern extent of the project mining area (Figure 11).

The upper profile of the sub-cropping coal measures have been extensively weathered forming a clay cap.

The Permian coal measures are uniformly saturated across the project site. Some units of the Permian coal measures (e.g. Fort Cooper Coal Measures) may become unsaturated in areas where they outcrop to the east and southeast of the project site.

The coal seams have been extensively depressurised within the project site and surrounds due to CSG production and mining.

5.5.2 Hydraulic Parameters

Hydraulic conductivity within the Permian coal measures is typically associated with secondary porosity through fractures and cleats within the coal seams. The thick sequences of siltstone and sandstone interburden form confining aquitards within the coal measures.

The hydraulic conductivity of the Permian coal seams across the project site ranges from 1.2 to 4.5 m/d.

The interburden of the Permian coal measures has a greater range of hydraulic conductivity than the coal seams and ranges from 2 x 10^{-5} m/d to 2.95 m/d.

The hydraulic conductivity range in the interburden reflects the high degree of variability in the interburden strata, and includes measurements collected from very tight mudstones and extensively fractured horizons.

Hydraulic conductivity of the Permian coal measures also reduces with increasing depth, as a result of increasing lithostatic pressure causing compression of the strata. Regionally, the measured ranges of hydraulic conductivity therefore reflect the depth at which measurements were collected (AGE 2016). The regional and local dataset contains a high proportion of relatively shallow measurements due to the practical limitations of collecting deeper measurements.

5.5.3 Potentiometric Surface, Recharge, Flow and Discharge

Recharge occurs via rainfall infiltration on localised outcrops of Permian sediments to the east and southeast of the project site, and slow downward seepage from overlying strata. As a result, the groundwater recharge to the Permian coal measures is typically very low. The rate of recharge may also be enhanced where the coal measures subcrop against the overlying strata, although the clayey nature of this weathered material will also limit recharge. Overall, the rate of recharge remains very low.

Conceptually, the undisturbed groundwater flow direction in the Permian coal measures is towards the southeast.

Underground coal mining at MNM, Grosvenor Mine and the Goonyella Riverside Broadmeadow complex, and CSG production at the Moranbah Gas Project have reduced groundwater pressures in the surrounding coal measures, creating a zone of depressurisation that gradually diminishes with distance from these operations (Figure 18). The project site lies within the zone of depressurisation associated with both MNM and the Moranbah Gas Project (Figure 18). Depressurisation of the coal measures has reduced the potentiometric groundwater surface creating a hydraulic gradient towards the centre of the zone of depressurisation (i.e. MNM and the Moranbah Gas Project). Groundwater movement in vicinity of the project site is therefore a reflection of the depressurisation within the coal measures (i.e. towards these mining and CSG operations).

Groundwater discharge within the vicinity of the project site is therefore dominated by CSG production at the Moranbah Gas Project and groundwater drainage associated with the Moranbah North Mine and Grosvenor Mine. Groundwater discharge into overlying formations is negligible in the vicinity of the project site.

5.5.4 Groundwater Quality

Groundwater in the Permian coal measures is predominantly moderately saline to saline (Figure 23).

5.5.5 Yield and Use

Groundwater yields from the Permian coal measures are typically low, with a median yield of 0.8 L/s.

There are no known groundwater supply bores in the Permian coal measures within 5 km of the project site due to the typically low yields.

6 GROUNDWATER IMPACT ASSESSMENT

6.1 Introduction

Sections 6.1.1 and 6.1.2 provide an overview of the project activities relevant to the groundwater assessment.

Sections 6.2 and 6.3 present the groundwater depressurisation predictions during the UWIR period and over the mine life, respectively.

Section 6.1.2 summarises the key conclusions from the chemical risk assessment of the project hydraulic stimulation activities.

Section 6.5 describes potential impacts to groundwater users and the environment.

6.1.1 Longwall Mining Activities

The project involves the extension of underground longwall mining into the project site. The project will make use of the same longwall mining methods that are currently used at the existing Moranbah North Mine as described in Section 1.2.

The conceptual mine layout shows longwall panels will be 312 m wide and range from approximately 1.9 km to 4.2 km long (Figure 2). The extraction height will vary from 4.5 m to 4.6 m across the project site. The layout of the longwall panels is constrained by the approved Moranbah North Mine to the west, the Grosvenor Mine to the south and the depth of coal to the north and east.

In the project site, the GM seam has been extensively depressurised by underground coal mining at Moranbah North Mine and CSG production at the Moranbah Gas Project. The GM seam is overlain by the Permian coal measures, Tertiary basalt, Tertiary sediments and localised alluvium in the project site. The overburden between the GM seam and ground level has a minimum thickness of 370 m in the western part of the project mining area and increases to 540 m in the eastern part of the mining area (Figure 5).

When longwall mining takes place, subsurface cracking occurs in the strata overlying the area from which coal has been extracted (the goaf). Subsidence generates cracking that propagates upwards from the extracted seam until bulking of the goaf limits vertical movement and the tensile strength of the rock strata is sufficient to hold up the overburden without cracking. The height of cracking is important in assessing the impact of mining on the groundwater regime and groundwater inflow to the mine. The predicted height of connective cracking will be up to 125 m above the coal seam.

6.1.2 Gas Drainage Activities

As discussed in Section 1.2, the GM seam contains high concentrations of coal seam gas (CSG) and Arrow Energy has been extracting the gas from the GM seam on a commercial basis for many years using conventional gas drainage and hydraulic stimulation methods. As a result, much of the gas in the GM seam within the project site has been removed.

However, small amounts of residual gas may remain in the coal seam following commercial CSG extraction. It is necessary to ensure that the residual gas is removed prior to commencement of mining so that mining can proceed safely.

The project involves undertaking small-scale conventional gas drainage using pre-drainage of gas undertaken in advance of mining each longwall panel, and post-drainage of gas, undertaken following mining to control gas levels in the goaf (i.e. the area that has been mined). The residual gas within the project site will be removed using the same conventional gas drainage activities where conditions allow.

The project involves the use of hydraulic stimulation activities to remove residual gas from the GM seam prior to mining in areas of the project site that are not conducive to the use of conventional gas drainage methods. The GM seam is located between approximately 370 m and 540 m below ground level in the project site. The project hydraulic stimulation activities will allow mining to be undertaken safely in these areas.

The hydraulic stimulation methods used at the project site will be the same SurgiFrac hydraulic stimulation methods that are currently approved at the adjoining Moranbah North Mine PL191 and the Grosvenor Mine.

Hydraulic stimulation activities may be undertaken at existing gas drainage bores and do not require any new infrastructure. Temporary equipment required for the hydraulic stimulation activities will include trailer mounted and demountable surface equipment and downhole pipelines.

The hydraulic stimulation process will extend fractures within and around the target coal seam. The extent of the fracture network within the coal seam and surrounding geology will be monitored and mapped during selected hydraulic stimulation events. Hydraulic stimulation events will be selected for monitoring based on changes in the surrounding geology (e.g. a change in geological stress in the coal seam).

Microseismic events occur when rock fractures during hydraulic stimulation activities. The distribution and size of the microseismic events can be used to map the fracture network. An array of geophones will be installed within each gas drainage borehole to monitor microseismic events arising from hydraulic stimulation activities. Microseismic monitoring data indicates that fracturing is typically localised to the coal seam and its immediate surrounds within 25 m. Isolated fractures (i.e. less than 0.4% of all fractures) may extend approximately 80 m from the stimulation site within the coal seam, and up to approximately 50 m vertically above the coal seam.

Following completion of gas drainage and fracture network mapping, residual fluids and groundwater will be pumped from the borehole to the ground surface.

A mixture of groundwater and residual stimulation fluids will be recovered from the borehole. For each stimulation event, pumping will continue until at least 0.2 ML of groundwater and residual stimulation fluids is removed from the bore (i.e. equivalent to 150% of the stimulation fluid volume). The pumping process is expected to result in removal of the vast majority of the residual hydraulic stimulation fluids from the bore, the coal seam and the surrounding rock.

Following bore pumping, the coal seam will be extracted as part of longwall mining operations. Any residual fluids in the coal seam are likely to be completely removed during mining operations.

It is therefore extremely unlikely that any hydraulic stimulation fluids will remain in the underground strata after the completion of bore pumping, coal seam extraction and mine subsidence.

6.2 Groundwater Take

Table 6.1 shows the approved annual groundwater take for years 1, 2, and 3 of the UWIR period. The gradual increase from 25 ML in year 1 to 60 ML in year 3 is a result of the depth and extent of the underground workings increasing over the UWIR period, resulting in increased groundwater inflow rates.

Table 6.1 Predicted Volume of Groundwater Take during the UWIR Period

Year of UWIR Period	Predicted Inflow (ML)
1	25
2	42
3	60
Total for UWIR Period	**127**

The predicted groundwater take represents the theoretical volume of groundwater that could be removed from the groundwater regime. The actual volume of groundwater pumped from the underground mining area will be less than predicted by the numerical model, as a component of the groundwater will be lost to wetting of surfaces, ventilation and retained moisture within the extracted coal. The groundwater take presented in Table 6.1 does not account for the above mentioned losses that will occur when converting groundwater take to mine dewatering rates.

6.3 Groundwater Depressurisation during the UWIR Period

Figure 23 Salinity Hydrograph (as Total Dissolved Solids)

Figure 24 to Figure 26 shows that during the UWIR period localised depressurisation is predicted in the GM seam around the proposed longwall panels. The GM seam is predicted to experience up to approximately 356 m of depressurisation in this area (Figure 26), effectively lowering the potentiometric groundwater surface to 94 m above the GM seam. The zone of depressurisation is predicted to extend less than 0.76 km north of the project site boundary and remains within the project site and Moranbah North Mine in all other directions.

Figure 26 also shows the extent of the IAA in the GM seam. The IAA encompasses the area where drawdown during the UWIR period is predicted to exceed the applicable bore trigger threshold of 5 m for consolidated aquifers.

Depressurisation in the GM seam does not extend to the overlying Fort Cooper Coal Measures, Tertiary basalt and sediments, or the alluvium due to the thickness of overburden separating the coal seam from these formations. The Fort Cooper Coal Measures, Tertiary basalt and sediments, or the alluvium are not predicted to be depressurised by the project during the UWIR period.

6.4 Groundwater Depressurisation Over the Mine Life

Figure 27 shows that localised depressurisation is predicted in the GM seam around the proposed longwall panels. Depressurisation of the GM seam is predicted to be greatest in the eastern part of the project site, where the seam is deepest and hence groundwater pressure is greatest. The GM seam is predicted to experience up to approximately 356 m of depressurisation in this area (Figure 27), effectively lowering the potentiometric groundwater surface to 94 m above the GM seam. The zone of depressurisation is predicted to extend less than 1.02 km north and west of the project site, and less than 520 m to the east and south.

Figure 27 also shows the extent of the LTAA in the GM seam. The LTAA encompasses the area where drawdown over the life of the mine is predicted to exceed the applicable bore trigger threshold of 5 m for consolidated aquifers.

Depressurisation in the GM seam does not extend to the overlying Fort Cooper Coal Measures, Tertiary basalt and sediments, or the alluvium due to the thickness of overburden separating the coal seam from these formations. The Fort Cooper Coal Measures, Tertiary basalt and sediments, or the alluvium are not predicted to be depressurised by the project.

6.5 Environmental Impacts

This section describes the impacts of the project during the UWIR period on the following:

- Groundwater resources;
- Groundwater users;
- Surface water features;
- Springs;
- Groundwater dependent ecosystems; and,
- Groundwater quality.

The groundwater assessment also investigated potential impacts on groundwater quality due to the use of hydrocarbons and chemicals.

6.5.1 Impact on Groundwater Resources

The project site and its surrounds are located within the Isaac Connors Groundwater Management Area (GMA). Groundwater resources in the Isaac Connors GMA are managed under the *Water Plan (Fitzroy Basin) 2011* (the Water Plan). The Isaac Connors GMA comprises two groundwater units. Groundwater Unit 1 includes alluvial aquifers and Groundwater Unit 2 comprises all other sub-artesian aquifers.

There is no drawdown within the alluvium as a result of the project. There will be no groundwater take from the alluvium (i.e. Groundwater Unit 1) and therefore, the project will not impact on this groundwater resource.

Groundwater depressurisation is limited to the Moranbah Coal Measures which form part of Groundwater Unit 2. Table 6.1 shows the predicted groundwater take from the Moranbah Coal Measures, and hence, Groundwater Unit 2. The project will result in a total groundwater take of up to approximately 127 ML from Groundwater Unit 2 during the UWIR period.

As discussed in Section 6.2, the project's groundwater take and associated groundwater impacts have been approved under the EP Act.

6.5.2 Impact on Groundwater Users

A bore census was carried out to identify water supply bores surrounding the project site that could potentially be impacted by the project. The bore census drew upon information gathered through consultation with relevant landholders, advice from Anglo and a search of the DNRME's groundwater database.

The bore census was targeted towards bores and properties that could potentially be impacted by the project due to their proximity to proposed mining activities. The local hydrogeology was also taken into account in planning the bore census. The bore census included a conservative search radius of 5 km beyond the boundary of the project site.

The bore census confirmed that there is a general lack of water supply bores in the surrounding area. This is to be expected, given the generally low yields, access to alternative supplies (i.e. water supply pipelines) and brackish to highly saline quality of the groundwater.

The bore census confirmed the presence of two water supply bores within 5 km of the project site (as shown in Figure 12), namely:

- Registered bore RN81696 (i.e. Skeleton Bore) located approximately 0.65 km north of the project site boundary; and
- An unregistered bore (i.e. Flohr Bore) in the eastern part of the project site.

Skeleton Bore is currently installed with pumping equipment and groundwater from this bore is currently used as a stock watering supply. This bore is approximately 30 m deep and screened in the Tertiary sediments. As discussed in Section 6.3, the project is not predicted to result in any depressurisation of the Tertiary sediments. As a result, this bore is not predicted to be impacted by the project.

Anglo has agreed to purchase land within the project site from the bore owner. As part of the land purchase agreement, ownership of the Flohr Bore will transfer to Anglo. Anglo has advised that the land purchase (and bore acquisition) will be completed upon grant of ML700042. Anglo has advised that it will decommission the Flohr Bore prior to commencement of groundwater take on the project site, following the finalization of the land purchase agreement. Hence, there will be no groundwater supply bores present within the project site at the time Anglo first exercises its underground water rights in the project site.

As discussed in Section 6.4, the project's impacts on groundwater users have been approved under the EP Act.

6.5.3 Impact on Surface Drainage

Figure 4 shows the drainage setting of the project.

The project site is traversed by Teviot Brook and Skeleton Gully. The project site is drained by these drainage lines, associated minor tributaries and overland sheet flow. A small portion of the south eastern corner of the project site drains to an unnamed creek via overland sheet flow.

Teviot Brook, Skeleton Gully and their tributaries exhibit highly ephemeral short duration surface water flows that are typically restricted to periods during and immediately following rainfall events. This is consistent with observations made during the field surveys undertaken as part of the EAR. This is also supported by surface water flow data collected from DNRME's surface water gauging stations sited downstream of the project site and groundwater modelling predictions, which both indicate no perennial flows in the vicinity of the project site.

The groundwater table is currently located at least 10 m below the bed of Teviot Brook, Skeleton Gully and any other drainage features within the project site (Figure 21). The significant depth separating the groundwater table and the bed of these drainage features means that there is no direct inter-connection between the groundwater table and surface water flows in this area. Groundwater does not provide baseflow to surface waters in the vicinity of the project site.

Drawdown on the groundwater table will therefore not impact the overlying surface drainage features.

As discussed in Section 6.5.3, the project's impacts on surface drainage have been approved under the EP Act.

6.5.4 Impact on Springs

As discussed in Section 3.2, there are no springs within the project site or its surrounds.

6.5.5 Impact on Groundwater Dependent Ecosystems

As discussed in Section 4.1.2, the EAR database searches and GDE assessment have confirmed that the only potential GDEs within the project site are the channels and areas of the floodplain associated with Teviot Brook and its anabranch.

Limited potentially saturated zones occur where the alluvium thickens towards the southern (downstream) end of the project site. In these areas the base of the alluvium extends below the regional water table.

The alluvium is recharged by ephemeral surface water flows. Recharge flows seep from the alluvium to the regional water table below.

There is remnant woodland vegetation in the alluvial floodplain area that could potentially make use of the ephemeral alluvial groundwater.

The project could potentially impact the availability of groundwater in the Teviot Brook alluvium due to:

- Significant changes in the surface flow regime that recharges alluvium; and/or,
- Drawdown on the groundwater table due to mine subsidence.

The EAR concluded that the project is predicted to have a negligible impact on the flow regime of Teviot Brook. Consequently, the project will not impact the availability of surface water flow or groundwater recharge to the alluvium.

As detailed in Section 4.3, the groundwater modelling has predicted that the project will not result in any drawdown of the regional water table. Therefore, groundwater drawdown from the project will not impact groundwater levels in the Teviot Brook alluvium or any potential GDEs.

Given that the project is not predicted to significantly affect the hydrology of the Teviot Brook alluvium, the project is not likely to have any impact on any associated GDEs.

6.5.6 Impact on Groundwater Quality

6.5.6.1 Hydrocarbon and Chemical Storage

The storage of hydrocarbon and chemicals will continue to be managed in accordance with the existing MNM management practices, including the use of bunding and immediate clean-up of spills which are standard practice and a legislated requirement at mine sites that will prevent the contamination of the groundwater regime.

Given the limited activities proposed, and the controls that will be adopted, the project has a very limited potential to give rise to groundwater contamination as a result of hydrocarbon and chemical contamination.

6.5.6.2 Hydraulic Stimulation

Hydraulic stimulation may also be used in coal seam gas drainage, prior to mining. Arrow Energy has approval to undertake hydraulic stimulation as a part of its CSG activities; and has undertaken hydraulic stimulation within the petroleum tenement that covers the project site.

The hydraulic stimulation fluid comprises at least 99.8% water and sand. The remaining fluid comprises approximately 0.16% natural guar gel and less than 0.04% chemical additives. Bore pumping is expected to remove the vast majority of the natural guar gel and chemical additives from the gas drainage bore and the surrounding rock.

Following bore pumping, the coal seam will be extracted as part of longwall mining operations. Any residual fluids in the coal seam are likely to be completely removed during mining operations.

It is therefore extremely unlikely that any hydraulic stimulation fluids will remain in the underground strata after the completion of bore pumping, coal seam extraction and mine subsidence.

In the unlikely event that any guar gel or chemical additives remained within the rock fracture network surrounding the extracted coal seam, this would be a minimum of 290 m below the surface. Collectively, the potential hazards and environmental effects associated with these substances are summarised as follows:

- No evidence of environmental persistence or bioaccumulation;
- Direct contact may result in burns and irritation in humans. Ingestion can result in acute health effects. There is no evidence of carcinogenicity in humans; and
- May result in chronic and/or acute effects on the aquatic environment.

The guar gel and additives will be diluted with water and the resulting hydraulic stimulation fluid will contain negligible volumes of these substances. The potential effects of the guar gel and additives would be limited by the negligible volume that could potentially remain in the deep underground geology. Consequently, there is no significant risk of groundwater contamination.

In the unlikely event of a residual groundwater contamination source, adverse impacts would require the presence of a plausible pathway from the contamination source to a sensitive receptor. Section 5 describes the groundwater setting and shows that there are no groundwater users or sensitive environmental features associated with the GM seam or surrounding rock within the vicinity of the project. Hence, there is no feasible contaminant pathway by which groundwater users or sensitive environmental features are likely to be impacted.

The conclusions of the assessment are consistent with operational experience at Grosvenor Mine where hydraulic stimulation has been undertaken in advance of longwall mining.

As discussed in Section 5.1.4, the project's impacts on groundwater quality have been approved under the EP Act.

7 GROUNDWATER MONITORING PROGRAM

The following sections describe the monitoring and management measures for groundwater levels and quality, groundwater take and hydraulic stimulation. Each section provides an overview of the existing monitoring requirements and a detailed description of the approved monitoring and management measures. These measures will be implemented.

7.1 Groundwater Level and Quality Monitoring and Management

7.1.1 Environmental Authority Requirements

EA Condition C32 requires the maintenance of a groundwater monitoring and management program. The monitoring program must:

- Include a background groundwater monitoring program;
- Be able to detect a significant change to groundwater quality values due to mining activities carried out under the EA;
- Include measures to minimise the impact of the mining activities on groundwater resources;
- Include a program to investigate and respond to trends in changes to groundwater quality values and quantity that are identified to be associated with mining activities carried out under the EA;
- Include a program for monitoring and review of the effectiveness of the groundwater monitoring and management program; and
- Include contingency procedures for emergencies.

EA condition C36 requires that the groundwater monitoring program must be reviewed annually by an appropriately qualified person. The review must include an assessment of groundwater levels and groundwater quality data, an assessment of the suitability of the groundwater monitoring network and its compliance with the above requirements, recommended actions to ensure actual and potential environmental impacts are effectively managed and any necessary amendments to the groundwater monitoring and management program.

EA condition C37 requires that the findings of the annual review must be provided to the DES along with all supporting groundwater data. EA condition C38 requires that the proponent provides the DES a written response to the annual review findings that detail the actions taken to ensure EA compliance and minimise potential groundwater impacts. EA Condition C39 requires the recommended actions within annual review reports must be completed within the specified timeframe, unless agreed by the DES.

Groundwater monitoring must be undertaken in accordance with the approved groundwater monitoring and management program. All groundwater data must be compared to site-specific groundwater investigation trigger levels defined in EA Table C9 and condition C43. If the trigger levels are exceeded then the environmental authority holder must complete an investigation into the potential for environmental harm and notify the DES within the required timeframes. Compliance with the groundwater trigger levels is enforceable under Queensland legislation.

7.1.2 Approved Monitoring and Management Measures

Moranbah North Mine operates an extensive groundwater monitoring network in accordance with the Moranbah North Mine EA. The approved EA groundwater monitoring network comprises 28 monitoring bores located on the Moranbah North ML and the project site. The purpose of the groundwater monitoring network is to monitor groundwater levels and quality in the GM seam, Tertiary sediments and basalt, and alluvium in response to mining and hydraulic stimulation activities.

The EA groundwater monitoring network specifically includes four groundwater monitoring bores located on the project site (Figure 28), as listed in Table 7.1.

Table 7.1 Project Groundwater Monitoring Program

Bore ID	Easting[1]	Northing[1]	Target Unit
TWM17008A	609966	7581974	Alluvium
TWM17007A	609430	7582164	Tertiary Sediments
TWM17010B	609545	7584602	Tertiary Basalt
TWM17008B	609968	7581986	Fort Cooper Coal Measures

[1] coordinate provided in AGD84

These four bores were specifically selected for the following reasons:

- The bores target the groundwater table within the key alluvial and Tertiary basalt aquifers as well as the Tertiary sediments and upper Permian coal measures above the predicted zone of maximum depressurisation in the GM seam at the project site;
- The bores are located in the eastern part of the project site. Section 5 explains that groundwater flows west from this area towards the existing Moranbah North Mine. The remainder of the Moranbah North Mine groundwater monitoring network is located downgradient of the project site. These four bores therefore provide an effective means of monitoring groundwater quality within the key aquifers at the project site, and in conjunction with the existing Moranbah North Mine monitoring network, identifying any groundwater quality effects arising from within the project site; and,
- Bore TWM17007A is located close to the inactive water supply bore, in the same saturated Tertiary sediments.

The approved EA groundwater monitoring network is suitable for monitoring the effects of the project on the groundwater regime and will continue to be utilised throughout the life of the project.

In accordance with the requirements of the MNM EA, the groundwater monitoring program includes the following:

- Groundwater levels are recorded on a monthly basis, which enables natural groundwater level fluctuations (such as seasonal responses to rainfall) to be distinguished from potential water level impacts due to depressurisation resulting from mining activities, including any changes in the IAA and/or LTAA; and,
- Groundwater quality monitoring is undertaken on a quarterly basis to enhance the existing baseline dataset available prior to commencement of the project. This is used to detect

any changes in groundwater quality during and post-mining and hydraulic stimulation. Water quality samples are analysed for physico-chemical parameters including pH, electrical conductivity, alkalinity, major ions (Ca, Mg, Na, K, Cl and SO_4), metals and metalloids (Al, As, Fe, Mo and Se) and total petroleum hydrocarbons.

If the monitoring results show any unexpected results, an investigation will be triggered. The scope of the investigation will include confirming the likely cause of the unexpected results. If investigation findings show that the unexpected results are due to the approved mining activities (rather than natural fluctuations), additional management measures will be implemented. A risk assessment will be undertaken to determine whether any potential additional management measures are required to prevent adverse environmental impacts.

The EA groundwater monitoring and management program is reviewed annually to ensure that the groundwater regime is monitored effectively.

7.2 Groundwater Take Monitoring and Management

7.2.1 Regulatory Requirements

Anglo has an existing obligation to quantify its actual groundwater take from the project site under the MR Act. The DNRME *Guideline for quantifying the volume of take of associated water under a mining lease or mineral development license* (Groundwater Take Guideline) describes the acceptable methods for monitoring and quantifying actual groundwater take under the MR Act. The acceptable methods include direct measurement, water balance modelling, and numerical/analytical groundwater flow modelling.

7.2.2 Approved Monitoring and Management Measures

In accordance with the requirements of the MR Act, Anglo will continue to assess actual groundwater take using the acceptable methods. The method used will be reviewed annually and revised, as necessary.

The actual groundwater take assessed under the MR Act requirements will be compared to the predicted groundwater take presented in this UWIR. This comparison will be undertaken annually. If the monitoring program shows groundwater take exceeds the predictions presented in this UWIR, an investigation will be undertaken to confirm whether the actual impacts on groundwater users or sensitive environmental features are likely to be significantly greater than expected. The investigation outcomes will be considered as part of the annual UWIR review described in Section 8.

7.3 Hydraulic Stimulation Monitoring and Management

7.3.1 Environmental Authority Requirements

EA Schedule J – Stimulation Activities imposes the following key requirements on the project stimulation activities:

- Preparation of a comprehensive Stimulation Risk Assessment prior to undertaking hydraulic stimulation activities;

- Implementation of a baseline bore water quality assessment for any active landholder bores or other groundwater supply bores that could be adversely impacted by the stimulation activities, prior to undertaking hydraulic stimulation activities;
- Implementation of a stimulation impact monitoring program prior to undertaking hydraulic stimulation activities. The stimulation impact monitoring program must be able to detect groundwater quality impacts from the stimulation activities, and must specifically address the following:
    - Monitoring the quantity and quality of fluids used in the hydraulic stimulation activities;
    - Monitoring the quantity of flow back water from the hydraulic stimulation activities;
    - Monitoring that demonstrates the volume of flow back water recovered from each well is equal to, or greater than, 150% of the volume of fluids used and that all additives used in the hydraulic stimulation activities have been removed;
    - Monitoring of active landholder bores and other relevant groundwater supply bores; and,
    - The required monitoring frequency and timings (per EA conditions J13 and J14).

The proponent is required to make the findings of the stimulation impact monitoring program available to any potentially affected landholder. If the stimulation impact monitoring program detects a 10% increase in concentrations of monitoring parameters and the use of any active landholder bores is impaired, the proponent is required to notify the DES within 48 hours. In addition, the proponent is also required to notify the DES of any use of restricted stimulation fluids, or the unauthorised release of stimulation fluids or additives.

7.3.2 Approved Monitoring and Management Measures

The proponent has an existing Moranbah North hydraulic stimulation monitoring program (approved in 2019). This is undertaken during and following hydraulic stimulation activities and includes:

- Additional monitoring of groundwater quality and levels in the gas drainage bore and groundwater monitoring bores located within a radius of 2 km of a stimulation event. These bores will be monitored at monthly intervals for six months following a stimulation event. Monitoring will continue annually for five years, or until monitoring data returns to baseline levels for two monitoring rounds, or longwall mining progresses through the gas bore location;
- Stimulation fluid quality and quantity monitoring at representative intervals during each stimulation event;
- Microseismic monitoring comprising multi-level geophone arrays installed above the GM seam at the hydraulic stimulation site to measure the height of fracturing in the coal seam and surrounding rock;
- Sonic logging to measure the integrity of the well seal and identify any potential for inter-aquifer connectivity; and,

- Flow back fluid quality and quantity monitoring to demonstrate that 150% of the volume of the stimulation fluids has been extracted from the gas drainage bore and that all additives used in the stimulation activities have been removed.

The hydraulic stimulation monitoring program (including the requirement for removal of 150% of the volume of the stimulation fluids has been extracted from the gas drainage bore) is consistent with the Queensland Guideline: *Streamlined model conditions for petroleum activities* that is used successfully throughout the State.

If the monitoring results show any unexpected results, an investigation will be triggered. The scope of the investigation will include confirming the likely cause of the unexpected results. Hydraulic stimulation activities will be temporarily suspended during the investigation.

If investigation findings show that the unexpected results are due to the project's hydraulic stimulation activities (rather than natural fluctuations), additional management measures will be implemented. A risk assessment will be undertaken to determine whether any potential additional management measures are required to prevent adverse environmental impacts.

Management measures will be implemented to prevent any unexpected adverse impacts on sensitive environmental features. These management measures include:

- The storage of hydrocarbon and chemicals in accordance with the existing Moranbah North Mine management practices, including the use of bunding and immediate clean-up of spills which are standard practice and a legislated requirement at mine sites that will prevent the contamination of the groundwater regime; and
- Storage and handling of hydrocarbon and chemicals in accordance with the relevant legislative requirements and Australian Standards as necessary, including the provisions of AS 3780:2008 – The storage and handling of corrosive substances and AS 3833:2007 – Storage and handling of mixed classes of dangerous goods in packaged and intermediate bulk containers.

The approved monitoring and management measures are adequate for the potential impacts of the project.

8 UWIR UPDATES AND REVIEW

8.1 Roles and Responsibilities

Anglo is responsible for ensuring that the UWIR is implemented.

8.2 Review and Revision

As discussed in Section 6, depressurisation of the GM Seam is expected to exceed the bore trigger threshold.

Hence, MNM will undertake an annual review of the accuracy of the IAA and LTAA mapping, as required by Section 376(1)(e) of the Water Act.

The review process will comprise:

- An initial review of any new geology or groundwater data to identify potentially significant departures from the data used in the UWIR to develop the IAA and LTAA mapping.
- Where potentially significant departures are identified, the potential effect of these departures on the IAA and LTAA will be investigated.
- If the investigation concludes that the IAA or LTAA are likely to have been under-estimated and additional water bores are likely to be affected, the IAA and LTAA will be revised.

The UWIR has been designed to align with the current EA groundwater conditions. It is therefore necessary to review and update the UWIR in response to any material changes to the EA groundwater conditions.

8.3 Reporting and Record Keeping

The outcome of each annual review will be reported to the DES and the Office of Groundwater Impact Assessment following completion of each annual review. The reported outcomes will include a statement of whether there has been a material change in the information or predictions used to prepare the maps.

9 CONCLUSIONS

The key conclusions of this UWIR are as follows:

- The impacts of the project over the UWIR period and the life of the mine have been assessed and approved under the EP Act as part of the grant of the MNM EA amendment in November 2019.
- The approved mining operations will result in localised depressurisation of the GM Seam.
- The other potential aquifers and shallow formations (i.e. the Tertiary basalt, Tertiary sediments and alluvium) are not predicted to be depressurised by the project.
- The project will not impact surface waters or alluvial aquifers during the UWIR period because:
  - Localised alluvium that is present in the vicinity of the project site is typically unsaturated, relatively thin and compartmentalised, and it does not represent a significant aquifer;
  - All creeks near the site are ephemeral, with no measurable baseflow and therefore there is no significant groundwater contribution to surface water baseflow; and,
  - The significant depth of cover over the project mining area during the UWIR period (over 300 m) and the low permeability interburden of the Permian sediments will effectively prevent significant depressurisation of the shallow formations.
- There are no groundwater users or other sensitive environmental features within the GM seam at the project site or its surrounds, and therefore no significant groundwater impacts as a result of the project.
- There is a very low potential for groundwater contamination as a result of the project.

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NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale:

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PROJECT	MORANBAH NORTH EXTENSION UWIR
TITLE	PROJECT LOCATION (SOURCE: HANSEN BAILEY)
PROJECT No.	D10167A03
FIG No.	FIGURE 1.1
REV	A

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale:

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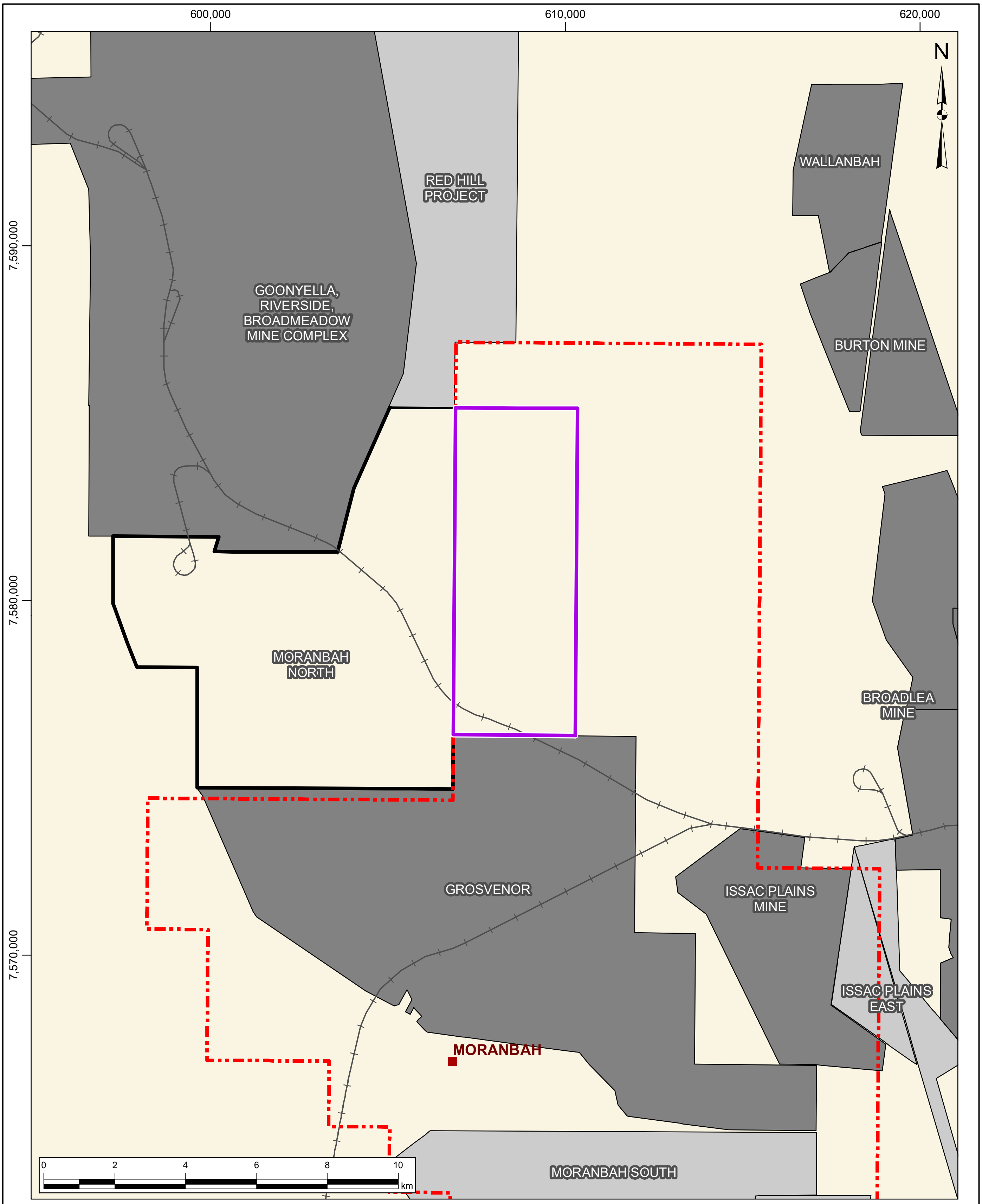
PROJECT	MORANBAH NORTH EXTENSION UWIR
TITLE	PROJECT LAYOUT (SOURCE: HANSEN BAILEY)

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 1.2	A

28/09/2020, nturner, Z:\DBNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_1.2_ProjectLocation.mxd



Legend

- Town
- Rail
- Undeveloped Coal Project
- Moranbah Gas Project
- Project Site
- Moranbah North Mine

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:150,000

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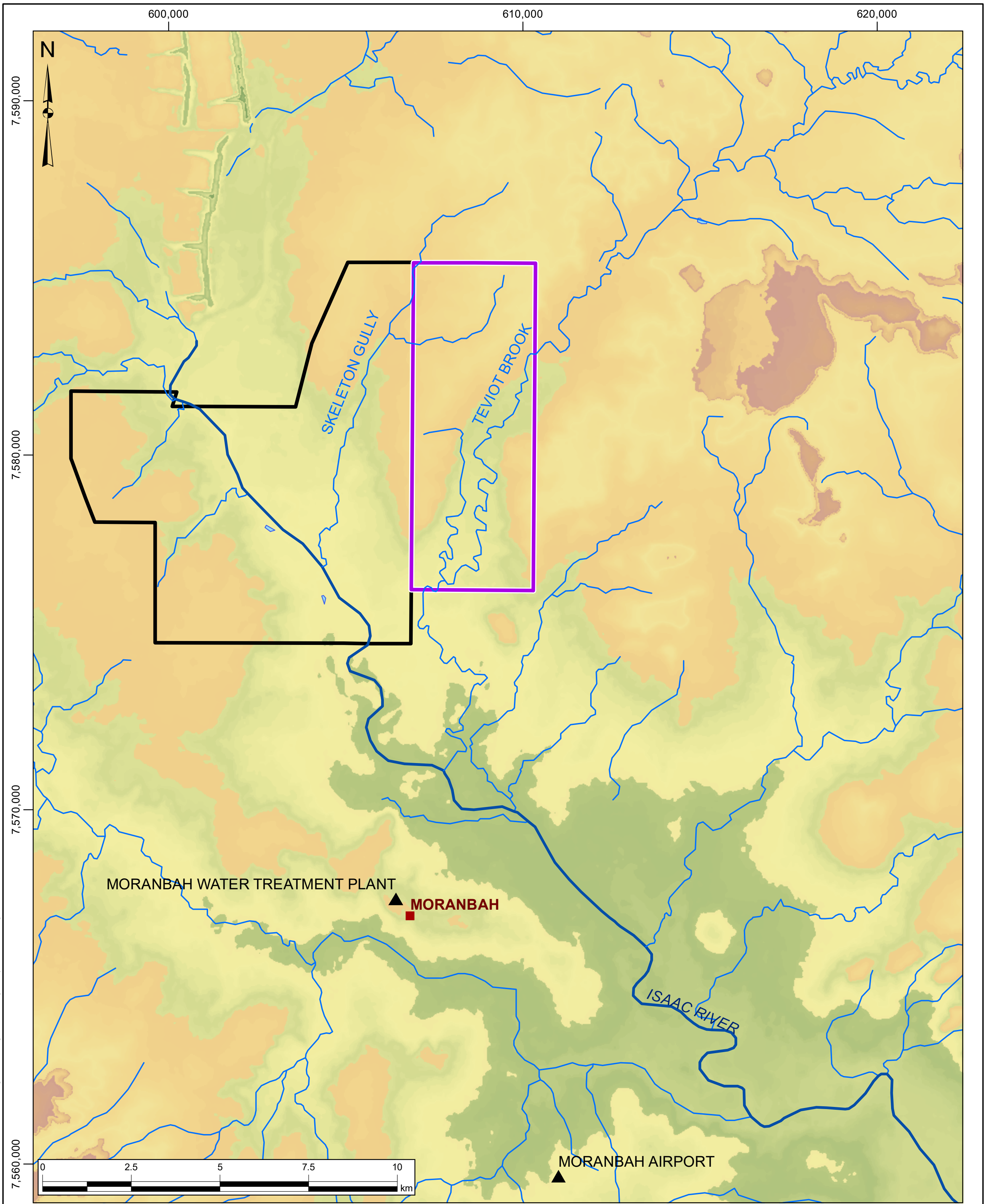
PROJECT	MORANBAH NORTH EXTENSION UWIR
TITLE	LOCAL MINES AND MINING PROJECTS
PROJECT No. D10167A03	FIG No. FIGURE 3.1 — REV A

15/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.1_Surrounding_Mines.mxd



Legend

- Town
- Weather Station
- River
- Creek
- Project Site
- Moranbah North Mine

Elevation (mAHD)
400
275
150

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:150,000

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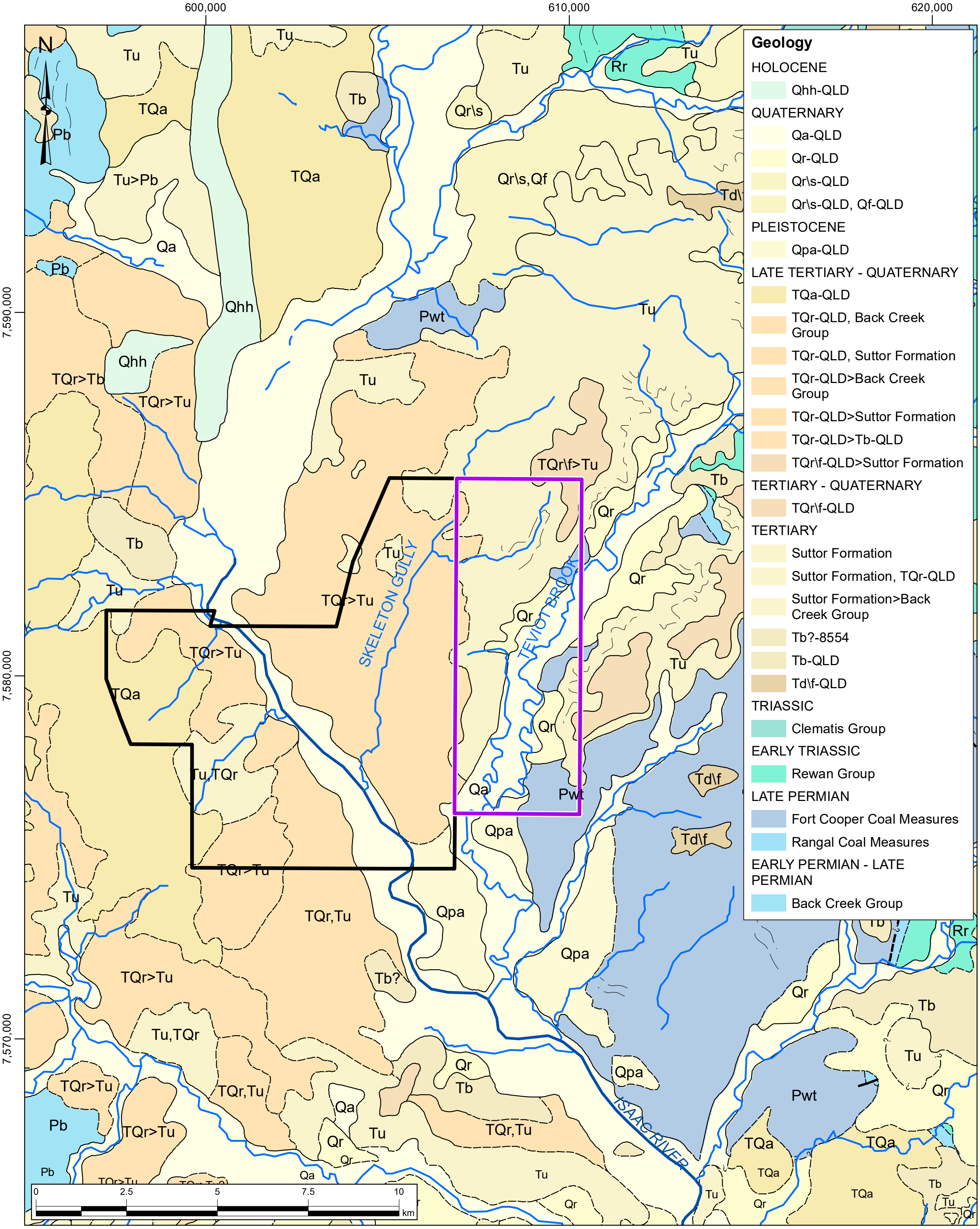
PROJECT	MORANBAH NORTH EXTENSION UWIR
TITLE	PROJECT SITE TOPOGRAPHY AND DRAINAGE
PROJECT No.	D10167A03
FIG No.	FIGURE 3.2
REV	A

15/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.2 Topography and Drainage_Update.mxd



Legend

- River
- Creek
- Project Site
- Moranbah North Mine
- Geological Boundary Accurate
- Geological Boundary Approximate
- Geological Boundary Inferred
- Fault Accurate
- Fault Approximate
- Fault Inferred
- Trend Line
- Trend Line Showing Dip

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:150,000

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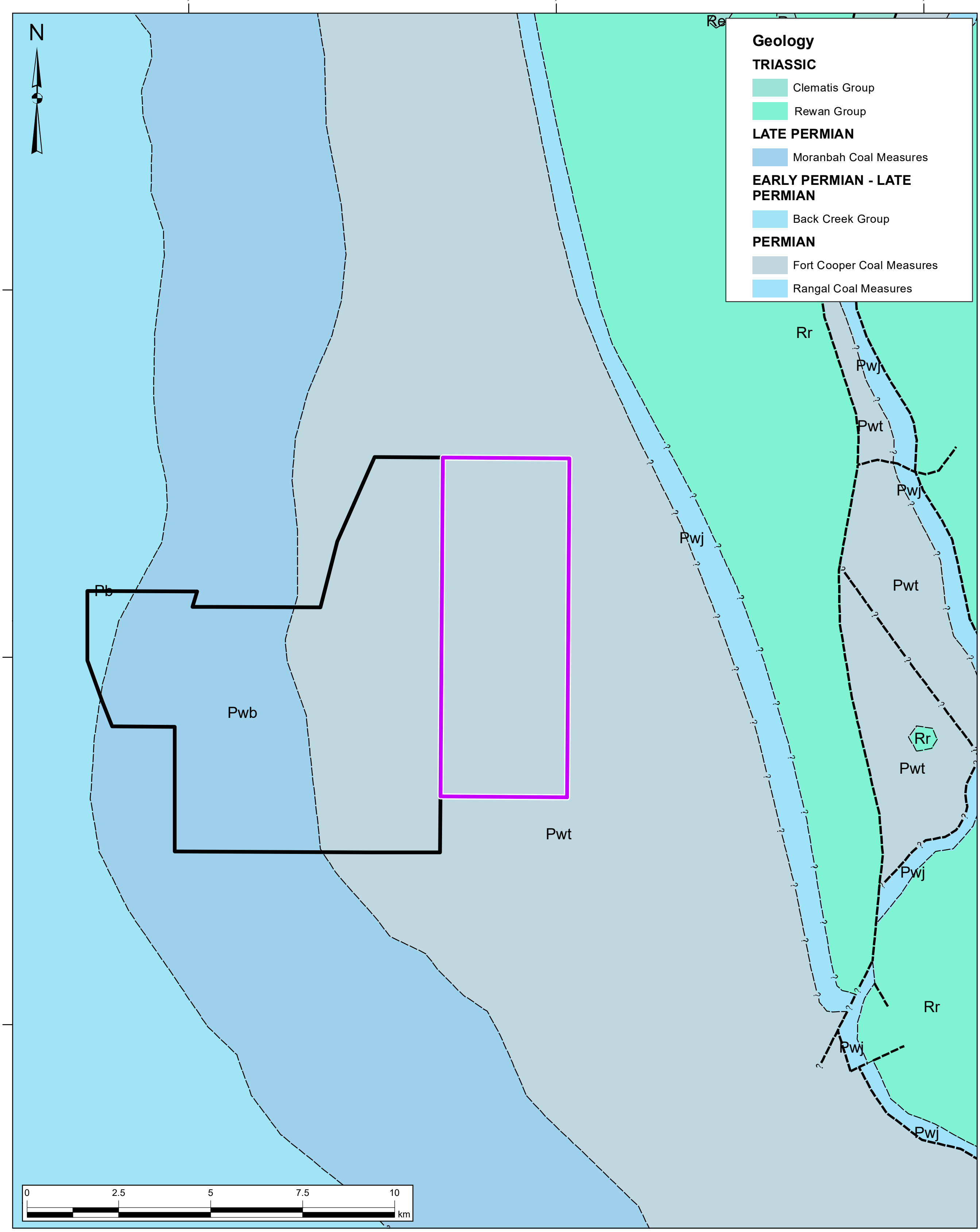
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
SURFACE GEOLOGY

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 3.3	A

15/09/2020, EMangos, \\int.klohn.com\Proj\Data\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.3_Surface_Geology.mxd



Legend

Project Site	Fault Approximate
Moranbah North Mine	Fault Inferred
Geological Boundary Approximate	
Geological Boundary Inferred	

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:150,000

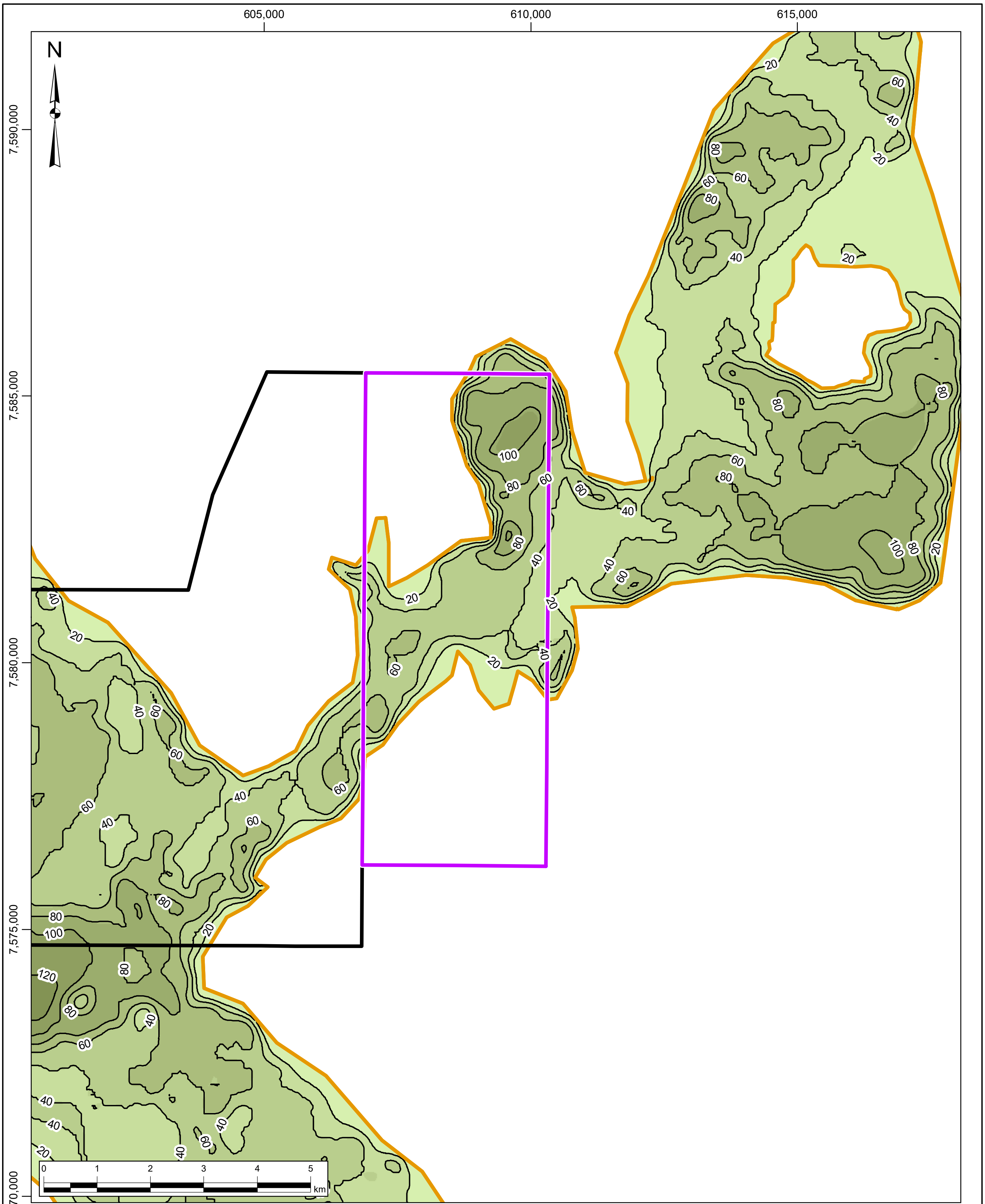
CLIENT: Klohn Crippen Berger

PROJECT: MORANBAH NORTH EXTENSION UWIR

TITLE: SOLID (REGIONAL) GEOLOGY

PROJECT No. D10167A03 | FIG No. FIGURE 3.4 | REV A

16/09/2020, EMangos, \\int.klohn.com\Proj\Data\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.4_Solid_Geology.mxd



Legend

Basalt Extent

Project Site

Moranbah North Mine

Tertiary Basalt Thickness (m)

0 - 20
20 - 40
40 - 60
60 - 80
80 - 100
100 - 120
120 - 140

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
TERTIARY BASALT EXTENT
AND THICKNESS

PROJECT No. D10167A03
FIG No. FIGURE 3.5
REV A

Age	Formation	Seams*
Cenozoic	Alluvium	
	Tertiary sediments	
	Tertiary basalt	
	Tertiary basal sands	
Triassic	Rewan Group	
Permian	Rangal Coal Measures	Leichardt Vermont
	Fort Cooper Coal Measures *Sandstone interlayered coal carbonaceous mudstone and tuffaceous material*	Cannis
		Fair Hill
	Morambah Coal Measures *Feldspathic sandstone, siltstone and shale., coal bearing strata up to 320m thick*	Qa seam
		Qb seam
		Goonyella Upper
		P seam
		Goonyella Middle Rider (GMR)
		Goonyella Middle (GM)
		Harrow Ck Lower (HCL)
		Dysart Upper 1 (DYU1)
		Dysart Upper 2 (DYU2)
		Dysart Rider (DYR1 and 2)
		Goonyella Lower (GL)
	Back Creek Group	N/A

* Listed shallowest to deepest within each formation

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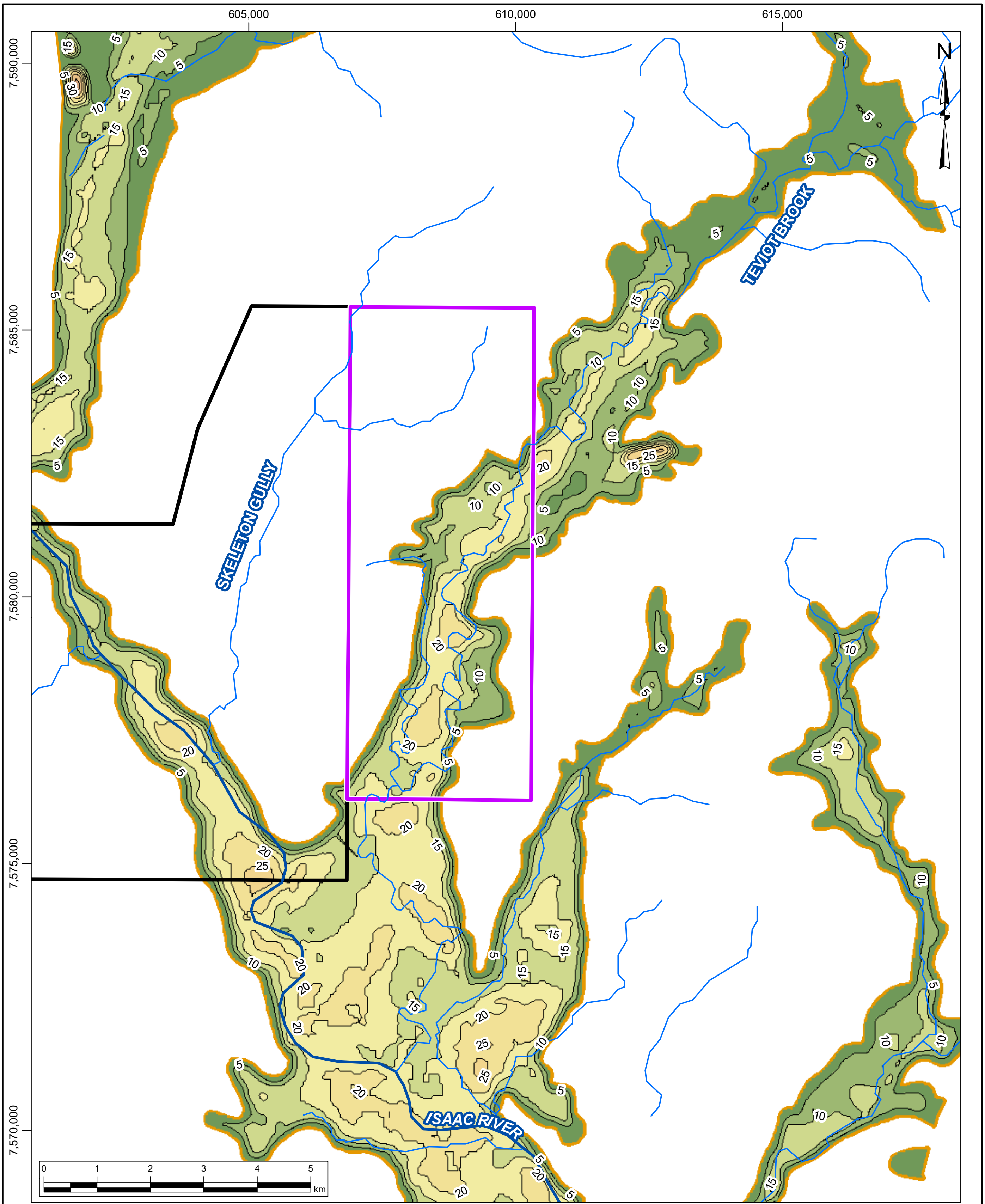
PROJECT: MORANBAH NORTH EXTENSION UWIR

TITLE: STRATIGRAPHIC PROFILE (SOURCE: HANSEN BAILEY)

PROJECT No. D10167A03 | FIG No. FIGURE 3.6 | REV A

Z\BNE\D10130A01 - Grasstree Expansion - Hydrogeology\400 Drawings\Issued\Grasstree longwall Extension report\Fig 7_Stratigraphic Column.pptx



Legend

- Contour, Alluvium Thickness (m)
- Alluvium Extent
- Project Site
- Moranbah North Mine

Quaternary Alluvium Thickness (m)

0 - 5	15 - 20	30 - 35
5 - 10	20 - 25	35 - 40
10 - 15	25 - 30	

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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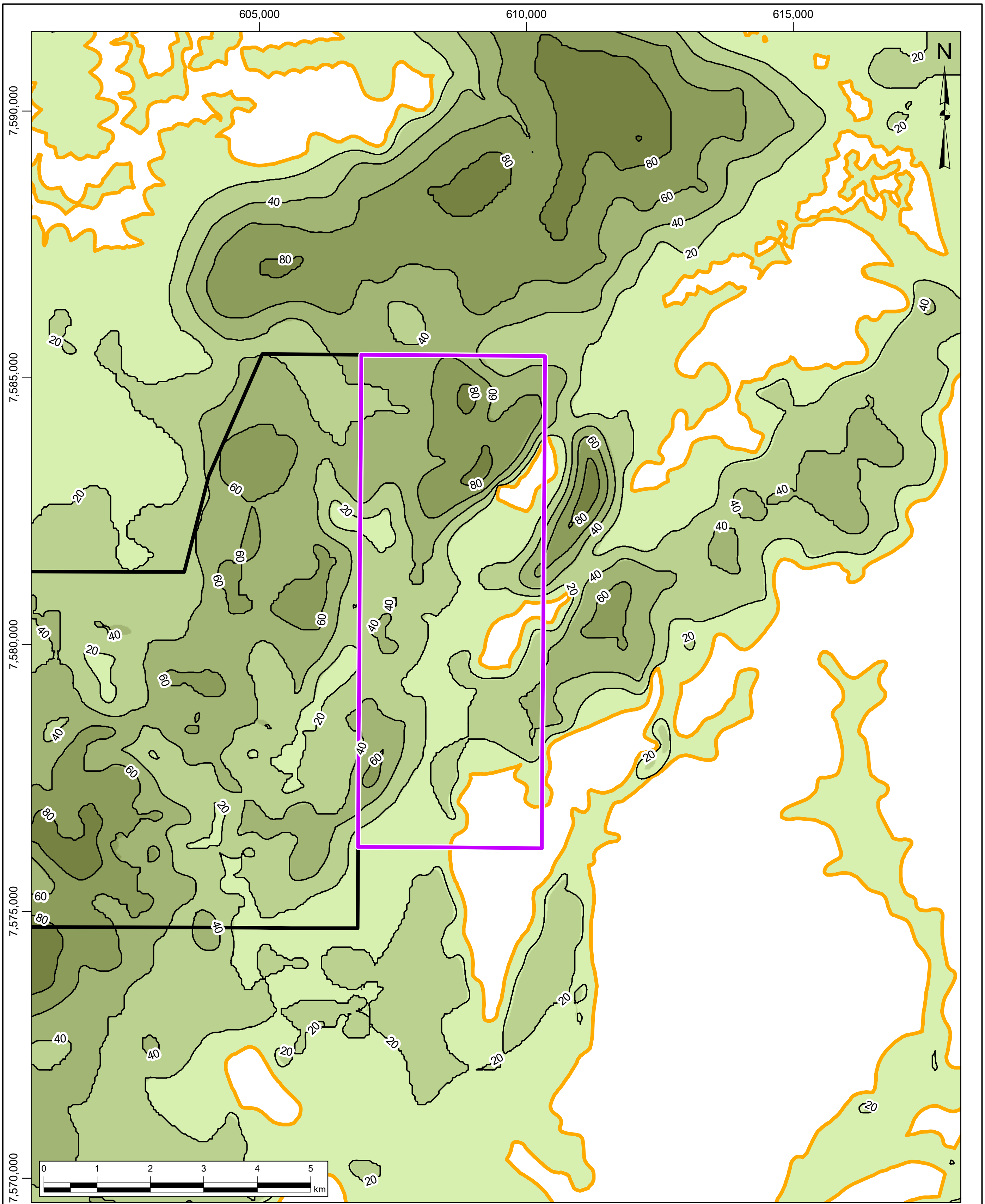
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
ALLUVIUM EXTENT
AND THICKNESS

PROJECT No. D10167A03
FIG No. FIGURE 3.7
REV A

16/09/2020, EMangos, \\int.klohn.com\Proj\Data\DIBNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.7_Alluv_Thickness_Update.mxd



Legend

- Contour, Tertiary Sediment Thickness (m)
- Tertiary Sediment Extent
- Project Site
- Moranbah North Mine

Tertiary Sediment Thickness (m)

- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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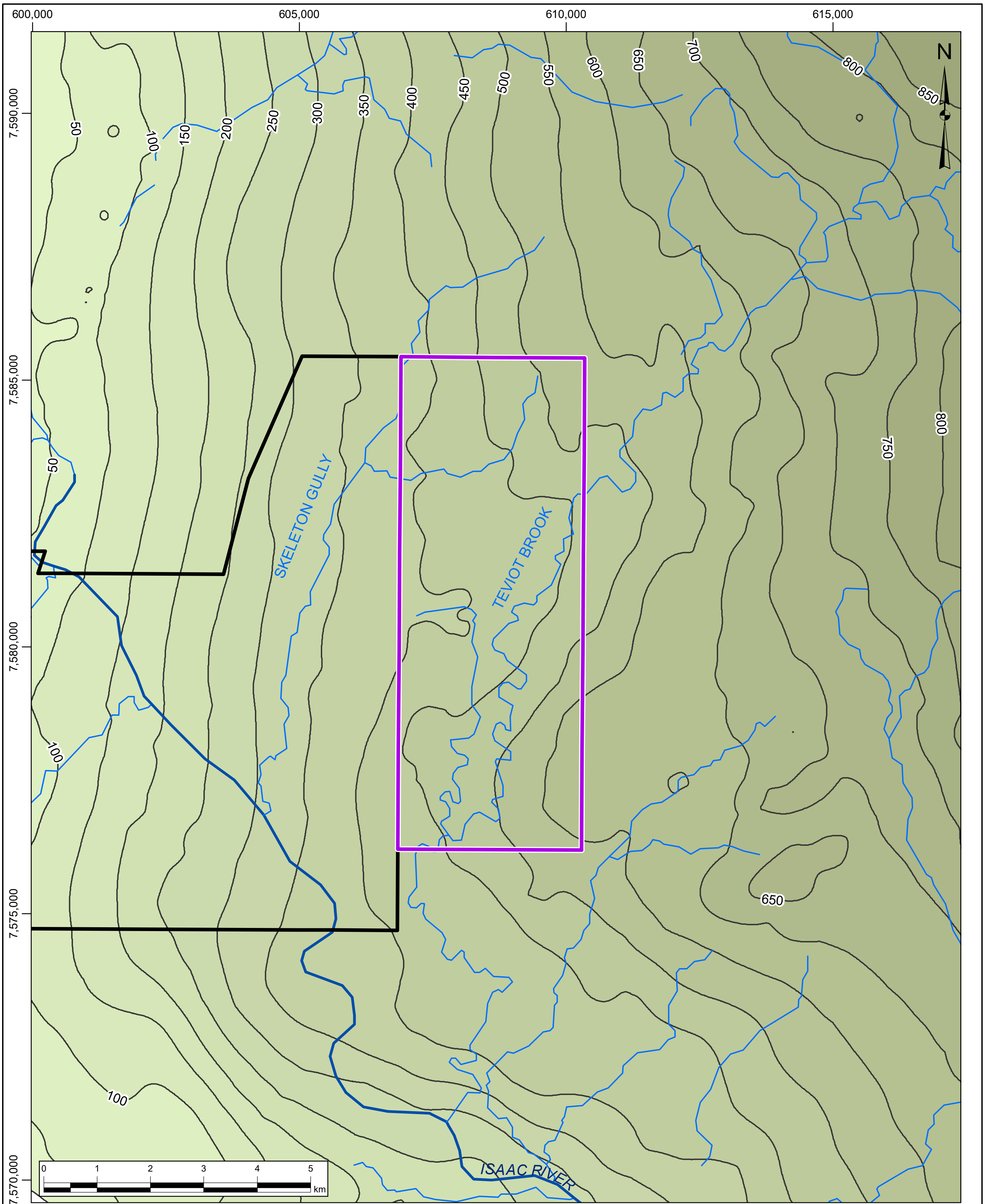
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
TERTIARY SEDIMENTS EXTENT
AND THICKNESS

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 3.8	A

16/09/2020, EMangos, \\int.klohn.com\Proj\Data\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.8_Tert_Seds_Thicknes_Update.mxd



Legend

- Project Site
- Model Boundary
- Moranbah North Mine

Depth to Goonyella Middle Seam (mbgl)

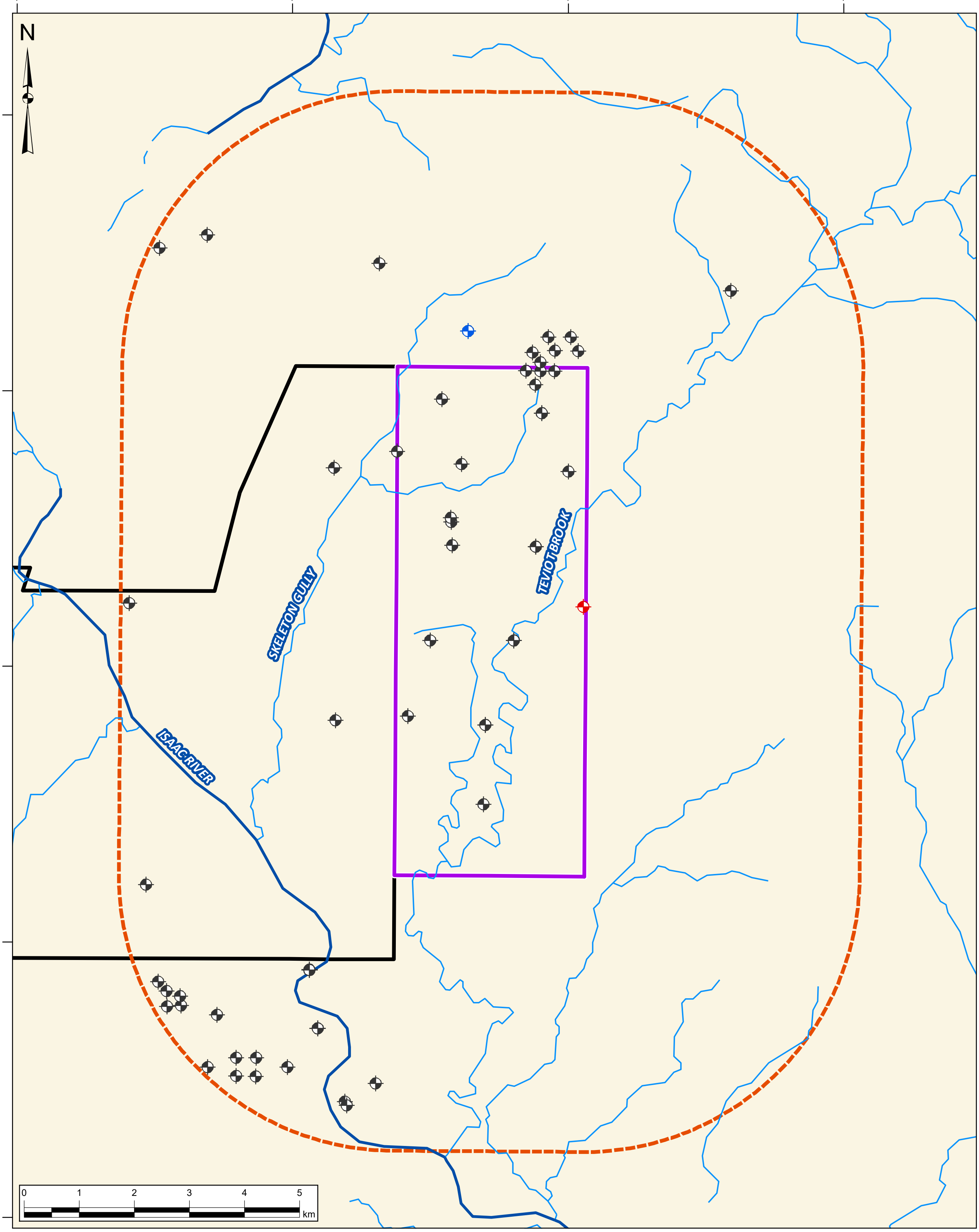
0 - 50, 50 - 100, 100 - 150, 150 - 200, 200 - 250, 250 - 300, 300 - 350, 350 - 400, 400 - 450, 450 - 500, 500 - 550, 550 - 600, 600 - 650, 650 - 700, 700 - 750, 750 - 800, 800 - 850, 850 -900

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

Klohn Crippen Berger

PROJECT	MORANBAH NORTH EXTENSION UWIR
TITLE	DEPTH TO GOONYELLA MIDDLE SEAM
PROJECT No.	D10167A03
FIG No.	FIGURE 3.9
REV	A

16/09/2020, EMangos, \\int.klohn.com\Proj\Data\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.9_Depth to GM_seam.mxd



Legend

- Groundwater Database Bore
- Inactive Unregistered Water Supply Bore (Flohr Bore)
- Registered Water Supply Bore (Skeleton Bore)
- 5km Buffer
- Project Site
- Moranbah North Mine

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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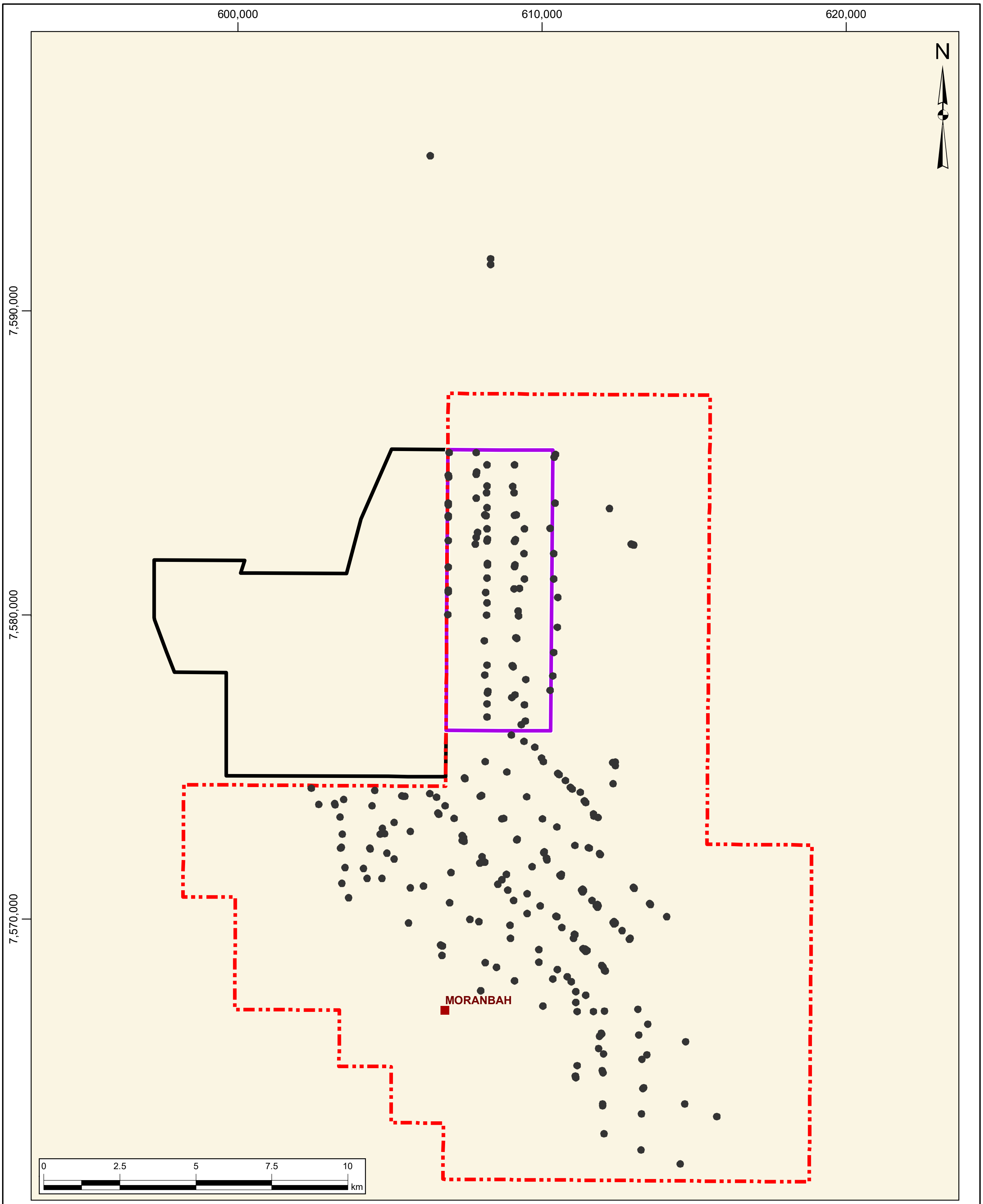
PROJECT	MORANBAH NORTH EXTENSION UWIR
TITLE	REGISTERED BORES WITHIN 5KM OF THE PROJECT SITE
PROJECT No.	D10167A03
FIG No.	FIGURE 4.1
REV	A

15/09/2020, EMangos, \\int.klohn.com\Proj\Data\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.1_GWDB.mxd



Legend

- Coal Seam Gas Production Well
- Town
- Combined Petroleum Leases
- Project Site
- Moranbah North Mine

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:175,000

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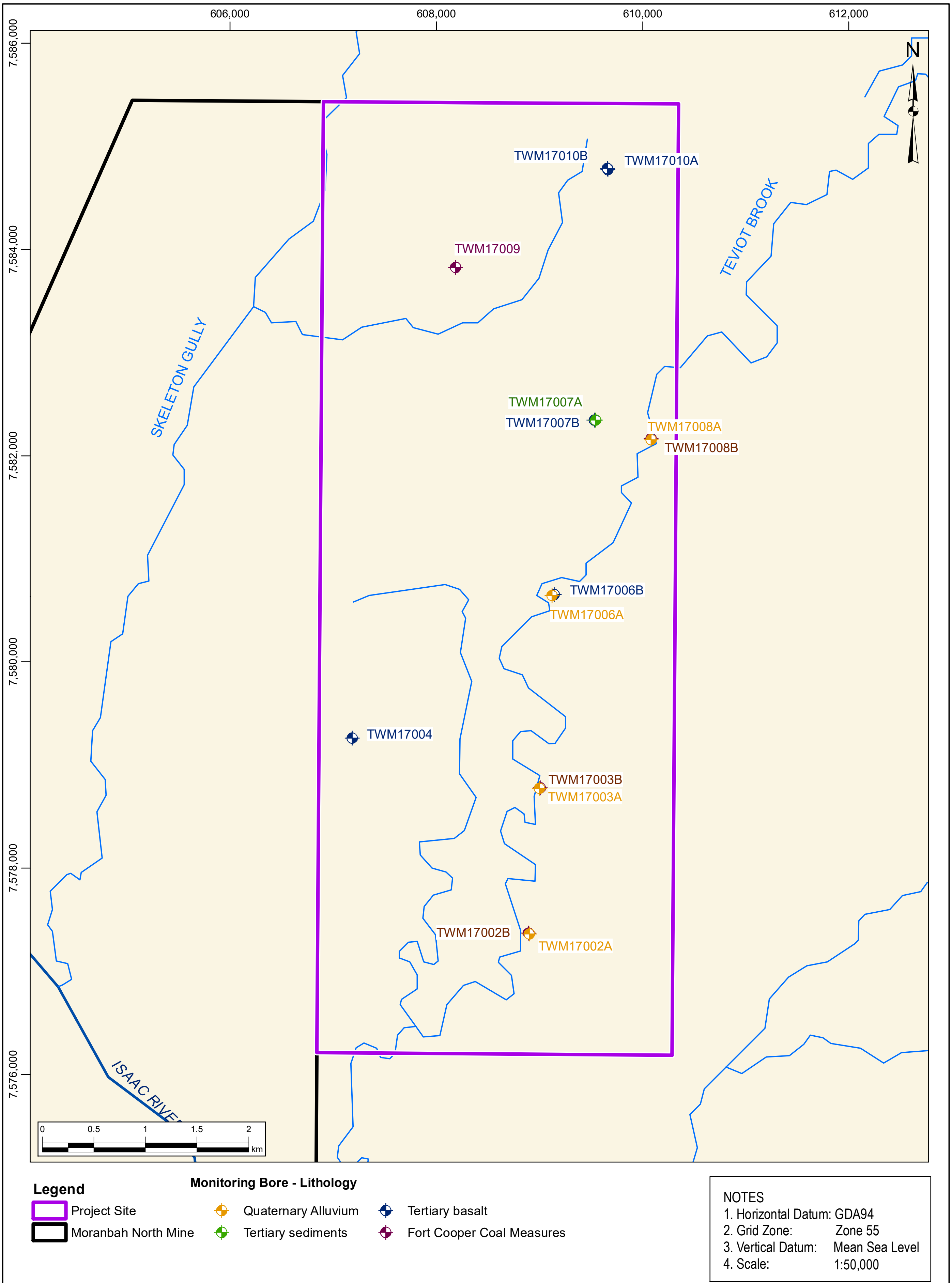
PROJECT	MORANBAH NORTH EXTENSION UWIR
TITLE	MORANBAH GAS PROJECT COAL SEAM GAS WELL LAYOUT
PROJECT No.	D10167A03
FIG No.	FIGURE 4.2
REV	A



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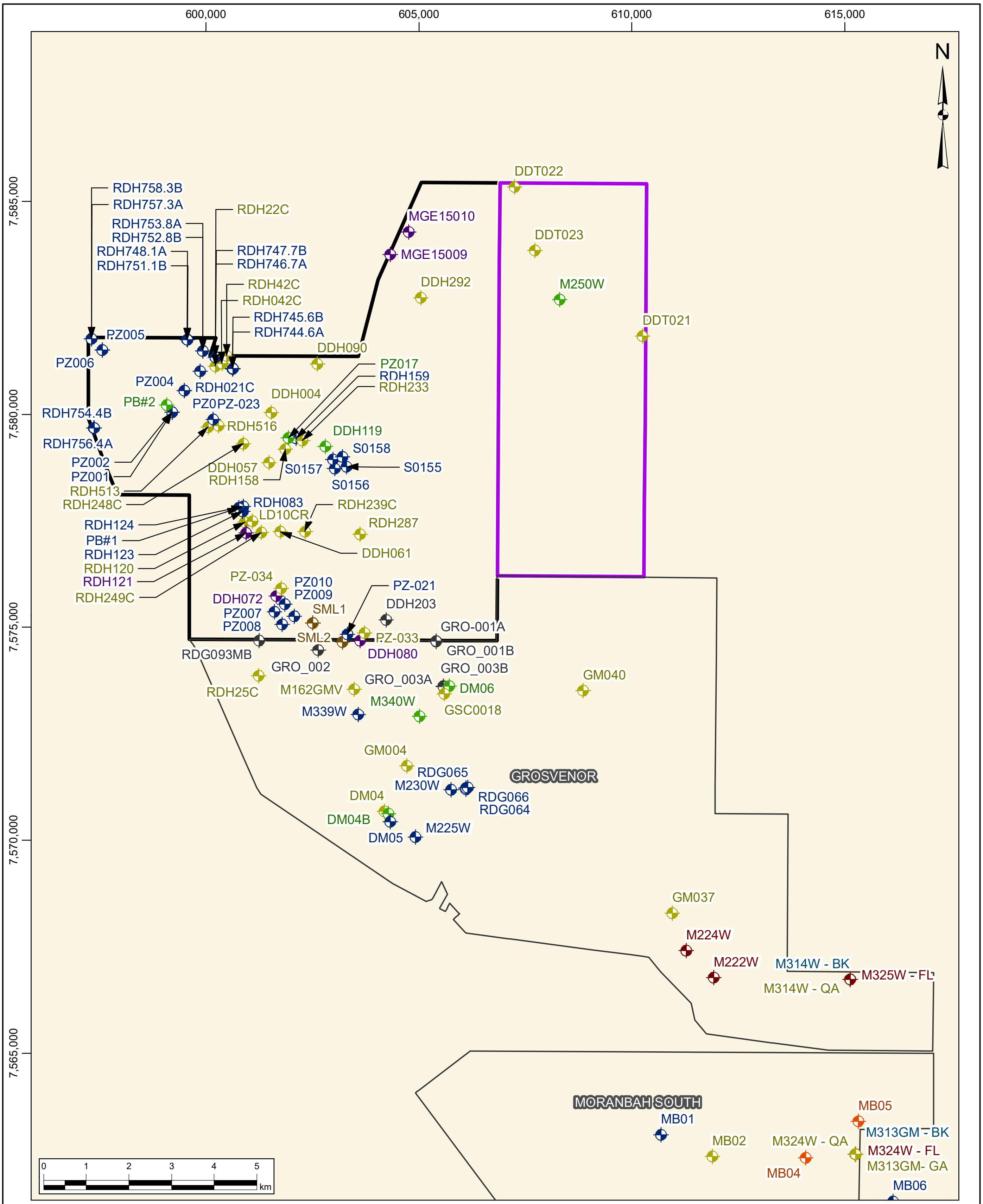
PROJECT: MORANBAH NORTH EXTENSION UWIR

TITLE: PROJECT SITE INVESTIGATION LAYOUT

PROJECT No. D10167A03 | FIG No. FIGURE 4.3 | REV A



Legend

- Project Site
- Mining Lease
- Moranbah North Mine

Monitoring Bore - Lithology

- Alluvium
- Tertiary Sediments
- Tertiary Basalt
- Basal Sands
- Fort Cooper Coal Measures
- Goonyella Middle Seam
- Moranbah Coal Measures
- Back Creek Group
- Unknown

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:125,000

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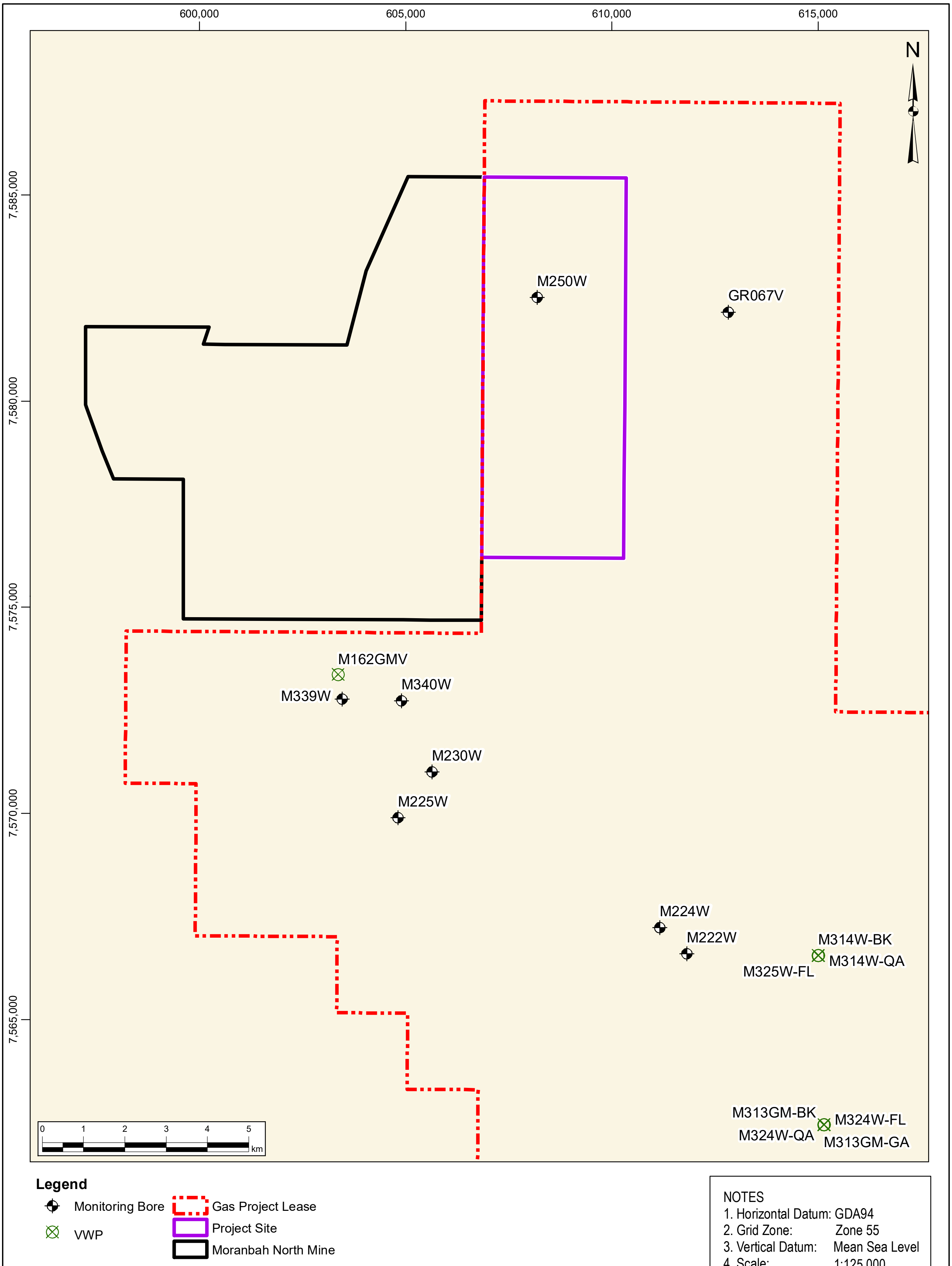
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
ANGLO AMERICAN REGIONAL
GROUNDWATER MONITORING NETWORK

PROJECT No. D10167A03 | FIG No. FIGURE 4.4 | REV A

15/09/2020, EMangos, \\int.klohn.com\ProjData\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.4_Reg Groundwater_Monitoring.mxd



NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:125,000

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PROJECT: MORANBAH NORTH MINE EXTENSION UWIR

TITLE: ARROW ENERGY GROUNDWATER MONITORING NETWORK

PROJECT No.: D10167A03 | FIG No.: FIGURE 4.5 | REV: A

15/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_3.5_ GAS Groundwater_Monitoring.mxd

Age	Formation	Seams*
Cenozoic	Alluvium	
	Tertiary sediments	
	Tertiary basalt	
	Tertiary basal sands	
Triassic	Rewan Group	
Permian	Rangal Coal Measures	Leichardt Vermont
	Fort Cooper Coal Measures *Sandstone interlayered coal carbonaceous mudstone and tuffaceous material*	Cannis
		Fair Hill
	Morambah Coal Measures *Feldspathic sandstone, siltstone and shale., coal bearing strata up to 320m thick*	Qa seam
		Qb seam
		Goonyella Upper
		P seam
		Goonyella Middle Rider (GMR)
		Goonyella Middle (GM)
		Harrow Ck Lower (HCL)
		Dysart Upper 1 (DYU1)
		Dysart Upper 2 (DYU2)
		Dysart Rider (DYR1 and 2)
		Goonyella Lower (GL)
	Back Creek Group	N/A

* Listed shallowest to deepest within each formation

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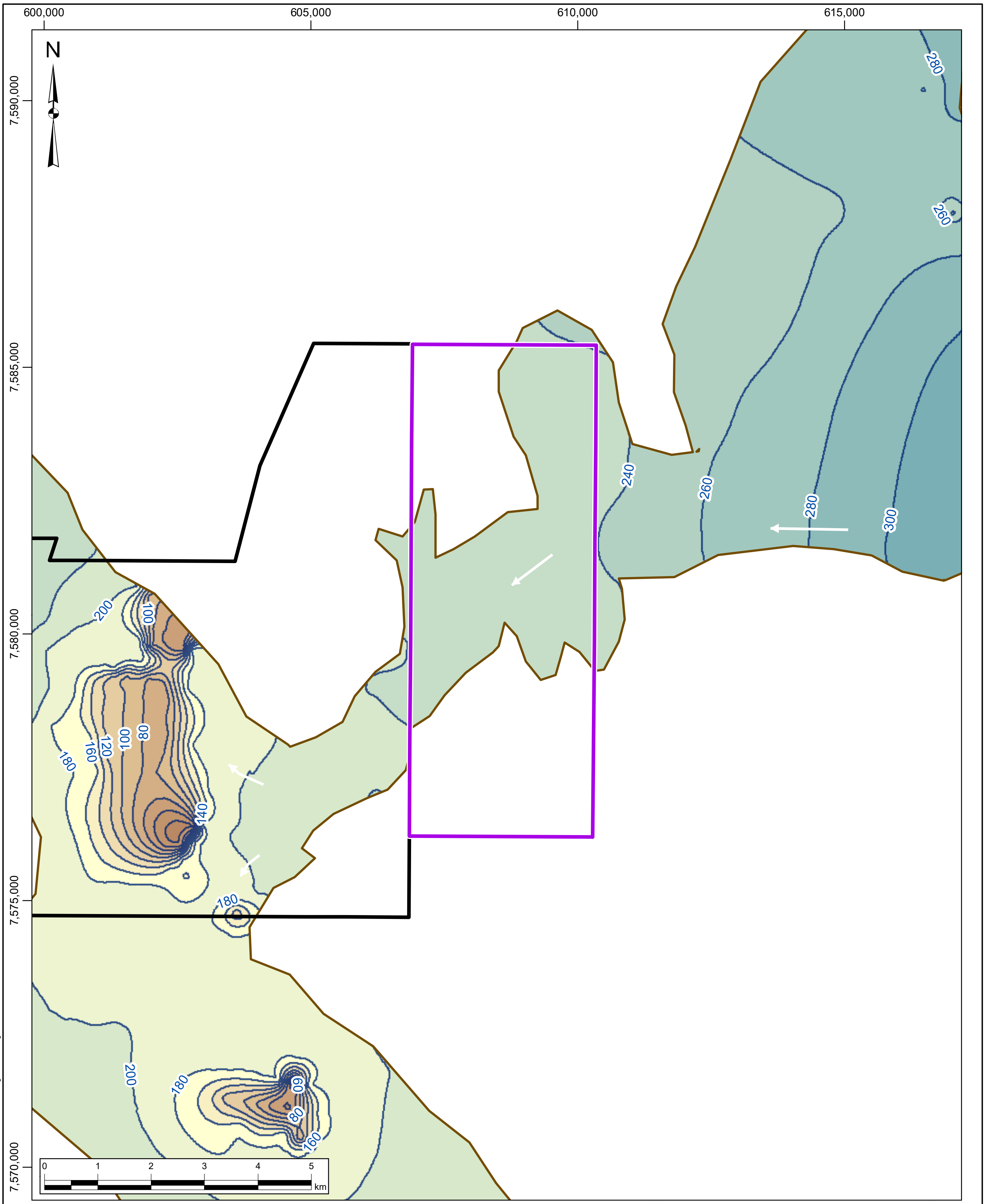
PROJECT: MORANBAH NORTH EXTENSION UWIR

TITLE: STRATIGRAPHIC PROFILE (SOURCE: HANSEN BAILEY)

PROJECT No. D10167A03 | FIG No. FIGURE 4.6 | REV A



Legend

- Contour, Groundwater (m)
- Basalt Extent
- Project Site
- Moranbah North Mine

Groundwater Elevation (m)

10 - 20	80 - 100	160- 180	240 - 260	320 - 340
20 - 40	100 - 120	180 - 200	260 - 280	
40 - 60	120 - 140	200 - 220	280 - 300	
60 - 80	140 - 160	220 - 240	300 - 320	

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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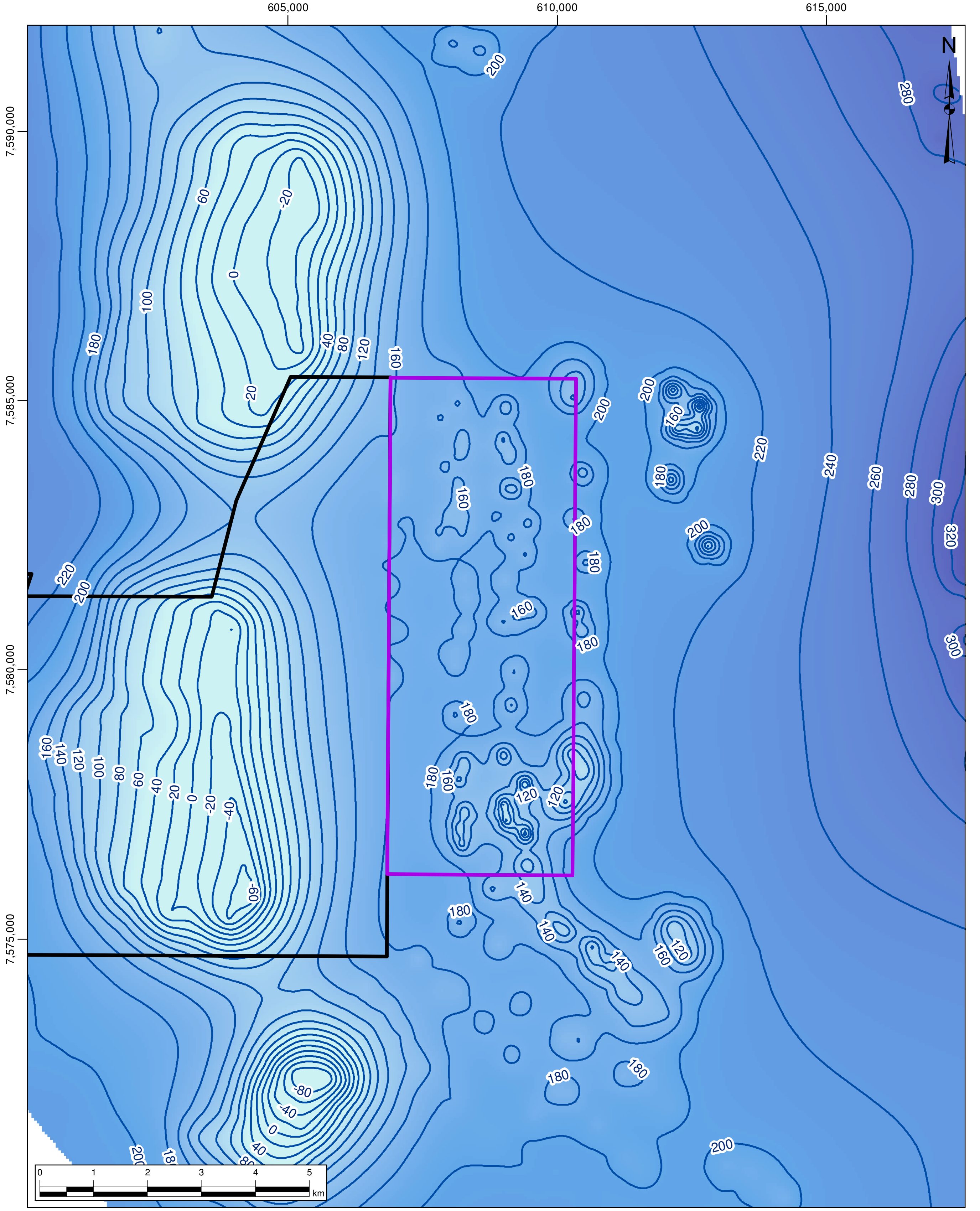
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
TERTIARY BASALT GROUNDWATER
ELEVATION AND FLOW

PROJECT No. D10167A03 | FIG No. FIGURE 5.1 | REV A

31/08/2020, EMangos, \\int.klohn.com\ProjData\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_5.1_TertBasalt_Cal_head.mxd



Legend

- Contour, Groundwater (m)
- Project Site
- Moranbah North Mine

Groundwater Elevation (m)

350

0

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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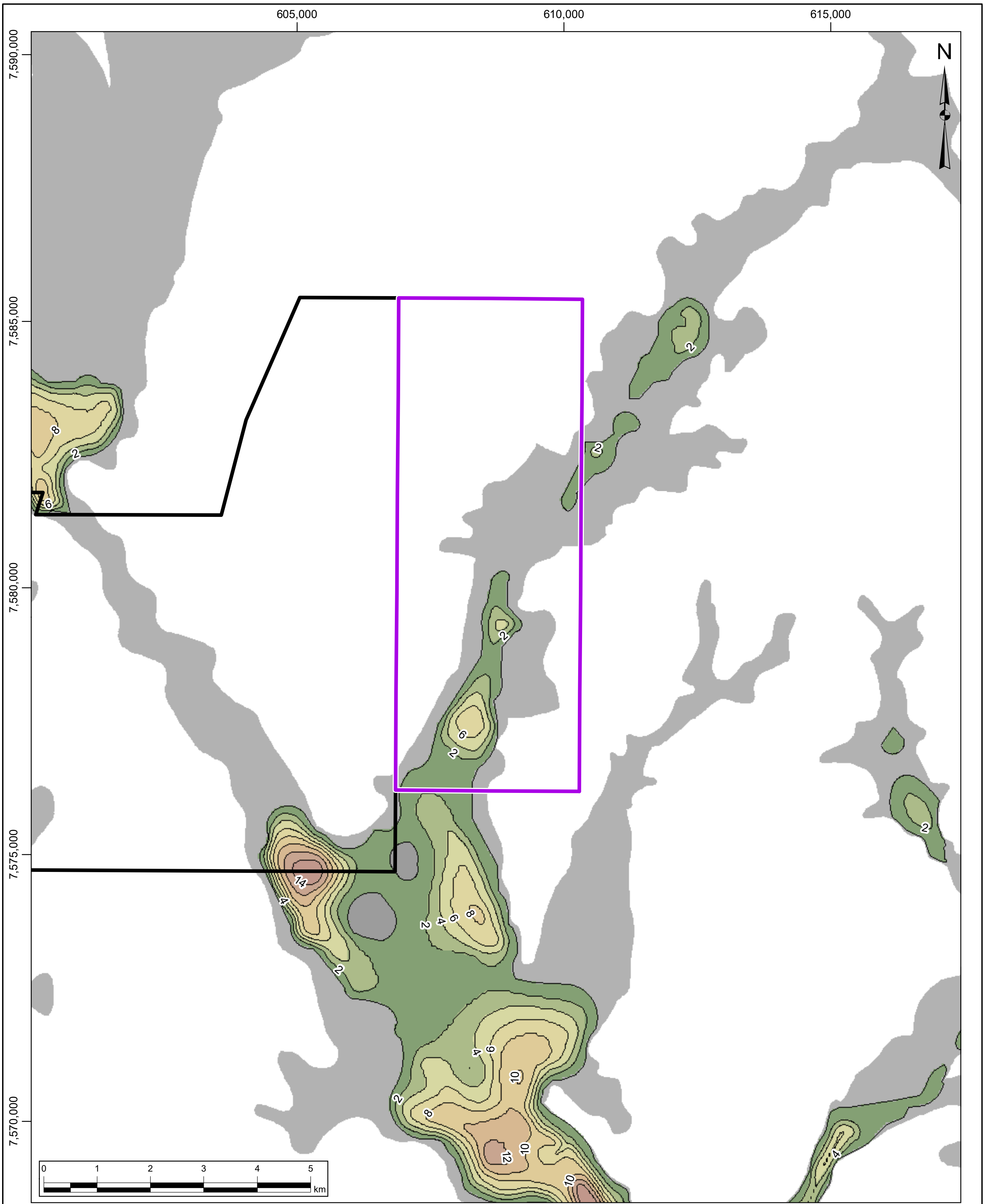
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
GOONYELLA MIDDLE SEAM
GROUNDWATER ELEVATION AND FLOW

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 5.2	A

28/08/2020, HMarais, Z:\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_5.2_GM_seam Calb Head.mxd



Legend

- Contour, Saturated Thickness (m)
- Alluvium Extent
- Project Site
- Moranbah North Mine

Alluvium Saturated Thickness (m)

0 - 2, 2 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, 12 - 14, 14 - 16, 16 - 18, 18 - 20

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

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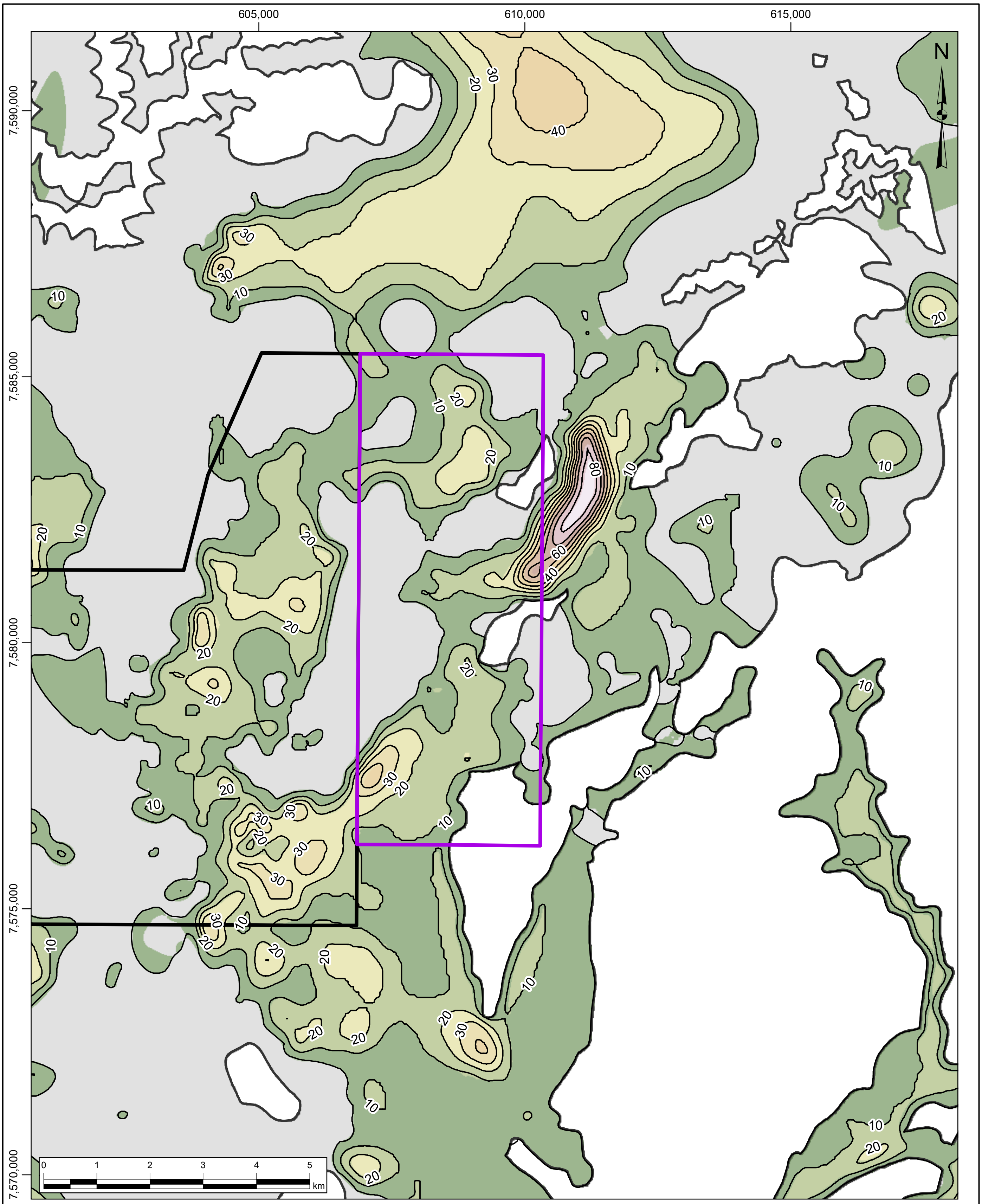
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
ALLUIVUM SATURATED THICKNESS
AND EXTENT

PROJECT No. D10167A03 | FIG No. FIGURE 5.3 | REV A

26/08/2020, EMangos, \\int.klohn.com\ProjData\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_5.3_Alluv_Sat_Thickness_Update_2.mxd



Legend

- Tertiary Sediment Extent
- Project Site
- Moranbah North Mine

Tertiary Sediments Thickness (m)

0 - 10	30 - 40	60 - 70
10 - 20	40 - 50	70 - 80
20 - 30	50 - 60	80 - 90

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

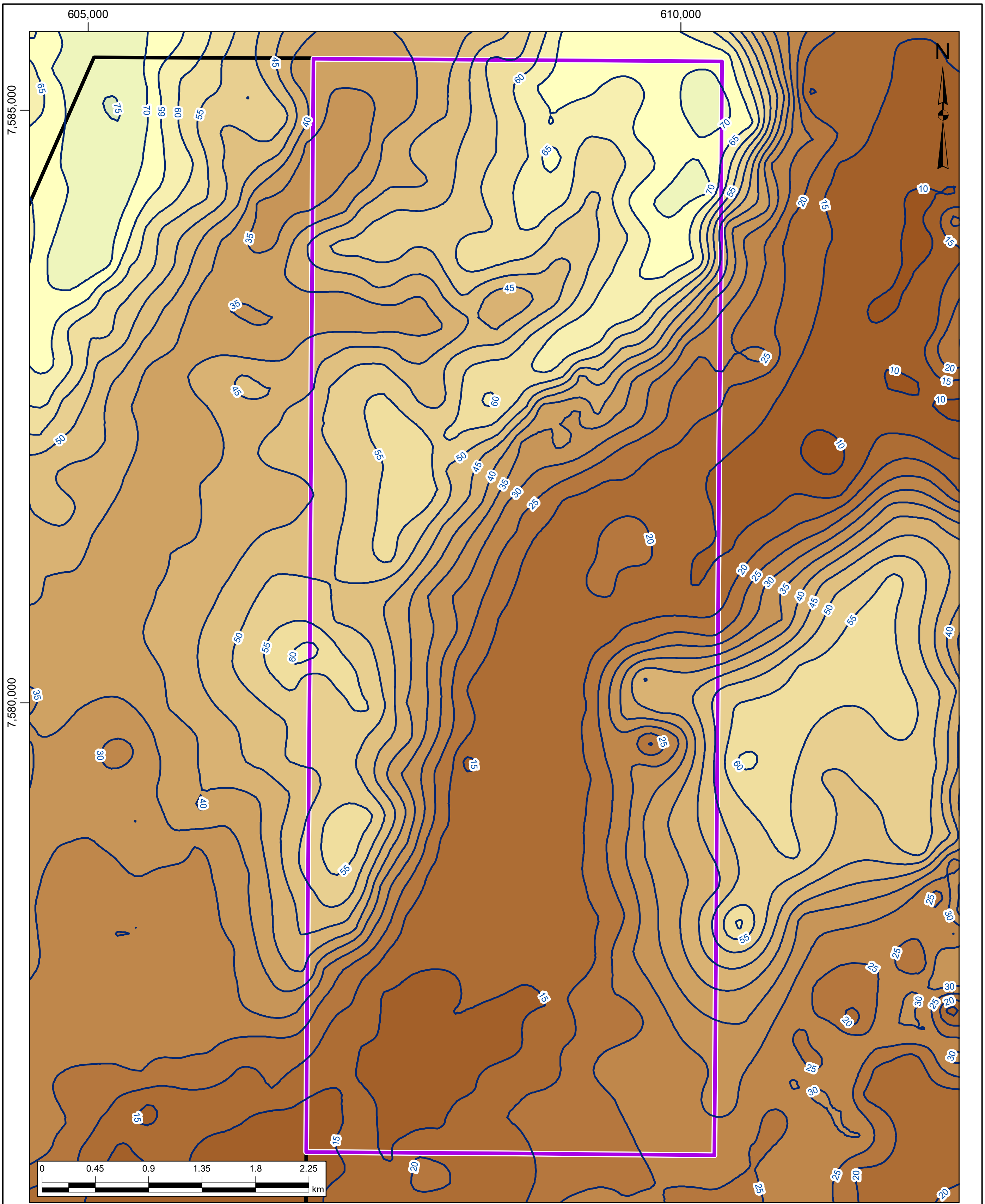
Klohn Crippen Berger

PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
TERTIARY SEDIMENTS SATURATED THICKNESS

PROJECT No. D10167A03
FIG No. FIGURE 5.4
REV A

26/08/2020, EMangos, Z:\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_5.4 Tert Seds Sat Thick_Update_2.mxd



Legend

Contour (5m)	
Project Site	
Moranbah North Mine	

Depth to Groundwater (m)

5 - 10	20 - 25	35 - 40	50 - 55	65 - 70
10 - 15	25 - 30	40 - 45	55 - 60	70 - 75
15 - 20	30 - 35	45 - 50	60 - 65	75 - 80

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:45,000

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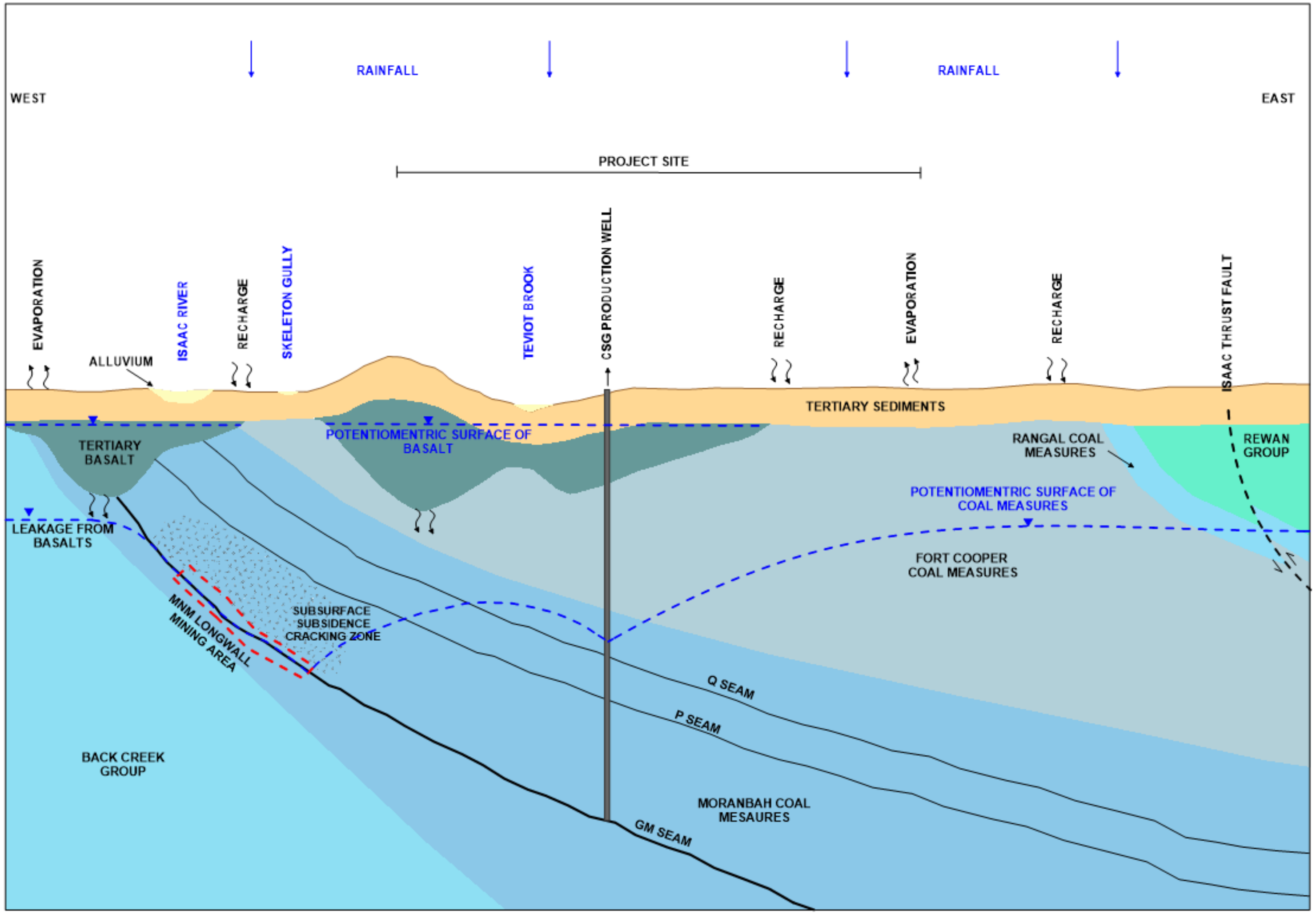
PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
DEPTH TO GROUNDWATER TABLE

PROJECT No. D10167A03 | FIG No. FIGURE 5.5 | REV A



Not to scale

NOT FOR CONSTRUCTION

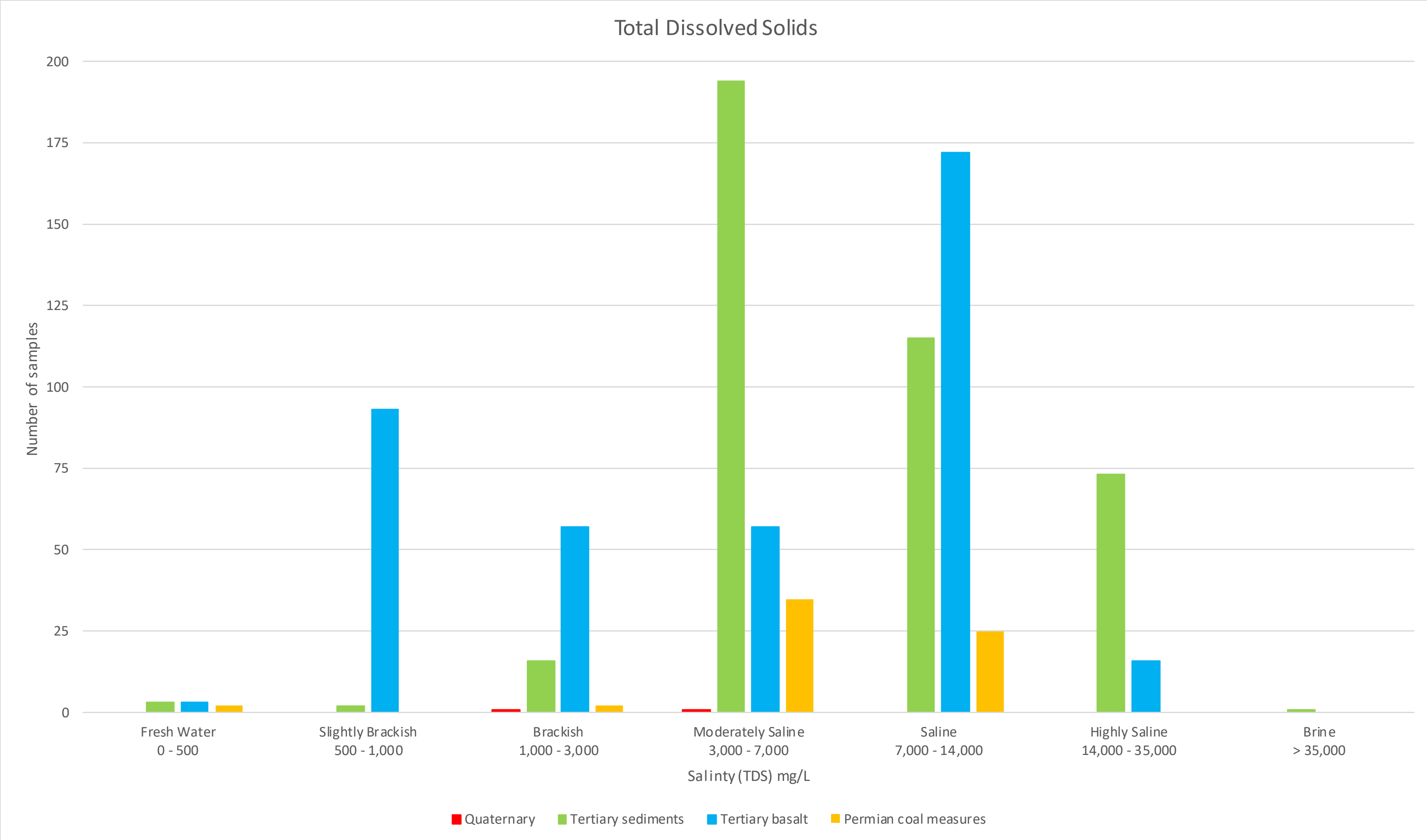
Klohn Crippen Berger

PROJECT: MORANBAH NORTH EXTENSION UWIR

TITLE: CONCEPTUAL GROUNDWATER REGIME CROSS-SECTION

PROJECT No. D10167A03 | FIG No. FIGURE 5.6 | REV A

Z:\D\BNE\D10167A01 - Moranbah Nth Expansion GW Ass\400 Drawings\Grapher



NOT FOR CONSTRUCTION

CLIENT:

Hansen Bailey

Klohn Crippen Berger

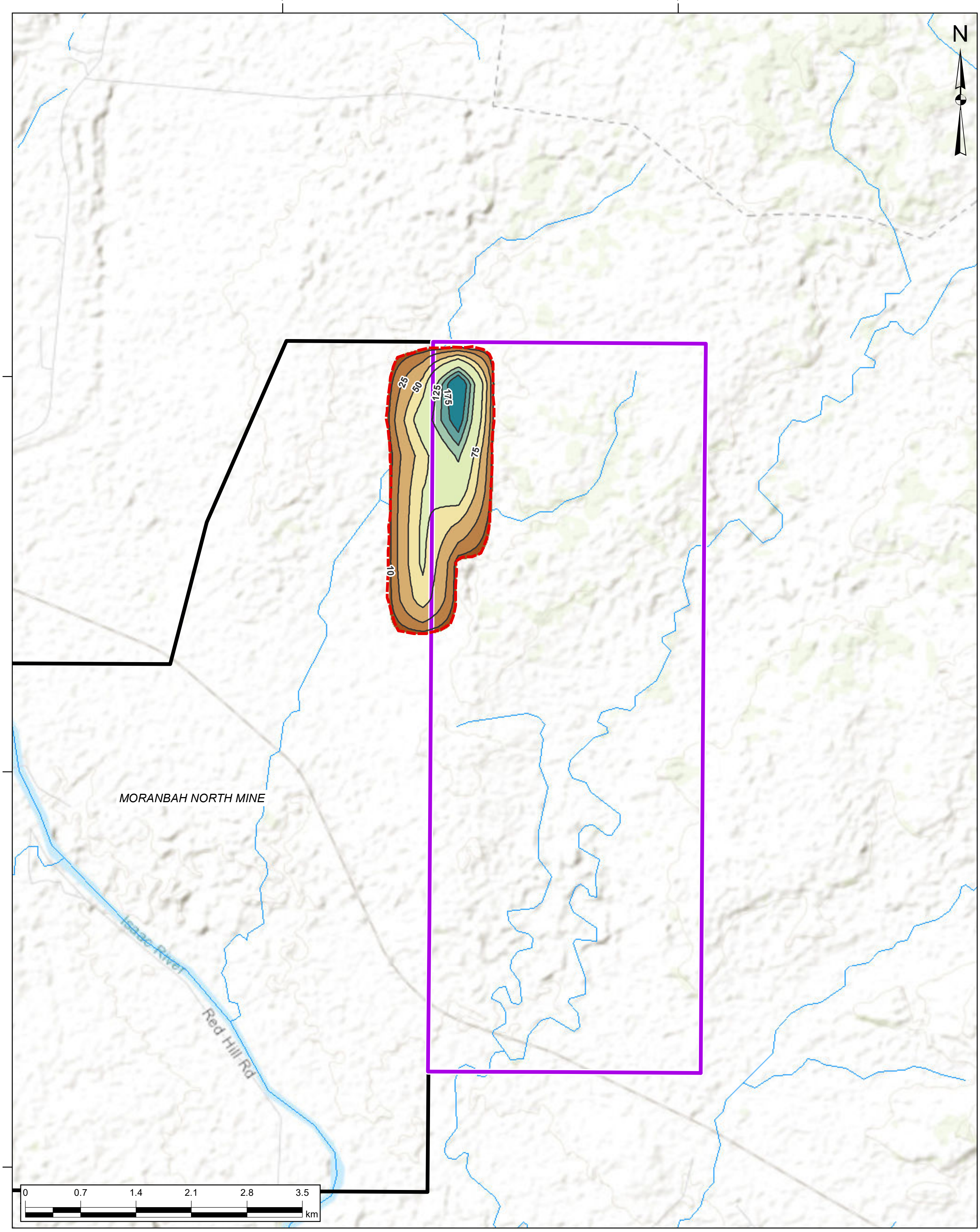
PROJECT NAME:

MORANBAH NORTH EXTENSION UWIR

TITLE:

Total Dissolved Solids Histogram

PROJECT NO:	FIG NO.:	REV:
D10167A03	**FIGURE 5.7**	**A**



Legend

Drawdown Extent (5m)
Moranbah North Mine
Project Site

Drawdown (m)

5 - 10
10 - 25
25 - 50
50 - 75
75 - 125
125 - 150
150 - 175
175 - 225

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:70,000

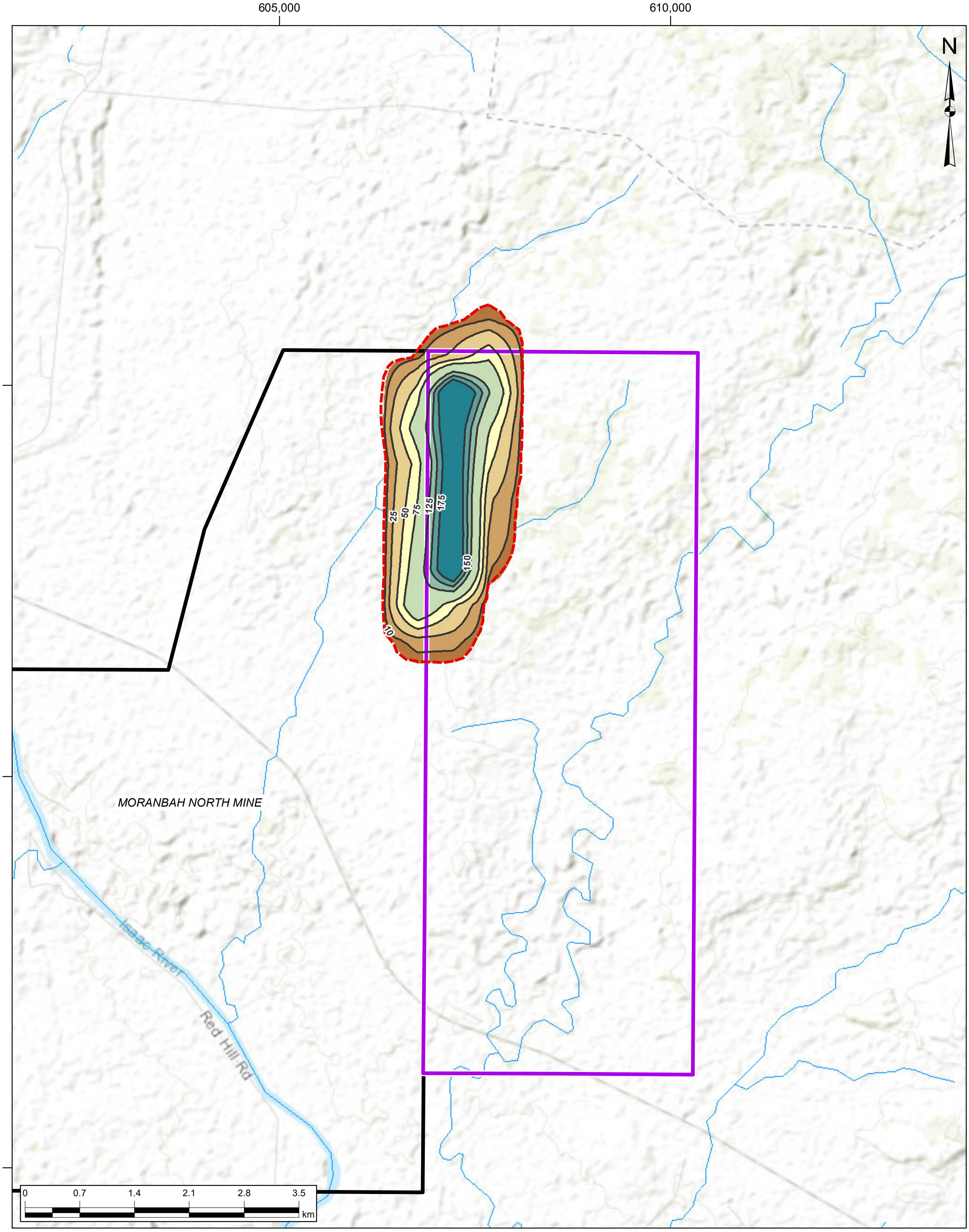
Klohn Crippen Berger

PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
PREDICTED DEPRESSURISATION IN THE
GOONYELLA MIDDLE SEAM - YEAR 1

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 6.1	B

16/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_6.3_MiddleSeam_Year3.mxd



Legend

- Drawdown Extent (5m)
- Moranbah North Mine
- Project Site

Drawdown (m)

- 5 - 10
- 10 - 25
- 25 - 50
- 50 - 75
- 75 - 125
- 125 - 150
- 150 - 175
- 175 - 225

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:70,000

Klohn Crippen Berger

PROJECT
MORANBAH NORTH EXTENSION
UWIR

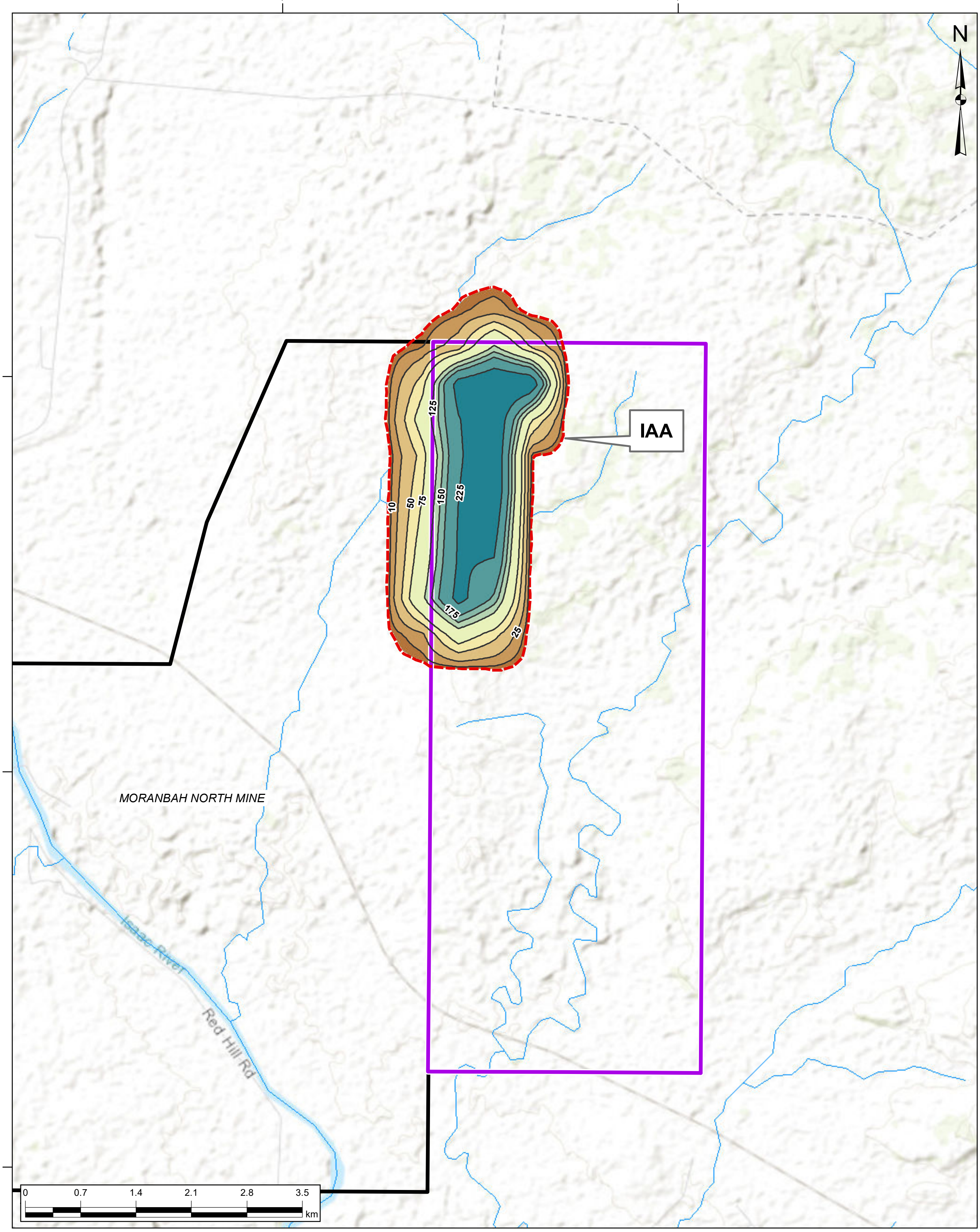
TITLE
PREDICTED DEPRESSURISATION IN THE
GOONYELLA MIDDLE SEAM - YEAR 2

PROJECT No. D10167A03

FIG No. FIGURE 6.2

REV B

16/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_6.3_MiddleSeam_Year3.mxd



Legend

- Drawdown Extent (5m)
- Moranbah North Mine
- Project Site

Drawdown (m)

- 5 - 10
- 10 - 25
- 25 - 50
- 50 - 75
- 75 - 125
- 125 - 150
- 150 - 175
- 175 - 225
- 225 - 400

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:70,000

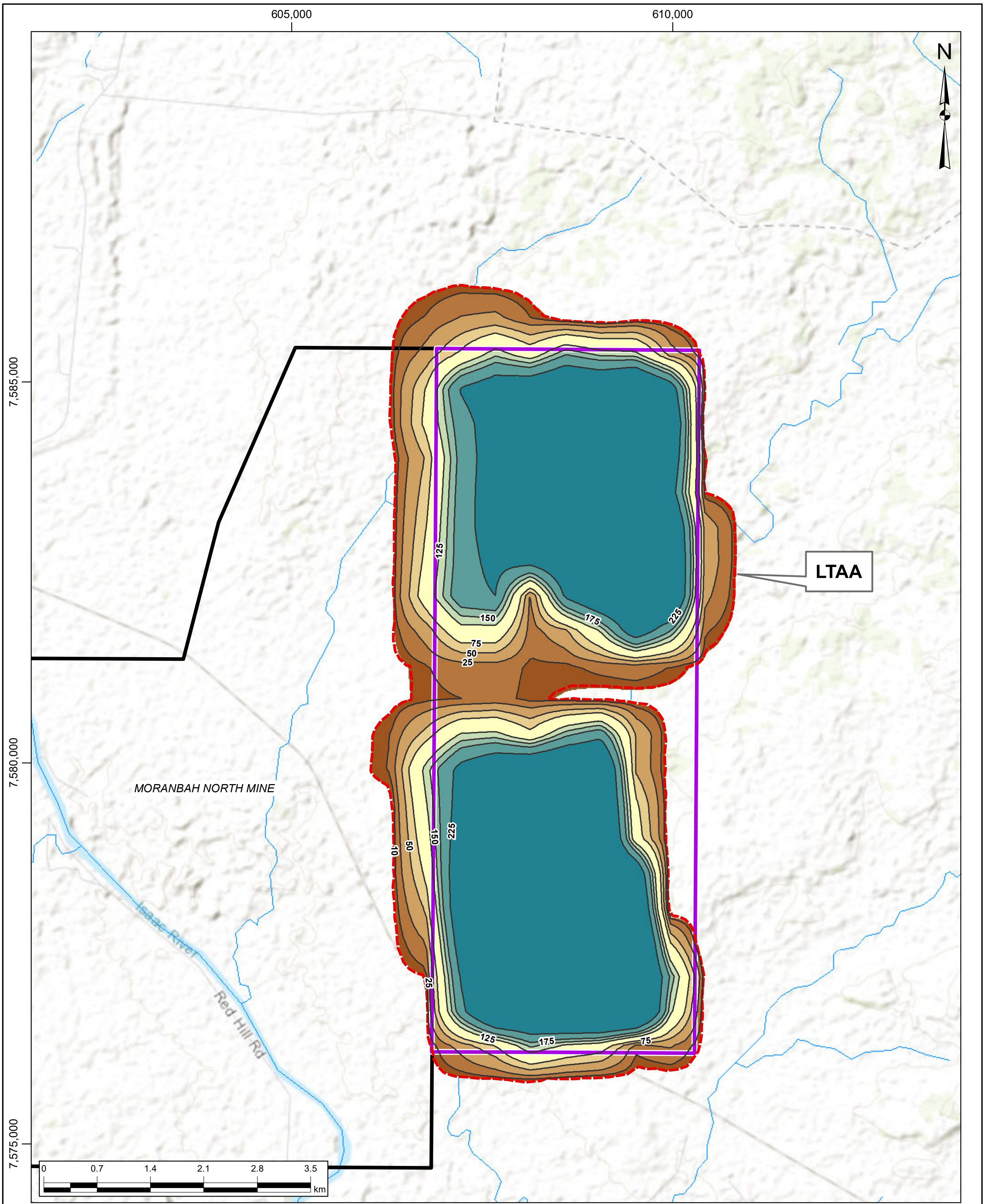
Klohn Crippen Berger

PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
PREDICTED DEPRESSURISATION IN THE
GOONYELLA MIDDLE SEAM - YEAR 3 (IAA)

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 6.3	B

16/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_6.3_MiddleSeam_Year3.mxd



Legend

- Drawdown Extent (5m)
- Moranbah North Mine
- Project Site

Drawdown (m)

5 - 10	50 - 75	150 - 175
10 - 25	75 - 125	175 - 225
25 - 50	125 - 150	225 - 400

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:70,000

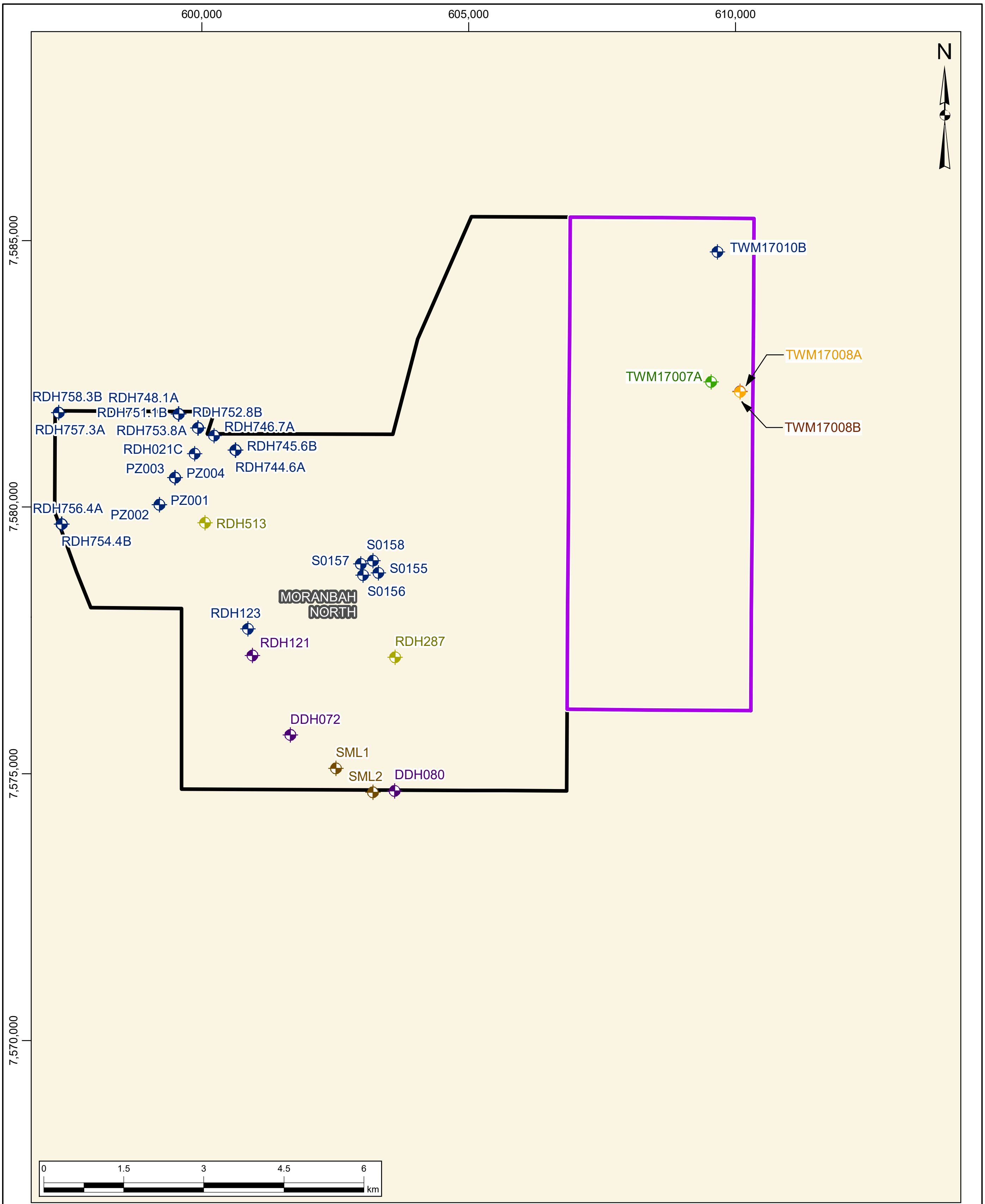
Klohn Crippen Berger

PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
PREDICTED DEPRESSURISATION IN THE
GOONYELLA MIDDLE SEAM - (LIFE OF OPERATION) (LTAA)

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 6.4	B

16/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_6.3_MiddleSeam_Year3.mxd



Legend

Town	
Project Site	
Moranbah North Mine	

Monitoring Bore - Lithology

Alluvium	Fort Cooper Coal Measures
Tertiary Sediments	Goonyella Middle Seam
Tertiary Basalt	Moranbah Coal Measures
Basal Sands	

NOTES
1. Horizontal Datum: GDA94
2. Grid Zone: Zone 55
3. Vertical Datum: Mean Sea Level
4. Scale: 1:100,000

Klohn Crippen Berger

PROJECT
MORANBAH NORTH EXTENSION
UWIR

TITLE
MNM GROUNDWATER MONITORING NETWORK

PROJECT No.	FIG No.	REV
D10167A03	FIGURE 7.1	A

15/09/2020, EMangos, \\int.klohn.com\ProjData\D\BNE\D10167A03 - MNE - UWIR and BAP\400 Drawings\MXD\Fig_7.1_ModelExtent_OverTopo.mxd

APPENDIX I

Summary of Monitoring Bores

Site	Hole ID	Type	Status	Easting	Northing	Surface Elevation (mAHD)	Screen interval/ sensor depth (mbGL)	Base of Casing/ hole	Target unit
Arrow	M250W	mb	Ex	608185	7582505	285.1A	-	-	Tu
Arrow	M314W-BK	VWP / mb	Ex	615004	7566548	231.3A	534.47	-	BCG
Arrow	M314W-QA	VWP / mb	Ex	615004	7566548	231.3A	205.46	-	MCM
Arrow	M339W	mb	Ex	603458	7572763	238.9	35-41	41	Tb
Arrow	M340W	mb	Ex	604902	7572726	228.2	20.5-28.5	28.5	Ts
Anglo	CBR Broadmeadow 1	mb	Ex	610002	7583535	308	96-529	529	FCCM/MCM
Anglo	CBR Broadmeadow 2	mb	Ex	609746	7585353	307	499-513	513	MCM
Anglo	CBR Broadmeadow 3	mb	Ex	609488	7585355	308	492-506	506	MCM
Anglo	CBR Broadmeadow 4	mb	Ex	609230	7585357	306	476-491	491	MCM
Anglo	CBR Broadmeadow 5	mb	Ex	609749	7585722	308	513-522	522	MCM
Anglo	CBR Broadmeadow 6	mb	Ex	609347	7585694	309	492-502	502	MCM
Anglo	CBR Broadmeadow 7	mb	Ex	610038	7585966	312	520-530	530	MCM
Anglo	CBR Broadmeadow 8	mb	Ex	609636	7585969	311	515-523	523	MCM
Anglo	CBR Broadmeadow 10	mb	Ex	609400	7585110	304	477-487	487	MCM
Anglo	NQE Broadmeadow 11	mb	Ex	606894	7583897	308	528-596	596	MCM
Anglo	NQE Broadmeadow 12	mb	Ex	610179	7585719	308	NA	630	MCM
Anglo	NQE Broadmeadow 9	mb	Ex	605744	7583597	310	616-640	640	MCM
Burton	MGC Teviot Brook 1	exp	Ex	612943	7586807	274	NA	801	FCCM/MCM
Anglo	MGC Broadmeadow 14	mb	Ex	609489	7585509	307	108-611	611	FCCM/MCM
Anglo	MGC North Moranbah 1	mb	Ex	605771	7579015	251	NA	NA	NA
Anglo	MGC West Broadmeadow	mb	Ex	607704	7584844	276	51-499	499	FCCM/MCM
Private	Skeleton Bore	WS	AD	608182	7586081	288	NA	NA	NA
BHP	B1S1	-	AD	603448	7587837	255	NA	20	NA
BHP	B2S2	-	AD	602585	7587596	254	NA	24	NA
Anglo	TWM15003B	mb	Ex	609402	7582170	268	95-100	100	Tb
Anglo	TWM15006A	mb	Ex	607083	7579092	275	43-50	50	Tb
Anglo	TWM15005A	mb	Ex	609007	7580468	251	5-11	11	Qa
BHP	RDH761	mb	Ex	602029	7581141	242	1-27	27	Ts
Anglo	M344W	mb	Ex	602713	7573827	245	13-21	21	Ts
Anglo	M343W	mb	Ex	602969	7573843	245	11-22	22	Ts

Site	Hole ID	Type	Status	Easting	Northing	Surface Elevation (mAHD)	Screen interval/ sensor depth (mbGL)	Base of Casing/ hole	Target unit
Anglo	M251W	mb	Ex	607875	7582613	286	13-20	20	Ts
Anglo	TWM15008	mb	Ex	608456	7577496	243	8-12	12	Qa
Anglo	TWM15003A	mb	Ex	609402	7582170	269	22-27	27	Tb
Anglo	TWM15004A	mb	Ex	607495	7580467	277	34-39	39	Tb
Anglo	TWM15002	mb	Ex	608062	7583664	286	56-60	60	Ts
Anglo	TWM15009	mb	Ex	606570	7587309	292	38-43	43	FCCM
Anglo	TWM15001B	mb	Ex	609518	7584593	297	115-120	120	Tb
Anglo	TWM15005B	mb	Ex	609007	7580468	251	66-70	70	Tb
Anglo	TWM15006B	mb	Ex	608491	7578934	247	105-110	110	Tb
Anglo	M226W	mb	Ex	602335	7576038	258	15-22	22	Tb
Anglo	M330W	mb	Ex	604331	7572894	237	10-18	18	Ts
Anglo	M332W	mb	Ex	603970	7572564	239	6-10	20	Ts
Anglo	M329W	mb	Ex	603971	7572894	240	25-35	35	Ts
Anglo	M331W	mb	Ex	604323	7572556	238	6-13	19	TS
Anglo	M246W	mb	Ex	605941	7572100	228	21-28	28	Tb
Anglo	M245W	mb	Ex	605975	7572028	229	23-30	30	Tb
Anglo	TWM15007	mb	Ex	608491	7578934	247	8-12	12	Qa
Anglo	TWM15001A	mb	Ex	609518	7584593	298	77-83	83	Tb
Anglo	M342W	mb	Ex	602950	7574009	243	15-24	24	Ts
Anglo	M345W	mb	Ex	603623	7573671	237	21-32	32	TS
Anglo	M244W	mb	Ex	606500	7572429	232	26-33	33	FCCM
Anglo	M252W	mb	Ex	607861	7582692	283	45-48	48	Ts
Anglo	GRO_01A	mb	Ex	605295	7574494	232	11-17	17	Qa
Anglo	GRO_03A	mb	Ex	605453	7573430	231	7-15	15	Qa
Anglo	GRO_02	mb	Ex	602555	7574276	250	101-119	127	Tb
Anglo	GRO_01B	mb	Ex	605298	7574485	232	50-61	61	Ts
Anglo	GRO_03B	mb	Ex	605450	7573432	231	21-43	43	Tb

APPENDIX II

Description of the Numerical Modelling

Klohn Crippen Berger

September 16, 2020

Hansen Bailey
Level 15, 215 Adelaide Street
Brisbane, QLD, 4000

Ross Edwards
Senior Environmental Scientist

Dear Mr Edwards:

Moranbah North Mine Expansion
Groundwater Modelling Appendix

Klohn Crippen Berger Ltd (KCB) is pleased to provide this Groundwater Modelling Report, which supports the Underground Water Impact Report (UWIR) for the Moranbah North Mine Extension. This report forms Appendix II of the UWIR.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Xuyan Wang
Senior Groundwater Modeller

Author HM:CS

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1 INTRODUCTION

Klohn Crippen Berger (KCB) developed a 3D numerical groundwater flow model for the Moranbah North Mine Extension Project (the project) to simulate the existing conditions of the groundwater regime and provide predictions of the potential impacts of the proposed mining activities.

The model represents the hydrogeology of the project longwall mining area and its surrounds based on the conceptual groundwater model described in the UWIR and the proposed mine plan and mining schedule.

The modelling results presented in this Appendix were used to support the assessment of groundwater impacts presented in the UWIR, including the identification of the immediately affected areas (IAA) and long-term affected areas (LTAA).

1.1 Model Objectives

A calibrated groundwater flow model was developed for the project site and surrounds to assess the impact of project depressurisation on the local and regional groundwater systems. The groundwater flow model also incorporates cumulative stresses from neighboring mining activities. The objectives of the model are:

- Assess changes to local and regional groundwater flow patterns due to the project;
- Assess project-specific drawdown on groundwater resources, users and the environment;
- Estimate groundwater inflow into underground longwall mining operations;
- Assess project-specific recovery of groundwater systems at the cessation of mining;
- Assess cumulative drawdown on groundwater resources, users and the environment;
- Assess recovery of groundwater systems at the end of regional mining activities; and,
- Assess the sensitivity of the model to key parameter changes.

1.2 Model Domain and Hydrogeological Study Area

Figure 1 and Figure 2 present the spatial extents of the groundwater flow model domain. The model domain was selected to adequately reflect the regional hydrostratigraphic units and prevailing surface water/groundwater interactions while also providing a platform for regional assessment of cumulative groundwater impacts from approved and operating projects in the area. It includes the following hydrogeological elements of the project and study area:

- In the east the boundary is defined with consideration to the presence of the Isaac Plains fault which conceptually forms a highly resistive boundary to groundwater flow in the easterly direction;
- The northern extent of the domain is primarily defined by topography and hence coincides locally with groundwater divide conditions. It also fully encompasses mining activities of the Redhill/Broadmeadows mining leases;

- In the west, the base layer of the model (i.e. Back Creek Group) outcrops. This boundary is therefore defined with regard to topography and therefore local groundwater divide conditions; and
- The Isaac River discharges in the southern part of the model domain. The model boundary in this region is coincident with the confluence of Grosvenor Creek with the Isaac River. This extent allows for inclusion of the Board and Pillar operations of the northern part of the Moranbah South Mine. Elsewhere the southern extent of the model domain follows topography.

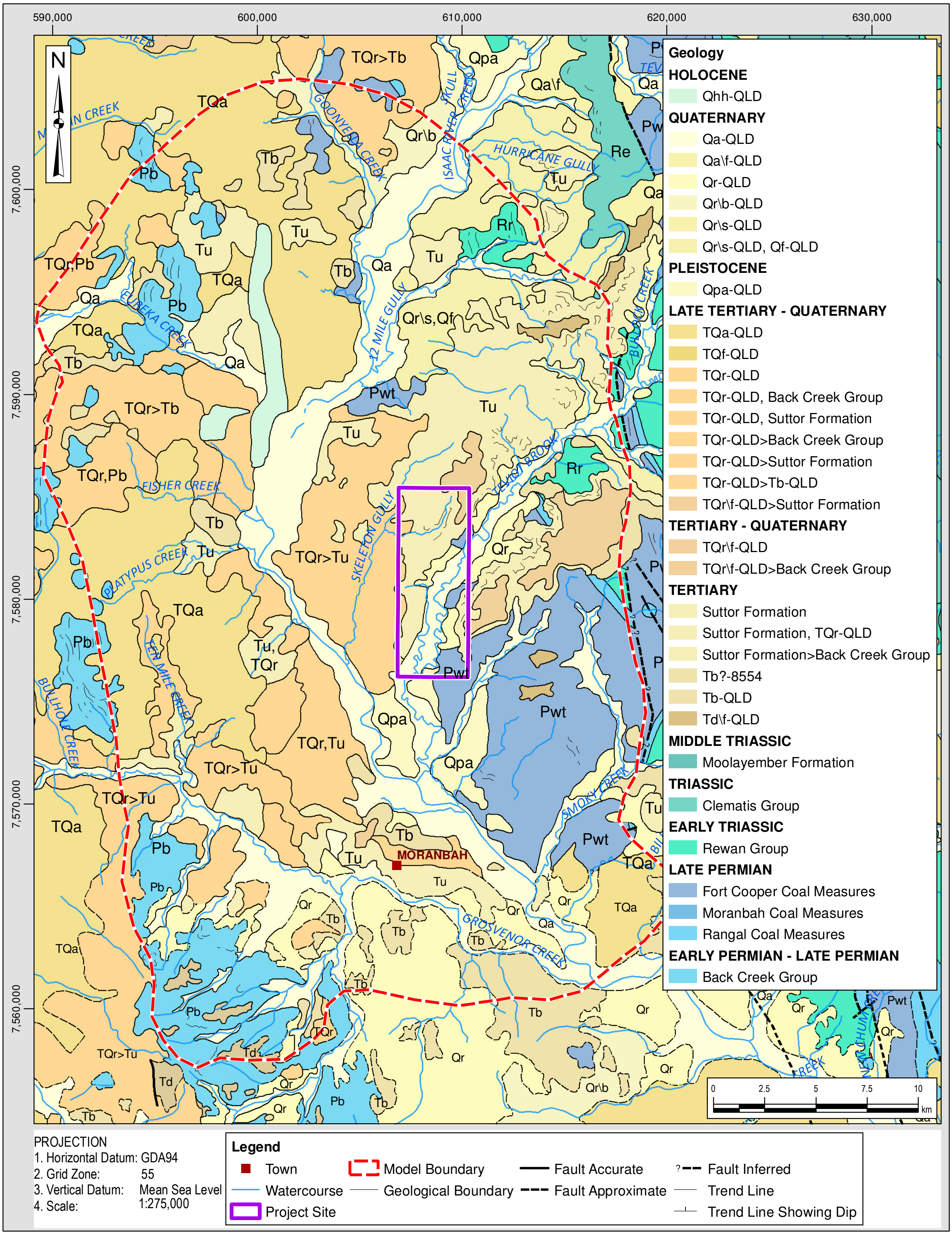

Figure 1: Model extent over surface geological mapping

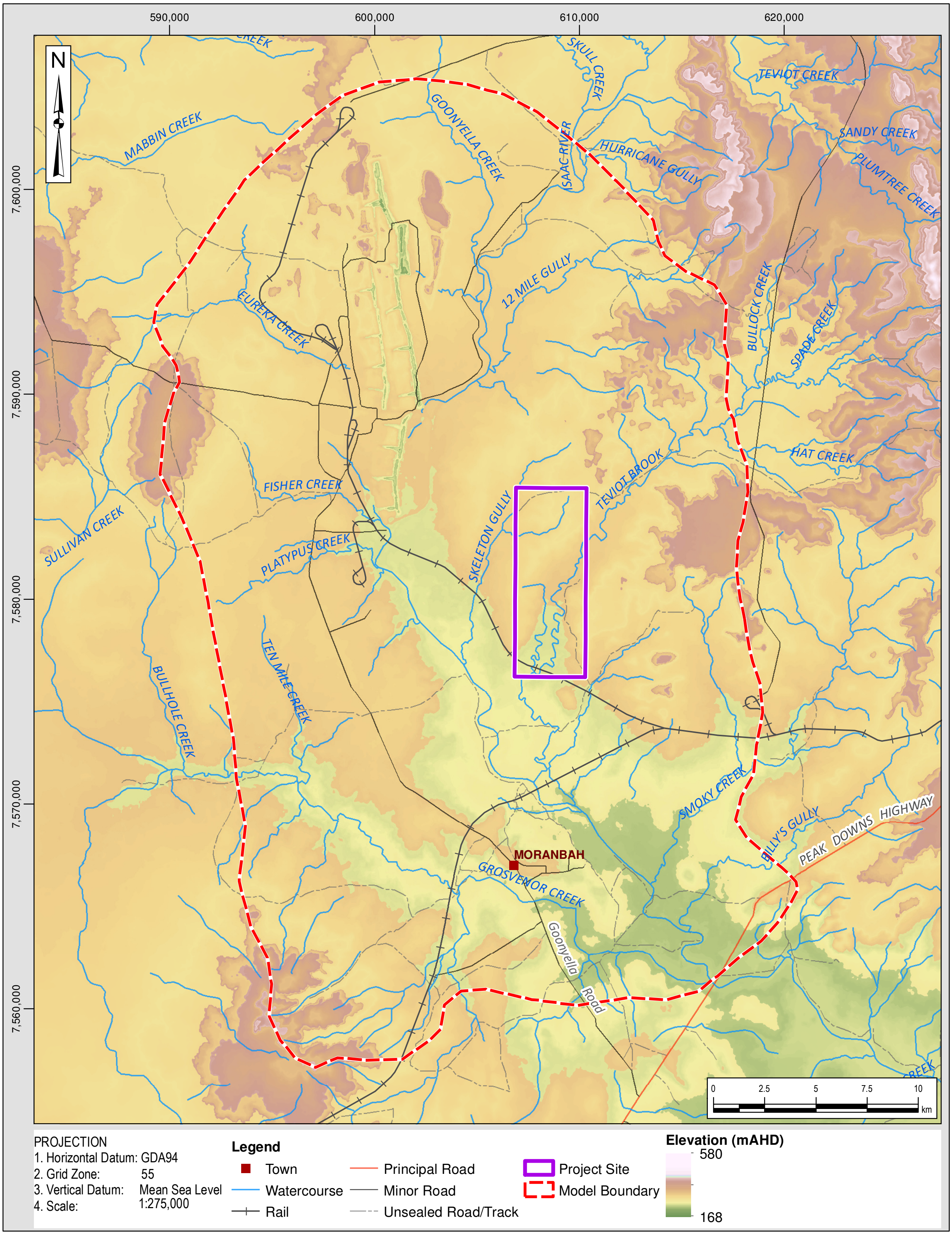

Figure 2: Model extent over topography

A key consideration for the numerical modelling assessment is the potential cumulative impacts of the proposed Moranbah North Mine extension when superimposed on impacts from other operational and approved mining projects near the study area. The location of existing and proposed mines near the project site is shown in Figure 3. The development schedule for mines incorporated into the model is presented as Figure 4.

1.3 Application of the Conceptual Model

The groundwater flow model is based on the hydrogeological conceptual model. This conceptual model is described in Section 7 of the groundwater assessment report. A hydrogeological conceptual model is a descriptive representation of the groundwater flow system and stresses. The closer the conceptual model approximates the field situation, the more accurate the numerical model predictions (Anderson and Woessner, 1991). A conceptual model defines the current understanding of the key processes of the groundwater system with consideration of the influence of stresses (Barnett et al., 2012).

The application of the conceptual model to the groundwater flow model required synthesis and description of the geology framework and consideration of the groundwater flow systems that are present within the vicinity of the project site.

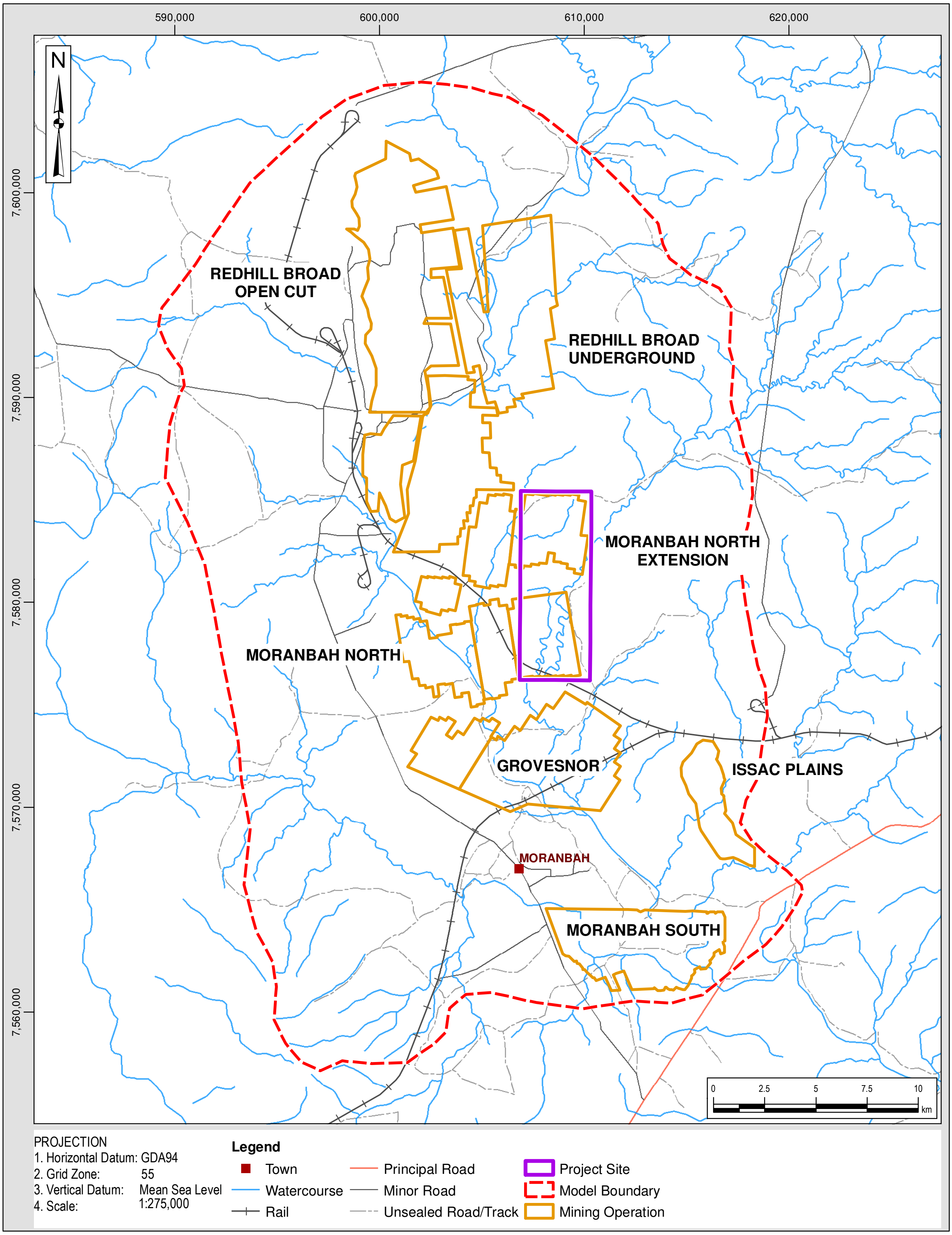

Figure 3: Location of existing and approved mines in study area

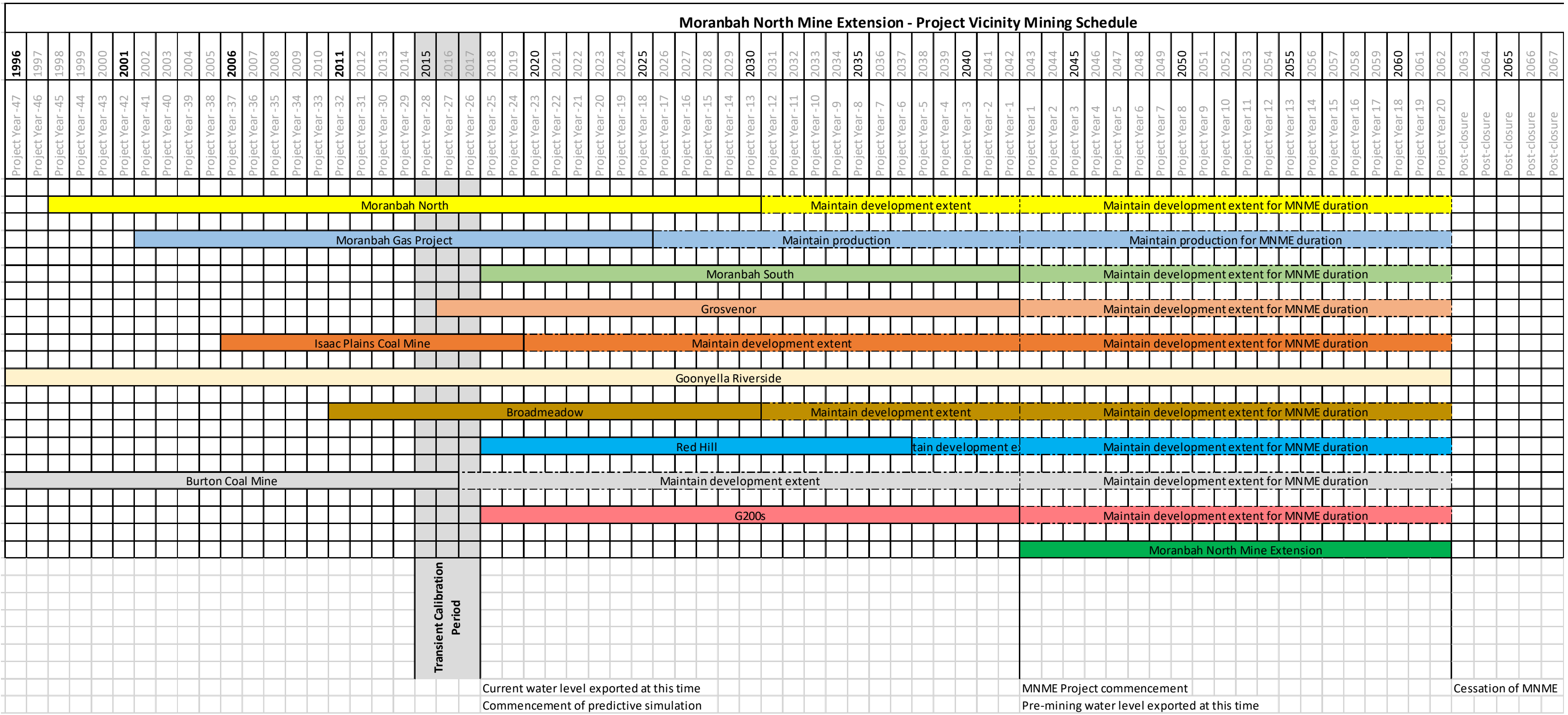

Figure 4: Mining development schedule implemented in model prediction

2 MODEL DESIGN

2.1 Model Code Selection

MODFLOW-USG is an "unstructured grid" version of MODFLOW that can use an irregular grid structure with arbitrary cell/node connections. This enables focused grid refinement to occur in areas where detail is important, without the need for continuation of grid refinement to the extremes of the model domain. It also facilitates implementation of pinching-out layers and/or layer discontinuities within the modelled domain. This can greatly reduce the number of grid cells within the model domain and thus greatly reduce model runtimes. In addition, MODFLOW-USG implements an "upstream weighting" formulation of the groundwater flow equation that allows cells to dewater and re-saturate easily.

For these reasons, MODFLOW-USG was selected for this groundwater modelling assessment.

A recent modelling exercise near the study area (G200's Project), conducted by Australasian Groundwater and Environmental consultants (AGE, 2016) referenced during model development. In that study, AGE also implemented MODFLOW-USG. Using a similar modelling approach allowed for integration of certain integral characteristics of that modelling effort, most notable being the geological interpretations and model geometry.

2.2 Model Processing and Discretisation

Algomesh was used to develop an unstructured grid based on Voronoi polygons and to calculate cell connectivities along with geometries of connected cell interfaces necessary for execution of the MODLOW-USG model. In doing so, grid mesh refinement was focused around:

1. The Quaternary alluvium;
2. Major surface water drainage lines; and,
3. Mining development areas.

The maximum allowable grid cell edge length was limited to 1,000 m and the minimum allowable internal angle in any single cell was set to 30 degrees. The minimum allowable cell thickness was set at 0.2 m thereby instructing Algomesh to pinch-out cells that have thicknesses less than this. The resulting grid cell mesh developed from these settings is shown in Figure 5. In representing the hydrostratigraphic units underlaying the study site, a total of 19 model layers were used and these are discussed further Section 2.3. The final model grid is comprised of 92,979 active cells. Figure 6 illustrates in a 3D view the model grid structure.

The transient period used for model calibration consists of monthly time-steps with quarterly stress periods over the period Jan 2015 to July 2017 and a combination of annual and quarterly stress periods were used in the predictive runs.

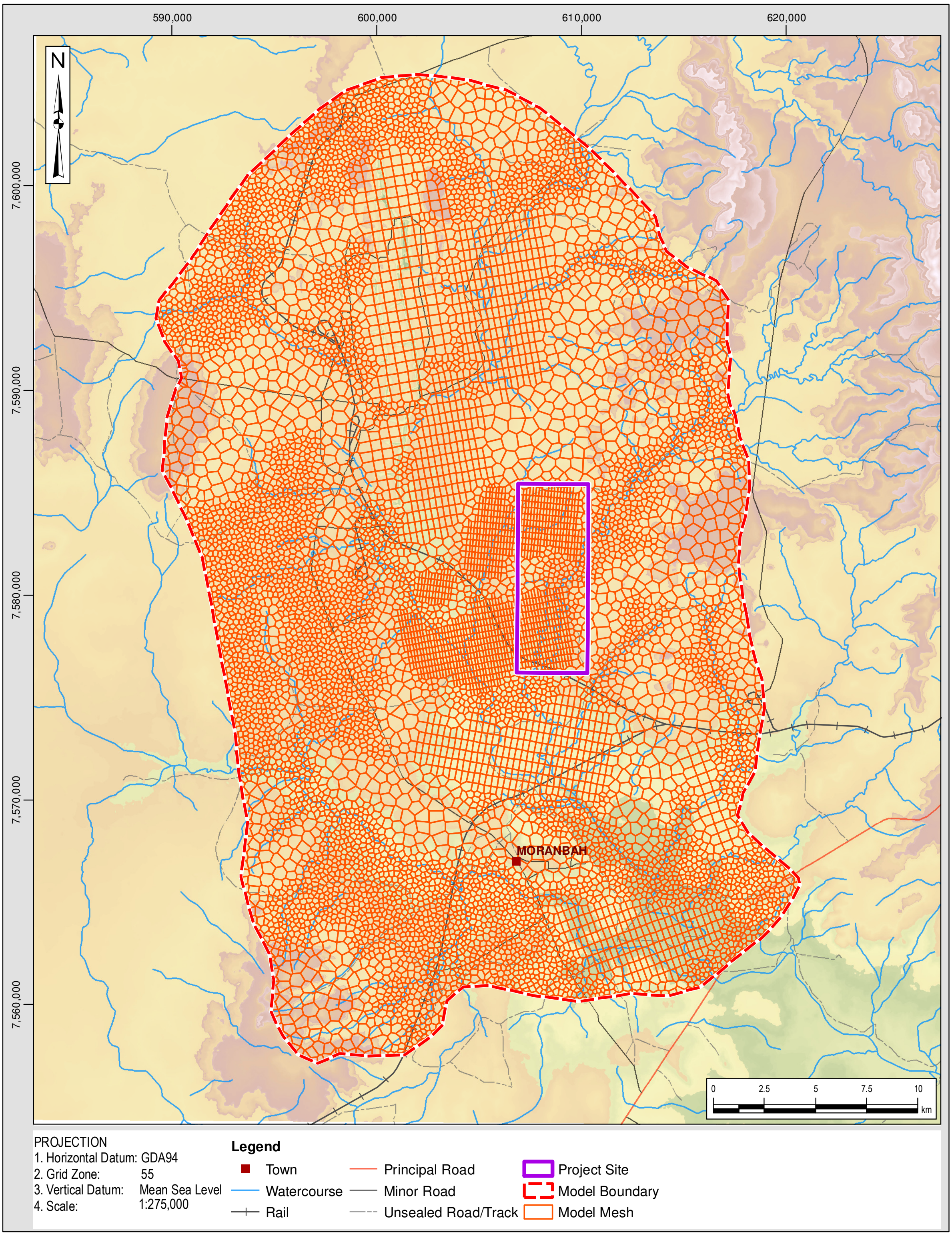

Figure 5: Algomesh generated grid mesh

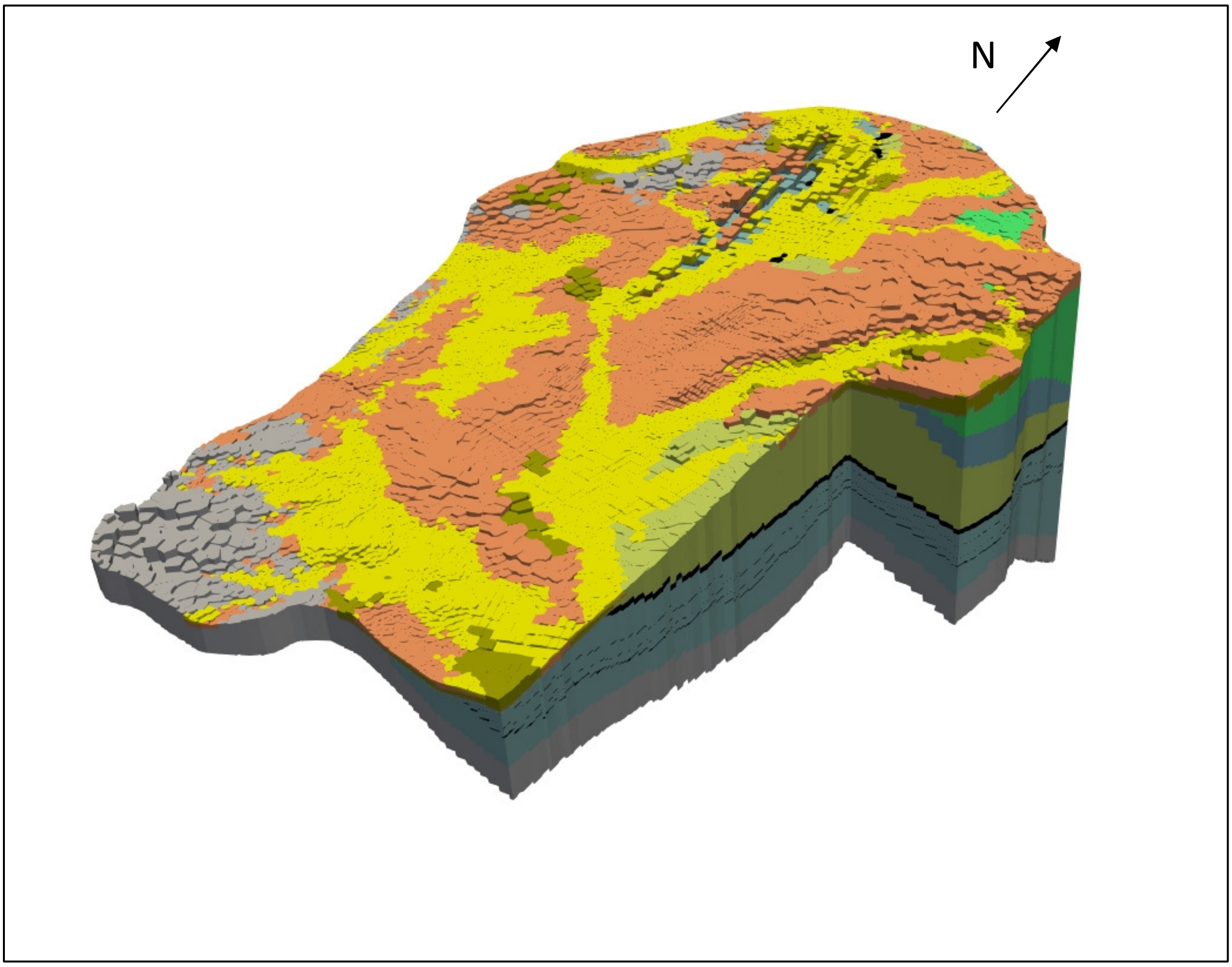

Figure 6: 3D illustration of model geometry (vertical exaggeration = 10:1).

2.3 Model Layers

The hydrostratigraphy of the study area is represented using 19 model layers that are mainly discontinuous across the model domain. The uppermost surface is defined by a digital elevation model derived from SRTM data and is used in its unaltered form. Table 2-1 presents the model layers and the primary geological units that are represented by each.

Table 2-1: Summary of Model Layers

Model Layer	Hydrogeological unit	Geological age
1	Alluvium	Tertiary
2	Tertiary Sediments	
3	Weathered Basalt	
4	Fresh Basalt	
5	Basal sand	
6	Rewan Group	Triassic
7	Rangal Coal Measures	Permian (RCM)
8	Fort Cooper Coal Measures Interburden	Permian (FCCM)
9	Fairhill seam	
10	Moranbah Coal Measures Interburden 1	Permian (MCM)
11	Q Seam	
12	Moranbah Coal Measures Interburden 2	
13	P Seam	
14	Interburden 3 (goafing layer)	
15	Interburden 4 (goafing layer)	
16	Interburden 5 (goafing layer)	
17	Goonyella Middle Seam	
18	Moranbah Coal Measures Underburden	
19	Back Creek Group	Permian (BCG)

The surfaces of these layers are derived from the following:

1. Corresponding layer elevations extracted from the G200's model developed by AGE consultants, where these are available;
2. Updated geological surface contours in the study area provided by the proponent which include:
   - Base of tertiary;
   - GM seam floor and roof;
   - Base of basalt
3. Borehole logs from recent investigation drilling in the Teviot Brook area;
4. Publicly available CSG drilling logs accessed from the QDEX database; and
5. Map products from the Bowen Basin Supermodel 2000.

The basal Tertiary sands have been included as a continuous unit underlaying the extent of basalt and have a nominal thickness of 5 m.

2.4 Model Boundary Conditions

Boundary conditions are necessary for solution of the 3D groundwater flow equation that is implemented by MODFLOW-USG. They also provide a means by which auxiliary groundwater fluxes and stresses can be specified within the model. The following boundary conditions were adopted in the model:

- Rainfall Recharge was applied in zones based on the extents of outcropping geological units, using the RCH package of MODFLOW. Recharge is regarded as the fraction of rainfall that passes through the unsaturated zone and arrives at the groundwater system. Within the model it was calculated as a percentage of rainfall. Four recharge zones are defined, each of which has a unique recharge rate that reflects the porosity of the strata through which it infiltrates. The percentage of rainfall that enters the model as recharge in each zone was adjusted during calibration. The zones are defined by the extents/outcrop of alluvium, tertiary sediments, tertiary basalt and Permian sediments, and are shown in Figure 7;
- Evapotranspiration can be a significant component of the water budget for the groundwater system. In the model, it was implemented using the EVT package in MODFLOW. A uniform extinction depth was applied across the domain and set at 1.5 m below the natural surface, below which evaporative losses from the groundwater surface are zero. Where the groundwater elevation is above this level, water is removed from the system at a maximum rate of 300 mm/annum. This value is approximately 50% of that presented in the average areal potential evapotranspiration map (BOM, 2008), which is based on a standard 30-year climatology from 1961-1990. The scale-back was necessary to achieve numerical stability and is consistent with that used in the G200's model;
- General head boundary cells (GHB package) were implemented around the perimeter of the model domain. They are applied to all layers where that layer is present at the boundary. Use of this boundary type allows for the regional groundwater flow system to be better replicated in the semi-regional model developed here. Conductance values applied to the GHB cells were calculated to be consistent with hydraulic conductivity values for each hydrostratigraphic unit and the average cross-sectional area of the boundary cells. A reference head for these cells was calculated as 15 m below ground surface. This boundary is sufficiently distant from the study area so as not to materially influence model performance;
- The waste water storage facility at the Isaac Plains mine site was represented by constant head cells set at an elevation of 204.1 mAHD. Two adjacent cells adequately cover this area;
- The major water courses in the model domain are represented using the MODFLOW Streams package (STR7). This boundary type is appropriate where stream flows are intermittent or highly variable; as is the case in this area. The package also allows for head-dependent surface water/groundwater exchanges to take place. This package calculates a stream stage height through application of Mannings' equation. Streambed conductances for Four main water courses were calculated using properties and geometries presented in Table 2-2. Estimates of stream flows used as input in this package, were calculated from data recorded by stream gauge station 130414A at Goonyella;

- Coal seam gas extraction has been in operation near the study area for some time. The impact of these operations on the regional groundwater system is difficult to replicate, though necessary to include for the purposes of the cumulative impacts assessment. CSG dewatering was implemented using drain cells (DRN package). At the location of each CSG development well, drains were placed in layers 11, 13 and 17 which correspond to Moranbah coal measures Q, P and GM coal seams respectively. A reference head level for these drains was set at 75 m above the top of the respective seam at that location. This simulates the partial dewatering of the seams that is optimal for CSG extraction. Drain conductances for these cells were refined during calibration;
- Drains cells were also used to simulate open-cut and underground mining activities. For open-cut mining, drains are placed in all layers above and including the target extraction layer. In underground mining, drains are placed in the target seam only. Reference heads were specified as the bottom of the target seam while conductances were refined during calibration; and,
- The default, no flow boundary condition is applied to the base of the model which is located approximately 200 m below the base of the Moranbah Coal Measures, in the Back Creek Group formation.

Table 2-2: Summary stream bed properties

Stream segment	Vertical hydraulic conductivity of stream bed (m/day)	Stream width (m)	Streambed thickness (m)
Isaac River	0.05	15	5
Teviot Brook	0.03	2	5
Smoky Creek	0.51	2	1.77
Grosvenor Creek	0.41	2	1.77

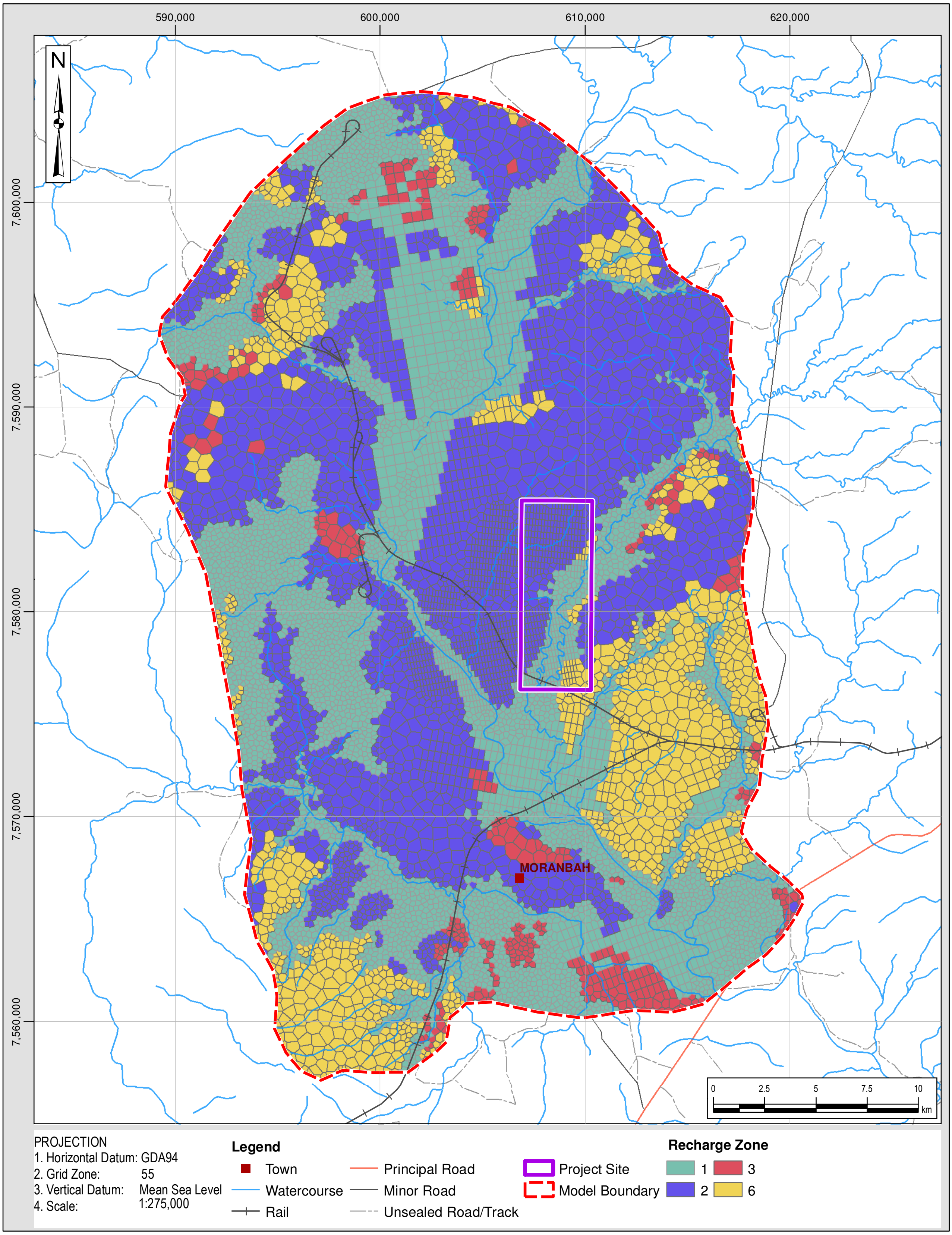

Figure 7: Recharge zones implemented in the model

2.5 Application of Hydraulic Properties

Hydraulic properties for the model layers 1 to 5, corresponding to the Quaternary and Tertiary age units overlaying the weathered surface of the Permian age sediments, were assumed to be homogeneous. This was also the approach taken for the Rewan Group, Fort Cooper Coal Measures and Fairhill Coal seam represented by layers 6, 7 and 8. In the case of the Moranbah Coal Measures, the approach taken by AGE consultants in assessment of the G200's project was adopted, whereby hydraulic conductivity is dependent on depth.

In addition, as the goafing zone induced by underground mining propagates fracturing vertically, the vertical hydraulic conductivity of the units impacted by this mechanism, is enhanced. Representation of these processes within the model are now discussed.

2.5.1 Spatial Distribution of Hydraulic Conductivity

Conceptually, the horizontal hydraulic conductivity of the Permian coal seams and interburden reduces as a function of the depth of the material. This is the result of increasing pressure with depth due to the overlaying material. The Permian interburden consists mostly of conglomerate, siltstone and sandstone and so the function that describes hydraulic conductivity change with increasing depth in these units is different from that which describes the hydraulic conductivity change of the coal seams. As the general dipping of the Permian units is laterally west to east at the site, the distribution of hydraulic conductivity is spatially variable with values decreasing toward the east of the model domain.

As was implemented in the G200's model, the function that describes Permian interburden horizontal hydraulic conductivity is given by:

$$Kh_{inter} = Kh_0 \times e^{(slope \times depth)}$$

And the equation describing coal seam horizontal hydraulic conductivity variability is:

$$Kh_{coal} = Kh_0 \times depth^{(slope)}$$

Where: $Kh_{inter/coal}$ is depth specific horizontal hydraulic conductivity;

Kh_0 is horizontal hydraulic conductivity of material at depth of 0 meters;

slope is a term representing steepness of the curve;

depth is the depth to the mid-point of the cell at that location.

Values of *slope* were taken from the G200's report and are -0.0186 and -2.246 for coal and interburden respectively.

Figure 8 illustrates these relationships. Note the use of log scale for conductivity in this figure.

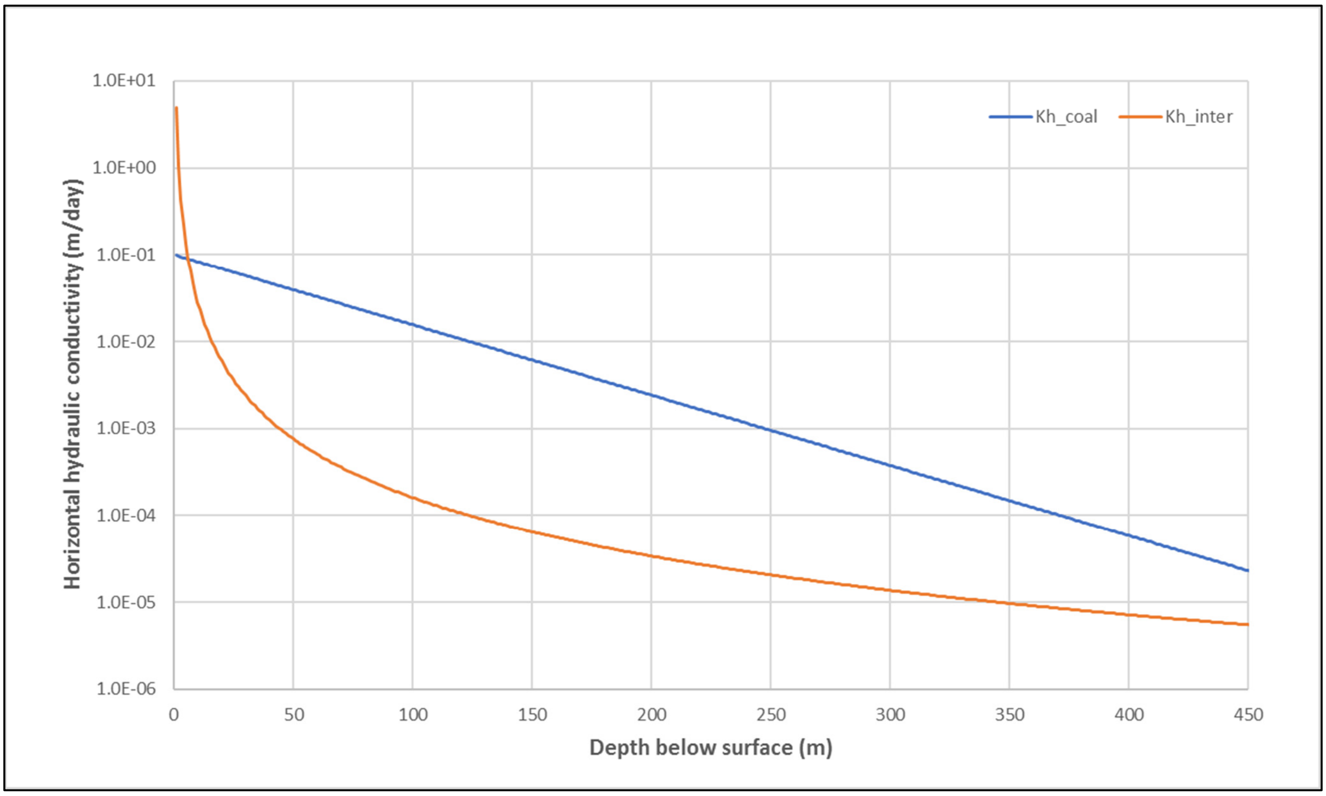

Figure 8: Depth dependent relationship implemented for distribution of hydraulic conductivities of coal and interburden layers

Values for Kh_0 in each of the layers 9 through 19 were estimated during calibration. Adjustment of these intercept values has the effect of raising or lowering the curves presented in Figure 8.

Vertical hydraulic conductivity in all layers is calculated as a factor of the horizontal hydraulic conductivity. Therefore, in layers 9 to 19 vertical hydraulic conductivity also varies spatially across the model domain with decreasing conductivity toward the east.

2.5.2 Goaf Induced Hydraulic Properties

Enhanced vertical hydraulic conductivity resulting from the effects of goafing was calculated as the Geometric mean of the in-situ vertical hydraulic conductivity (calculated as described in the previous section where appropriate) and a free draining fracture network with linearly varying conductivity over the height of goaf fracturing. Geotechnical advice provided by the proponent suggests that goafing extends vertically from the mined layer to a height of 125 m above the mined seam.

Similarly, storage properties of the goaf affected materials changes as mining advances. The changes to storage properties is calculated by multiplication of the in-situ storage properties by a factor, which varies linearly over the height of goafing, between a maximum of 10 (adjacent to the mined seam) to a minimum of 1 (at maximum goafing height).

These hydraulic property changes are applied in the model as mining progresses during the simulation.

2.6 Calibration Process and Metrics

Model calibration was performed to adjust model parameter values so that the model can better replicate historical observations of the system state. The outcome of the calibration process also provides the initial conditions for transient predictive simulations used to assess potential impacts of the project on the groundwater regime.

2.6.1 Calibration Approach

This area of the Bowen Basin has numerous mining operations that have been in operation for some time. Calibration of this model aimed to focus parameter estimation on the more recent prevailing conditions over the period Jan 2015 to July 2017. Upon review of the existing information this was deemed to be a more reliable sequence of observation data.

The calibration model run is initiated in steady state with boundary conditions applied to replicate known mining development at the beginning of 2015. This includes the Arrow Energy CSG project at full development. Following this initial model conditioning period, the model transitions to transient mode for the aforementioned period in which quarterly stress periods are implemented. This stress period length is sufficient to allow for seasonal climatic variations to be included and to replicate mine development in the model. All observations used as calibration targets pertain to the transient part of the simulation.

Automatic parameter estimation was implemented with the use of PEST. In all 87 adjustable parameters were used. These include hydraulic conductivities, storage properties, drain conductances and recharge.

2.6.2 Calibration Targets

All observations that comprise the calibration dataset are water level measurements. These measurements are compiled from 34 monitoring bores for which reliable water level measurements were available over the transient simulation period. In total 609 individual measurements are used in the calibration process, with the majority of these arising from six installed vibrating wire piezometers.

2.6.3 Calibration Results

Figure 9 presents a comparison between groundwater level measurements and the calibrated model output equivalents. During calibration, all measurements of the calibration dataset were given equal weight, thereby seeking to extract maximum information from the calibration dataset for inference of parameters. In Figure 9, measurements from bores installed at the Teviot brook site are shown in orange.

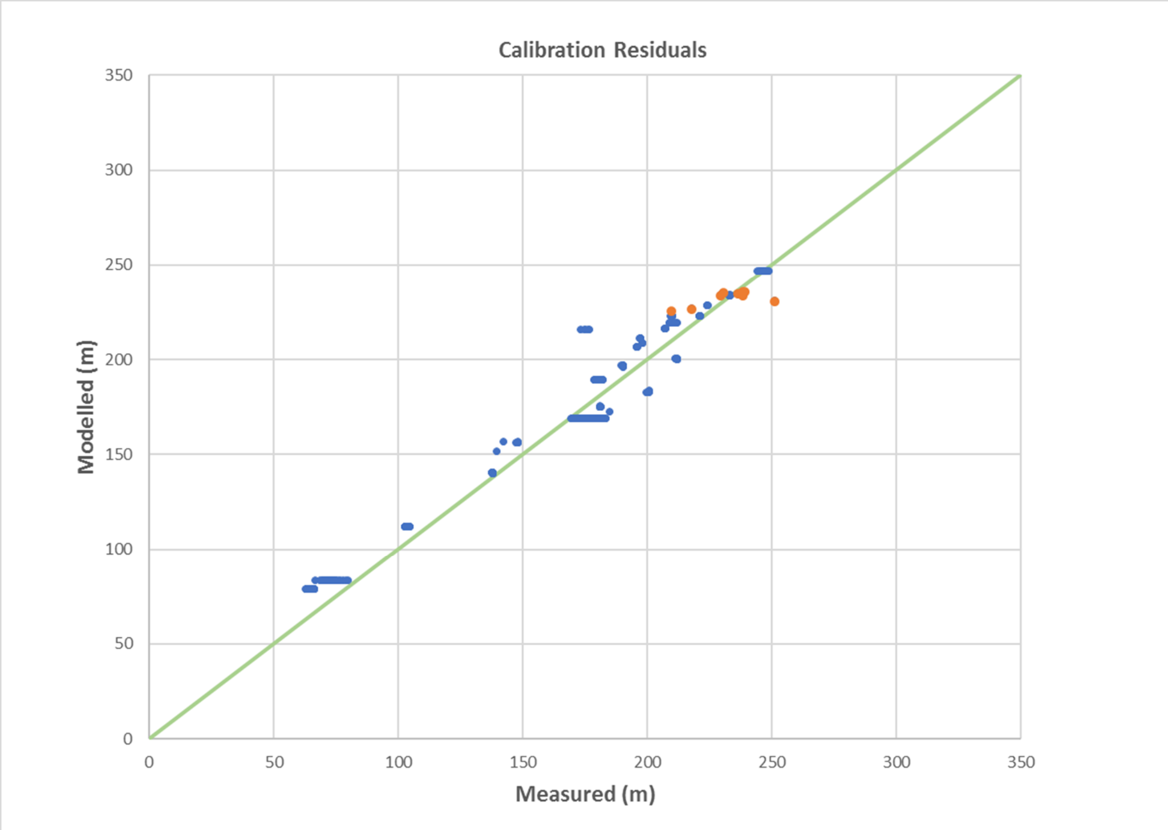

Figure 9: Cross-plot of calibration residuals

Table 2-3 presents statistics from the calibration process. As can be seen in this table, the scaled root Mean Square (SRMS) of errors is 5.2% which is within limits recommended by the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) of 10% SRMS.

Table 2-3: Summary model calibration performance

Statistical Metric	Value
Number of Observations	609
RMS error (m)	9.8
Scaled RMS (%)	5.2
Mean Sum of Residuals (m)	-1.9
Scaled Mean Sum of Residuals (%)	3.1
Correlation coefficient	0.98

2.7 Calibrated Hydraulic Parameters

Table 2-4 summaries calibrated hydraulic conductivity values for each model layer and the calibrated storage parameters. As was described in Section 2.5.1, hydraulic conductivity values of the Permian age sediments (layers 8 to 19) vary in accordance with the specified depth dependent relationship. As such the values presented in Table 2-4 for layers 8 to 19 represent the average values for these layers, which includes a decrease in hydraulic conductivity of the hydrostratigraphic units with depth. Similarly, the vertical hydraulic conductivity values presented in this table represent the average values for these layers.

Table 2-4: Summary calibrated hydraulic properties

Model Layer	Geological Unit	Calibrated Kh (m/d)	Calibrated Kv (m/d)	Calibrated Specific Yield (-)	Calibrated Specific Storage (m^{-1})
1	Quaternary Alluvium	21.1	7.46	0.21	5.13E-04
2	Tertiary Sediments	0.53	0.02	0.00128	4.68E-06
3	Weathered Basalt	1.28	0.17	0.0069	2.93E-05
4	Fresh Basalt	4.6	0.11	0.0086	2.64E-04
5	Tertiary Basal Sands	1.0	0.04	0.031	7.29E-04
6	Rewan Formation	0.0159	0.0011	0.0007	1.47E-05
7	Rangal Coal Measures	0.0037	0.0003	0.003	1.33E-05
8	Fort Cooper Coal Measures Interburden	1.90E-03	4.33E-05	0.0008	3.14E-05
9	Fairhill seam	2.66E-01	7.46E-02	0.0071	1.84E-05
10	Moranbah Coal Measures Interburden 1	3.46E-04	1.04E-04	0.012	1.33E-05
11	Q Seam	3.80E-02	3.37E-02	0.0106	1.69E-05
12	Moranbah Coal Measures Interburden 2	2.45E-03	1.36E-03	0.019	9.69E-07
13	P Seam	2.41E-01	2.34E-01	0.0003	6.18E-07
14	Interburden 3 (goafing layer)	3.70E-03	8.50E-04	0.012	4.57E-05
15	Interburden 4 (goafing layer)	2.27E-03	6.30E-04	0.03	1.69E-05
16	Interburden 5 (goafing layer)	2.02E-03	5.64E-04	0.004	1.63E-06
17	Goonyella Middle Seam	6.51E-02	5.36E-02	0.011	5.66E-06
18	Moranbah Coal Measures Underburden	7.70E-06	6.32E-07	0.0004	1.60E-05
19	Back Creek Group	7.45E-06	8.68E-07	0.014	6.24E-05

As is described in section 2.5.2, where materials are impacted by continuous cracking from underground mining activities simulated in the model, these property values change with progression of mining in accordance with the aforementioned methodology.

2.8 Calibrated Recharge Rates

Recharge to the model domain was calculated as a percentage of recorded rainfall within the model domain during each stress period of the calibration model run. During the steady state warmup period long-term average annual rainfall was converted to daily rainfall, while during the quarterly, transient periods, recorded quarterly rainfall totals were used to calculate average daily rainfall for that period. The percentage of this average daily rainfall that results as recharge were estimated during calibration and these are provided in Table 2-5.

Table 2-5: Summary calibrated recharge rates

Modelled Recharge Zone	Percentage of daily rainfall
Quaternary alluvium	5.28E-03
Tertiary sediments	1.32E-03
Tertiary basalt	6.02E-04
Permian and other	2.21E-03

2.9 Calibrated Water Balance

The mass balance error of the transient calibration model is the difference between model inflows and model outflows calculated by the model. An error of approximately 1% is considered acceptable (Anderson and Woessner, 1991). The model reported water budget for the steady state period of the calibrated model is presented in Table 2-6. The water balance error is less than 1%, indicating that convergence of the numerical solution of the groundwater flow problem has been achieved.

Table 2-6: Summary Water Balance at end of Calibration Period

Water Budget Item	Inflow (m^3/day)	Outflow (m^3/day)
Recharge (Rainfall deep drainage)	525	0
General Head Boundary Throughflow (Regional flow across model extents)	39,929	9,060
Evapotranspiration (from surface heating/vegetation)	0	3,225
Stream Leakage (Groundwater exchanges with water courses)	27,723	35,387
Drains (Groundwater removed from system via mining and CSG operations)	0	20,503
Groundwater exchanges via Isaac Plains water storage facility	0.2	1.9
TOTAL	68,177.5	68,178.5
Mass Balance error	0.00%	

2.10 Model Classification

Barnett et al. (2012) developed a system to classify the confidence level of groundwater flow models based on the calibration process used and the predictive capability of the model. Three classes of model were developed: Class 1, Class 2 and Class 3. A Class 3 model has the greatest confidence level, and a Class 1 model has the least. Factors that are considered when determining model confidence level are:

- Data availability;
- Calibration procedures;
- Consistency between calibration and predictive analyses; and,
- Stresses induced on the model.

The model outlined in this report is considered a Class 2 model because:

- A transient calibration was undertaken and mining-induced groundwater trends were replicated;
- Independent observations and calculations were used to support the calibration process; and,
- The water balance error is less than 1%.

The model meets the criteria for a Class 2 model, and exceeds the criteria for a Class 1 model. The model is therefore assessed as being a suitable tool for assessing groundwater impacts that may arise as a result of the project.

3 MODEL SIMULATIONS

3.1 Modelling Approach

The transient model for the predictive scenarios is an extension of the transient calibration model, and is comprised of annual stress periods for the 25 years and then quarterly stress periods covering the project operation period of 20 years. Mine development for the predictive scenarios followed the schedule presented in Figure 4; and involved the progressive assignment and removal of MODFLOW drain cells representing underground mining, and the modification of hydraulic parameters to represent continuous cracking above underground workings.

In simulation of mine advancement, drain cells were assigned to the corresponding target coal seam for each mine, and had an elevation equivalent to the seam floor. A drain conductance value of 388 m^2/d was applied to each drain; this is the value that was derived through calibration. Drain cells were removed following the completion of mining at end of each stress period, however, alterations to hydraulic properties applied to mined and goaf affected areas remained in place.

3.2 Underground Mining

The EAR subsidence report assessed the potential height of continuous cracking induced above the subsiding longwall panels, and concluded that subsidence cracking would extend to a height of 125 m above the mined Permian coal seams. Continuous cracking will increase the vertical hydraulic conductivity within the affected zone, with the magnitude of the increase dropping with increased height above the mined coal seam.

As with the prediction of cracking height, the estimation of the hydraulic conductivity within the zone of continuous cracking is inherently uncertain. Given the combined uncertainty in cracking height and hydraulic conductivity change, this assessment has conservatively adopted the following key modelling assumptions as the basis for predicting subsidence-induced impacts to groundwater.

- The continuously cracked zone will be permeable, with a decreasing hydraulic conductivity relationship with increased height above the coal seam. The modified hydraulic conductivity was represented using a function that accounts for the hydraulic conductivity of open fractures and intact rock fragments, both of which will exist within this zone.
- Where the zone of continuous cracking is predicted to intersect only part of the geological unit, the entire thickness of that unit was assumed to be continuously cracked.

Based on these assumptions, the vertical hydraulic conductivity assigned to the cracked strata is sufficiently high that it will be free draining. These assumptions conservatively account for uncertainty associated with subsidence cracking predictions, and therefore likely represent the 'upper bound' conditions for depressurisation and inflow that might be expected as a result of the project.

3.3 Post – Closure Recovery

An analysis of post-closure recovery was performed to assess the response of the system to total cessation of mining operations. The model was over 1,000 year period in which all drain cells were removed and recharge was applied in accordance with the long-term historical average. A pseudo-observation point was placed in the centre of the project area, within the GM seam, to examine the system response. This is the unit that is expected to be most impacted by local and regional mining activities. Figure 10 shows the recovery in the GM seam following cessation of all mining in the vicinity of the project area. This figure shows that full recovery of the system can be expected to have been achieved after approximately 500 years following mine closure.

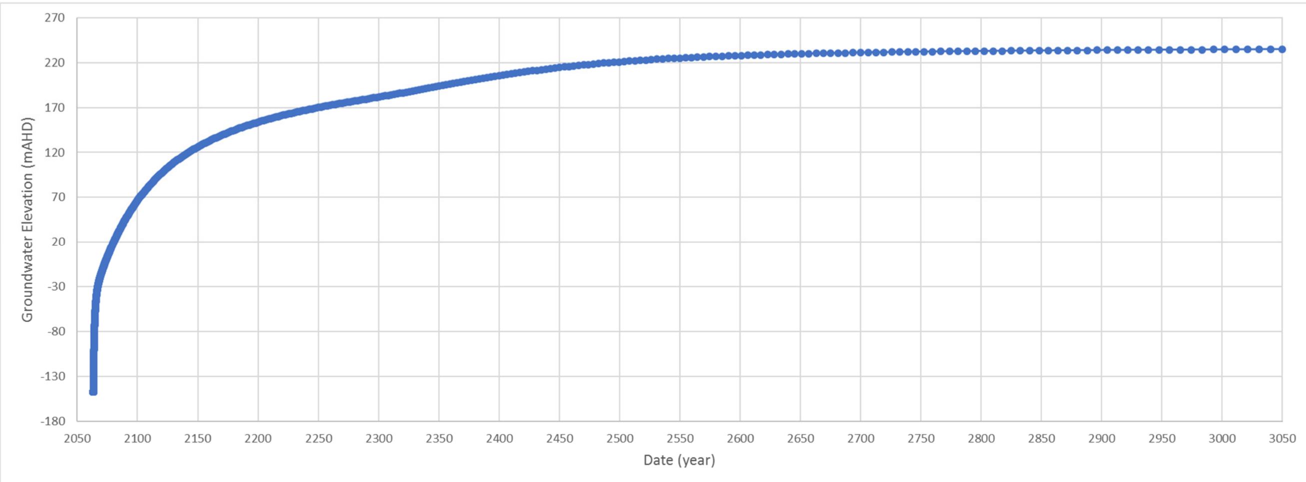

Figure 10: Post-closure recovery of the GM seam

3.4 Sensitivity Analysis for Predicted Project Impacts

3.4.1 Overview

A sensitivity analysis was performed to assess the response of the model to varying hydraulic properties. This analysis provides for a comparison of the influence of these properties on the outcomes of predictions made by the model. Impacts to predictions of mine groundwater inflows and maximum drawdown due to changes in hydraulic properties were examined.

Parameters that were assessed during predictive sensitivities were grouped and varied in the following manner:

- Horizontal (Kx) and vertical (Kv) hydraulic conductivity of all layers was varied by 50% above and below their calibrated values;
- Specific storage (Ss) and specific yield (Sy) values for all layers was varied by 50% above and below their calibrated values; and,
- Recharge rates (Rch) and stream package (str) segment flows were varied by 50% above and below their calibrated values.

3.4.2 Mine Inflow Estimates

Impacts of these sensitivity scenarios on predicted mine inflows are shown in Figure 11. Table 3-1 presents a summary of the change in predicted mine inflows resulting from scenarios tested in the sensitivity analysis. This table shows that in this model, predictions of mine inflows are most sensitive to changes in hydraulic conductivity, with a maximum inflow rate of 9.81 L/s resulting from 50% increase in hydraulic conductivity parameters. This large change only marginally decreases the model's ability to fit the calibration dataset, as is demonstrated by the third column of Table 3-1 (i.e. SRMS metric).

Predicted mine inflows are also sensitive to large variations in storage parameters, though this sensitivity is smaller than that observed with increases in hydraulic conductivity. These changes in storage parameters have little effect on the model's calibration performance.

Modelled recharge rates have a negligible impact on predicted mine inflows. This is a consequence of the separation of the project area from areas where potential surface water/groundwater interactions occur at shallow depths. However, the calibration performance of the model is reduced when recharge rates are varied over these large ranges.

Table 3-1: Summary results from Sensitivity Analysis

Sensitivity Scenario	Parameter adjustment	Transient SRMS (%)	Maximum mine groundwater inflow (L/s)
Calibrated – Baseline	NA	5.19	6.06
1	Kx and Kz: Minus 50%	19.0	5.94
2	Kx and Kz: Plus 50%	8.05	9.81
3	Rch and Str: Minus 50%	19.5	6.06
4	Rch and Str: Plus 50%	19.3	6.06
5	Ss and Sy: Minus 50%	5.19	4.56
6	Ss and Sy: Plus 50%	5.19	7.09

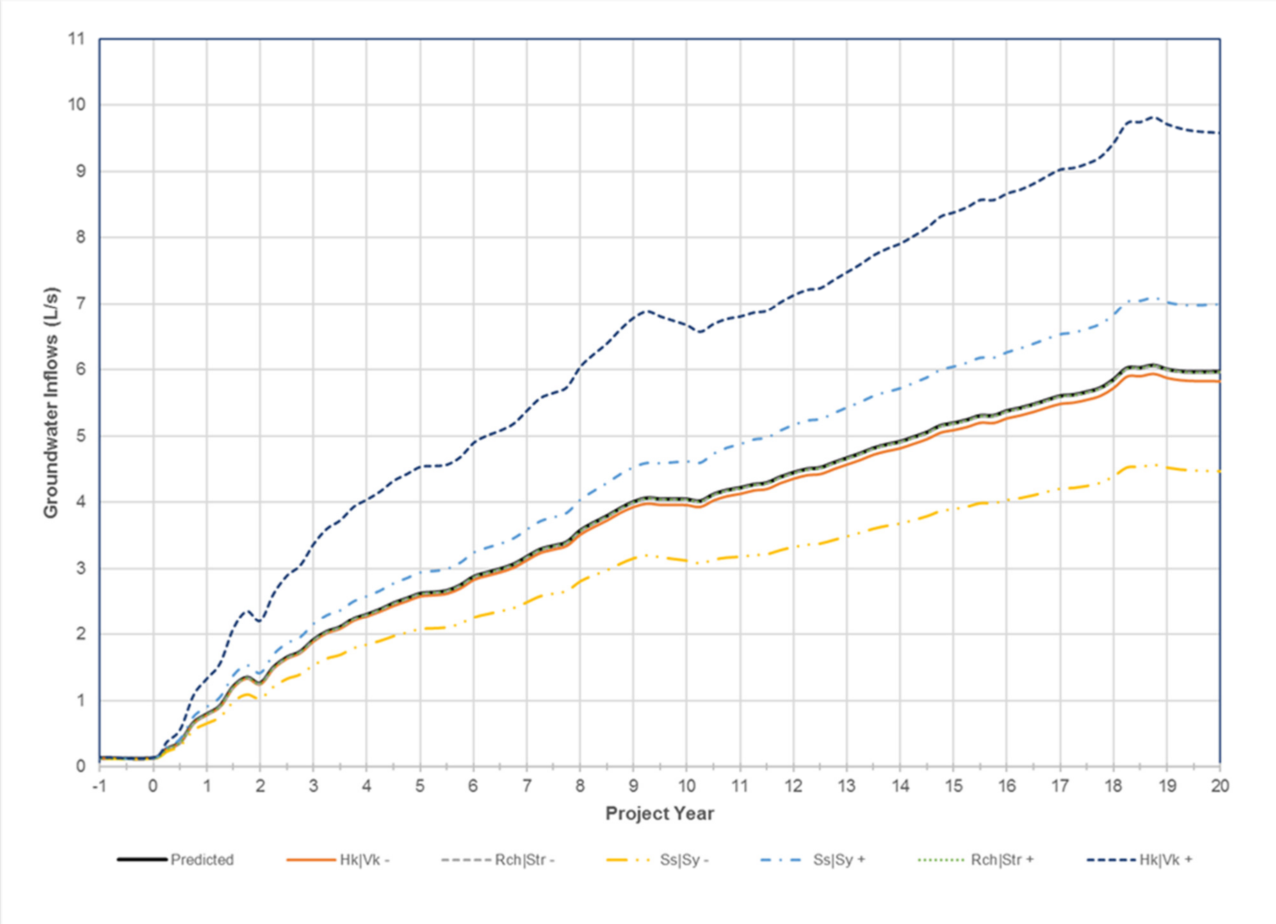

Figure 11: Sensitivity of predicted mine inflows

3.4.3 Drawdown Extents

The maximum extent of project induced drawdown that results from the scenarios outlined in Section 3.4.1 are shown in Figure 12. This figure presents cumulative drawdown impact in layer 17 (GM seam). This is the hydrographic unit most impacted by the project activities. As can be seen from this figure, the extent of drawdown impact (defined by the 1 m drawdown contour) changes little under the sensitivity scenarios assessed. The maximum increases in drawdown extent arises from decreases in hydraulic conductivity and storage parameters.

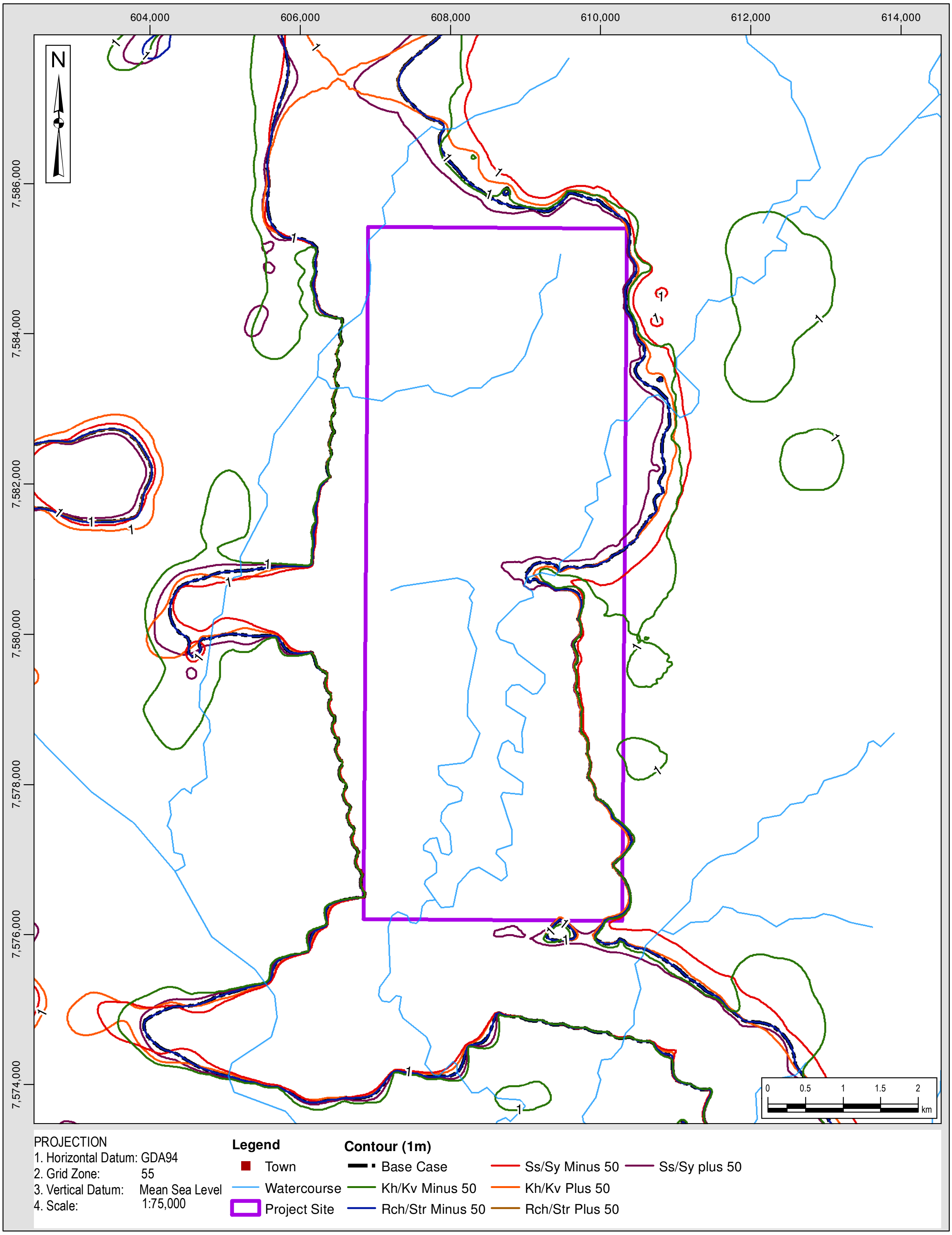

Figure 12: Sensitivity of zone of depressurisation – GM seam

3.4.4 Sensitivity Classification

The Murray Darling Basin Modelling Guidelines (MDBC, 2000) provide a framework for classification of a predictive model parameters in terms of their impacts on the model. These can be summarised as follows;

- Type I: Insignificant changes to calibration and predictions;
- Type II: Significant changes to calibration with insignificant changes to predictions;
- Type III: Significant changes to calibration with significant changes to predictions; and,
- Type IV: Insignificant changes to calibration and significant changes to prediction.

Types I to III present no concern where management decisions are to be based on the model, provided the model is calibrated and encapsulates sufficient complexity to replicate the system. However, Type IV classification may be of concern as calibration may have done little to reduce potential for predictive error.

With consideration to the results of the sensitivity analysis, parameters employed in this model can be considered Type I to II classification.

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