MALABAR COAL

MAXWELL PROJECT

Agricultural Impact Assessment
In Support of an Application for a Gateway Certificate

ATTACHMENT C
Preliminary Groundwater Assessment

August 2018

Maxwell Project: Preliminary Groundwater Assessment – In support of an Application for a Gateway Certificate

FOR

Malabar Coal Limited

BY

NPM Technical Pty Ltd
trading as:
HydroSimulations

Project number: MAL002

Report: HS2018/43D

Date: 22nd August 2018

EXECUTIVE SUMMARY

The Maxwell Project is a proposed underground coal mining operation within Exploration Licence 5460 located in the Upper Hunter Valley of New South Wales, east-southeast of Denman and south-southwest of Muswellbrook.

This report has been prepared for Malabar Coal Limited to provide a preliminary groundwater assessment of the Project for the purposes of the Gateway process. The assessment relies on numerical modelling of the potential risks associated with the mine's development under the terms of the New South Wales Aquifer Interference Policy and Gateway process requirements. This modelling was undertaken in consideration of the Murray-Darling Basin Commission Groundwater Flow Modelling Guideline (2001), the Australian Groundwater Modelling Guidelines (2012), as well as the Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources (2013) and the Information Guidelines for Proponents Preparing Coal Seam Gas and Large Coal Mining Development Proposals (2018).

A comprehensive review of data, literature, conceptual hydrogeology, and other numerical groundwater models and assessments developed within and surrounding the Project area, was carried out to support the model development. The report has also been prepared cognisant of the outputs of the Northern Sydney Basin Bioregional Assessment for the Hunter subregion, and prior advice for the Project area and surrounds provided by the Independent Expert Scientific Committee for Coal Seam Gas and Large Coal Mining Development.

The complexity of the numerical groundwater model developed as part of this study is consistent with the intent of the Gateway process and is suitable for this preliminary groundwater assessment by simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system because of the proposed development. Based on the Australian Groundwater Modelling Guidelines (2012), the model is classified as Class 2, with a good steady-state calibration and verification (transient) performance of 7.5% and 4.5% scaled root mean square error respectively, both achieving the target for less than 10% suggested in the Murray-Darling Basin Commission Groundwater Flow Modelling Guideline (2001).

Based on the findings of the groundwater modelling and assessment, the Project meets the Level 1 minimal impact consideration classification of the Aquifer Interference Policy for 'highly productive' water associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) (**Table ES-1**).

Based on available data, the unconsolidated alluvial sediments associated with Saddlers Creek within the Jerrys Management Zone of the Jerrys Water Source are classified as a 'less productive' groundwater source. The Permian porous rock groundwater sources within the Sydney Basin – North Coast Groundwater Source are also classified as 'less productive'.

While 'less productive' groundwater sources are exempt from consideration under the Strategic Regional Land Use Policy Guideline for Gateway Applicants (2013), the minimal impact considerations of the Aquifer Interference Policy for the 'less productive' groundwater sources have been classified in this report (i.e. Level 2, as more than 2 metres drawdown or cumulative drawdown is predicted at some water supply works).

Accordingly, a groundwater management plan would be required in the future to define groundwater level triggers, and a trigger action response plan.

In conclusion, the Project would have "*no more than minimal harm*" on any water sources as a consequence of water being taken under licence in accordance with the Water Management Act 2000. Malabar currently holds adequate licences for 'highly productive' water associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone).

Furthermore, consideration of the potential impacts against the Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources (2013) concludes that the Project is unlikely to have a significant impact on the groundwater resource.

Table ES-1 Summary of Aquifer Interference Policy Assessment – Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone)

<table>
<tr><td>Aquifer</td><td colspan="2">Alluvial Water Source: Hunter Regulated River Water Source (Upstream Glennies Creek Management Zone)</td></tr>
<tr><td>Category</td><td colspan="2">Highly Productive Groundwater Source</td></tr>
<tr><td colspan="2">Level 1 Minimal Impact Consideration</td><td>Assessment</td></tr>
<tr><td colspan="2">Water Table

1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 m from any:

(a) high priority groundwater dependent ecosystem; or

(b) high priority culturally significant site;

listed in the schedule of the relevant water sharing plan.

OR

A maximum of a 2 m water table decline cumulatively at any water supply work.</td><td>At the time of writing the nearest ‘high priority’ groundwater dependent ecosystem listed in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018) to the Project area is Wappinguy Spring, near Merriwa, more than 50 kilometres to the north-west. There are no listed groundwater-dependent culturally significant sites in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018). Hence there are no known risks of mine development to such ‘high priority’ groundwater dependent ecosystems or groundwater-dependent culturally significant sites.

No drawdown is predicted in excess of the criterion within the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone).

Level 1 minimal impact consideration classification.</td></tr>
<tr><td colspan="2">Water Pressure

1. A cumulative pressure head decline of not more than 40% of the “post-water sharing plan” pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.</td><td>Not applicable as only unconfined conditions in the alluvial water source. Therefore, only the above water table consideration is relevant.

Level 1 minimal impact consideration classification.</td></tr>
<tr><td colspan="2">Water Quality

1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.
1. (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.
1. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three-dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a “reliable water supply”.
1. (d) Not more than 10% cumulatively of the three-dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a “reliable water supply”.</td><td>There are no simulated risks of reduced beneficial use categories of the alluvial water source as a result of the Project. Nor is there any predicted increase in the salinity of the Hunter River.

No mining activity within these specified proximities to the alluvial water source is proposed. No excavation of the ‘highly productive’ alluvial sediments associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) is proposed.

Level 1 minimal impact consideration classification.</td></tr>
</table>

DOCUMENT REGISTER

Revision	Description	Date
A	Initial Draft (incomplete)	18 July 2018
B	1st Draft	30 July 2018
C	2nd draft	6 August 2018
D	Final draft	17 August 2018
E	Final	22 August 2018

ACKNOWLEDGMENTS

Person	Activity
Maxime Philibert, Joel Vernon	Model build, calibration, prediction and figures
Derek Yates	Impact assessment and reporting
Noel Merrick	Internal review

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1 INTRODUCTION

The Maxwell Project (the Project) is a proposed underground coal mining operation in the Upper Hunter Valley of New South Wales (NSW), east-southeast of Denman and south-southwest of Muswellbrook (**Figure 1**).

The Project would involve underground mining within Exploration Licence (EL) 5460, which is held by a subsidiary of Malabar Coal Limited (Malabar) (**Figure 2**).

Malabar also owns and manages the existing infrastructure within Coal Lease (CL) 229, Mining Lease (ML) 1531 and CL 395 (known as the Maxwell Infrastructure). The Maxwell Infrastructure includes an existing coal handling and preparation plant (CHPP), rail facilities, other infrastructure and services, and overburden emplacements and final voids associated with previous open cut mining activities. The Project would include the use of the substantial existing Maxwell Infrastructure and the development of some new infrastructure.

This report documents a preliminary groundwater assessment of the Project for the purposes of the Gateway process. This process applies to State Significant Development located on Biophysical Strategic Agricultural Land (BSAL) and/or Critical Industry Cluster (CIC) land, as defined in *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (Mining SEPP). BSAL and CIC land mapped near the Project area are presented on **Figure 3**.

1.1 EXPLORATION, ASSESSMENT AND APPROVAL HISTORY

Exploration in the Project area commenced in the late 1940s, with exploration occurring in several phases since that time. EL 5460 was granted in 1998 and has been systematically explored following its grant. In total more than 950 exploration boreholes have been drilled. In addition to this, approximately 75% of the area is also covered by 3D seismic survey.

In 1986, a Development Consent was granted to Mount Arthur South Coal Limited for an open cut mine in the Project area, although this consent lapsed in 1991.

Following the grant of EL 5460, groundwater and surface water studies of the Project area were conducted by Mackie Environmental Research (MER) (1998). The MER (1998) study included regional data gathering, installation of eight piezometers into coal measures, core inspections and laboratory testing, formation hydraulic testing, monitoring of groundwater levels and computer-based groundwater flow modelling. Subsequently, MER (2001) consolidated hydrogeological data arising from the 2001 exploration drilling program targeting the deeper Woodlands Hill, Arrowfield, Bowfield, and Warkworth coal seams.

Anglo American made two applications in 2012 and 2015 for an open cut coal project in EL 5460, known as the Drayton South Coal Project. These applications were supported by numerical groundwater modelling completed by AGE (2012, 2015).

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) provided advice on the Drayton South Coal Project open cut proposal at the Gateway and Assessment advice stages in February 2015 (IESC 2015-064) and June 2015 (IESC 2015-069).

The IESC had also previously provided advice to the Commonwealth Department of Sustainability, Environment, Water, Population and Communities on the initial project proposal for the Drayton South Coal Project (dated 1 February 2013), however the previous advice was provided prior to the introduction of the 'water trigger'. The most recent IESC advice (IESC 2015-069) focused on the assessment of potential cumulative impacts on Saddlers Creek and the Hunter River and made recommendations for improvements to the monitoring program (Question 7 and response, IESC 2015-069).

The NSW Planning Assessment Commission (PAC) Determination Report (dated 22 February 2017) found that the Drayton South Coal Project "… would, subject to the mitigation measures proposed by the Applicant and the conditions recommended by the Department, have an acceptable impact on surface water and groundwater resources".

Malabar acquired EL 5460 in February 2018 for the purposes of developing an underground mining operation. The current conditions of EL 5460 only allow prospecting for the purposes of the assessment and potential future extraction of underground resources.

Data from previous investigations and studies within the Project area and surrounds have been used to inform the current assessment.

1.2 PROJECT DESCRIPTION

1.2.1 UNDERGROUND MINING

The Project would involve extraction of coal from four seams within the Wittingham Coal Measures using the following underground mining methods:

- bord and pillar with pillar extraction in the Whynot Seam, and
- longwall extraction in the Woodlands Hill Seam, Arrowfield Seam and Bowfield Seam.

Extraction would occur over a period of approximately 26 years.

Indicative mining layouts in the four seams are presented in **Figure 4**.

1.2.2 INFRASTRUCTURE AND SERVICES

The Project would include the use of the existing Maxwell Infrastructure for handling, processing and transportation of coal for the life of the Project.

An overland coal conveyor would be constructed and operated to transport sized ROM coal from the mine entry to the existing CHPP at the Maxwell Infrastructure (**Figure 5**).

During the development stage of the Project ROM coal would be transported via internal roads along a similar route as the proposed overland conveyor. This would cease when the overland conveyor is constructed and commissioned.

ROM coal would be processed at the existing CHPP and then stockpiled prior to transport to the domestic market or to the Port of Newcastle for export.

1.2.3 MANAGEMENT OF CHPP REJECTS

CHPP reject material would be produced over the life of the Project, including coarse rejects and tailings.

This CHPP reject material would be emplaced preferentially within the existing East Void in ML 1531 at the Maxwell Infrastructure as shown on **Figure 5**.

1.3 OTHER PROJECTS IN THE REGION

As shown on **Figure 1**, several operating open cut mines exist in the region, including:

- Mt Arthur Mine located west of the Maxwell Infrastructure and north of the Maxwell Underground.
- Hunter Valley Operations North to the east of the Maxwell Underground, including the Carrington Pit, West Pit and North Pit.
- Hunter Valley Operations South to the south-east of the Maxwell Underground, including Riverview Pit, Cheshunt Pit and South Lemington Pits 1 and 2.
- Liddell Coal Mine located to the east-northeast of the Maxwell Underground.
- Wambo Open Cut at the Wambo Mine located further afield to the south-southeast of the Maxwell Underground.
- Bengalla Mine located further afield to the north of Maxwell Underground and Mt Arthur Mine.
- Mt Pleasant Operations located further afield to the north of Maxwell Underground and Bengalla Mine.
- Mangoola Mine located further afield to the north-west of Maxwell Underground.

There is also a current application for Development Consent for the United Open Cut at the United Collieries (SSD-7142) located further afield to the south-southeast of the Maxwell Underground.

Underground operations for the Mount Arthur Underground Project located to the north of the Maxwell Underground were approved in 2008 for a mining rate of up to 8 million tonnes per annum (Mtpa). The approved project comprises longwall mining operations from five coal seams with transport of ROM coal by conveyor, but no underground mining is currently taking place.

In addition, Spur Hill Management Pty Ltd, a subsidiary of Malabar, made an application for a Gateway Certificate for the Spur Hill Underground Coking Coal Project in December 2013 and is located to the west of the Maxwell Underground. Malabar is continuing to undertake work to enhance the geological understanding of the zone where EL 5460 meets the Spur Hill EL 7429. This improved understanding would be used to optimise the development plans for the Spur Hill Underground Coking Coal Project in the future. At this stage, it is not anticipated that the Spur Hill Underground Coking Coal Project would proceed as proposed in the previous documentation.

2 REGULATORY FRAMEWORK

This section provides a summary of the NSW and Commonwealth groundwater related legislation, policies, licences and guidelines relevant to the Project.

The approach to the Gateway process is also outlined below.

2.1 NSW WATER REGULATION

2.1.1 WATER MANAGEMENT ACT 2000

The primary objective of Water Management Act 2000 is for the sustainable management and use of NSW's water resources, balancing environmental, social and economic considerations.

Water Sharing Plans (WSPs) have been developed which establish rules for sharing and trading both groundwater and surface water between competing needs and users.

With respect to water management, the following WSPs under the Water Management Act 2000 are relevant to the Project area and surrounds. Figure 6 provides a map of the Project in relation to the areas covered by the relevant WSPs and associated Water Sources and Management Zones.

Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016

- Of specific relevance to the Project area are the Sydney Basin – North Coast Groundwater Source (within which the Maxwell Underground Mining Area is wholly located) and the New England Fold Belt Coast Groundwater Source (to the north-east).
- There are no 'high priority' groundwater dependent ecosystems (GDEs) listed in the WSP within 20 km of the Project. At the time of writing the nearest high priority GDE listed in the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (version current for 1 July 2016) to the Project area is Parnell Spring in the Wollemi National Park, 25 km to the south-southeast.

Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009

- In relation to unregulated surface water, the Project is located within the Jerrys Water Source. A portion of the Maxwell Infrastructure area (including CHPP) is located within Muswellbrook Water Source.
- In relation to alluvial water sources, the unconsolidated alluvial sediments associated with Saddlers Creek are located within the Jerrys Management Zone of the Jerrys Water Source to the north and west of the Project area. The Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) is located to the south of the Project area.

- There are no ‘high priority’ GDEs listed in the WSP in the vicinity of the Project. At the time of writing the nearest ‘high priority’ GDE listed in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018) to the Project area is Wappinguy Spring, near Merriwa, more than 50 km to the north-west (**Figure 7**).

Water Sharing Plan for the Hunter Regulated River Water Source 2016

- Management Zone 1B (Hunter River from Goulburn River Junction to Glennies Creek Junction) of the Hunter River is located to the south of the Project area.

2.1.2 NSW AQUIFER INTERFERENCE POLICY

The NSW Aquifer Interference (AI) Policy is designed to provide a framework for the assessment of impacts of the taking of water under a proposed development, such as the Project. The AI Policy divides groundwater sources into “highly productive” and “less productive” categories based on salinity and aquifer yield as shown in **Table 1**.

Table 1 NSW Aquifer Interference Policy – Salinity and Aquifer Yield Criteria

Criteria		Salinity (Total Dissolved Solids)	
		Less than 1,500 mg/L	**More than 1,500 mg/L**
Aquifer Yield	**More than 5 L/s**	**Highly Productive**	Less Productive
	Less than 5 L/s	Less Productive	Less Productive

The water sources identified by the WSP that are directly relevant to the Project are (**Figure 6**):

- the ‘highly productive’ alluvial sediments associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone);
- the ‘less productive’ unconsolidated alluvial sediments associated with Saddlers Creek within the Jerrys Management Zone of the Jerrys Water Source; and
- the ‘less productive’ Permian porous rock groundwater sources within the Sydney Basin – North Coast Groundwater Source.

It is noted that the average alluvial groundwater total dissolved solids (TDS) in the Saddlers Creek alluvial sediments (**Section 3.6**) is greater than the 1,500 mg/L criteria in the AI Policy, therefore on the TDS data alone is considered a ‘less productive’ groundwater source. Further, results recorded during a previous bore census suggest the long-term yield from the bores/wells in the Saddlers Creek alluvium is less than 5 L/s (AGE 2015).

The AI Policy also specifies minimal impact considerations for both ‘highly productive’ and ‘less productive’ aquifers; these comprise thresholds for watertable and groundwater pressure drawdown, and changes in groundwater and surface water quality.

Different minimal impact considerations are specified for 'highly productive' and 'less productive' groundwater for:

- water supply works;
- listed GDEs; and
- culturally significant sites.

2.1.3 GROUNDWATER QUALITY PROTECTION POLICY

The NSW State Groundwater Quality Protection Policy (Department of Land and Water Conservation [DLWC] 1998) states that the objectives of the policy will be achieved by applying the following management principles:

1. All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.
2. Town water supplies should be afforded special protection against contamination.
3. Groundwater pollution should be prevented so that future remediation is not required.
4. For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.
5. A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters.
6. GDEs will be afforded protection.
7. Groundwater quality protection should be integrated with the management of groundwater quantity.
8. The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.
9. Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.

2.1.4 GROUNDWATER QUANTITY MANAGEMENT POLICY

The NSW State Groundwater Quantity Management Policy (DLWC 2002a) states that the objectives of the policy are to:

- achieve the efficient, equitable and sustainable use of the State's groundwater;

- prevent, halt and reverse degradation of the State's groundwater and their dependent ecosystems;
- provide opportunities for development which generate the most cultural, social and economic benefits to the community, region, state and nation, within the context of environmental sustainability; and
- involve the community in the management of groundwater resources.

2.1.5 GROUNDWATER DEPENDENT ECOSYSTEMS POLICY

The NSW State Groundwater Dependent Ecosystems Policy (DLWC 2002b) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

- **Deep Alluvial Groundwater Systems** – occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- **Shallow Alluvial Groundwater Systems** – coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- **Fractured Rock Groundwater Systems** – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and transmit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- **Coastal Sand Bed Groundwater Systems** – significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).
- **Sedimentary Rock Groundwater Systems** – sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

The NSW State Groundwater Dependent Ecosystems Policy (DLWC 2002b) also recognises the four Australian groundwater dependent ecosystem types that can be found in NSW, namely:

- terrestrial vegetation;
- base flows in streams;
- aquifer and cave ecosystems; and
- wetlands.

2.1.6 STRATEGIC REGIONAL LAND USE POLICY

In 2012, the NSW government introduced the Strategic Regional Land Use Policy for the Upper Hunter region of the state, as part of the introduction of the 'Gateway Process' for upfront assessment of the impacts of State Significant mining and coal seam gas proposals on Strategic Agricultural Land. This process is formalised through clause 50A of the NSW *Environmental Planning and Assessment Regulation 2000* and Part 4AA of the Mining SEPP. CICs and regional-scale mapping of BSAL is provided in the Mining SEPP, with a process for site verification of BSAL. BSAL and CIC land mapped near the Project area are presented on **Figure 3**.

The Strategic Regional Land Use Policy Guideline for Gateway Applicants (NSW Government 2013) has been referred to during the preparation of this report.

2.1.7 WATER LICENCES

Water licences currently held by Malabar in each WSP water source are listed in **Table 2.**

Table 2 Water Licences Held by Malabar

Water Sharing Plan	Water Source	Licence	Entitlement
North Coast Fractured and Porous Rock Groundwater Sources 2016	New England Fold Belt Coast Groundwater Source	WAL 41559	Aquifer (985 units)
North Coast Fractured and Porous Rock Groundwater Sources 2016	New England Fold Belt Coast Groundwater Source	WAL 41491 (converted from 20BL111869/ 20BL122620)	Aquifer (402 units)
North Coast Fractured and Porous Rock Groundwater Sources 2016	Sydney Basin – North Coast Groundwater Source	Nil	Nil
Hunter Unregulated and Alluvial Water Sources 2009	Hunter Regulated River Alluvial Water Source	WAL 18196	Aquifer (120 units)
Hunter Unregulated and Alluvial Water Sources 2009	Hunter Regulated River Alluvial Water Source	WAL 18201	Aquifer (5 units)
Hunter Unregulated and Alluvial Water Sources 2009	Jerrys Management Zone of Jerrys Water Source	Nil	Nil
Hunter Unregulated and Alluvial Water Sources 2009	Muswellbrook Water Source	WAL 30212	Aquifer (207 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 1143	Regulated River (General Security) (200 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 1220	Regulated River (General Security) (90 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 770	Regulated River (General Security) (300 units)

Water Sharing Plan	Water Source	Licence	Entitlement
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 771	Regulated River (General Security) (632 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 31439	Regulated River (General Security) (90 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 31440	Regulated River (General Security) (9 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 1066	Regulated River (General Security) (99 units)
Hunter Regulated River Water Source 2016	Hunter Regulated River Source	WAL 769	Regulated River (High Security) (3 units)

2.2 COMMONWEALTH ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999

The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) is the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places — defined in the EPBC Act as matters of national environmental significance, including (but not limited to):

- world heritage properties;
- wetlands of international importance;
- nationally threatened species and ecological communities; and
- a water resource in relation to coal seam gas (CSG) and large coal mining (the water trigger).

Guidelines relating to this last matter of national environmental significance (the water trigger) are available (Commonwealth Department of the Environment [DotE] 2013) which 'assist any person who proposes to take an action which involves a CSG development or a large coal mining development to decide whether the action has or is likely to have a significant impact on a water resource'.

The bilateral agreement under the EPBC Act with the NSW government notes that NSW should seek and consider expert advice from the IESC in relation to coal seam gas or large coal mining developments that are likely to have a significant impact on water resources.

The IESC is a statutory committee of leading scientists that independently advises government regulators on the impacts that coal seam gas and large coal mining development may have on Australia's waters resources.

2.2.1 SIGNIFICANT IMPACT GUIDELINES 1.3: COAL SEAM GAS AND LARGE COAL MINING DEVELOPMENTS – IMPACTS ON WATER RESOURCES (2013)

In December 2013, the DotE released guidelines for proponents of coal seam gas and large coal mining projects to assess the potential for significant impacts on water resources (DotE 2013). The guideline outlines a 'self-assessment' process that assists proponents to identify if their project is likely to have a significant impact on water resources.

Consideration of the aforementioned guidelines are made in **Section 11**.

2.2.2 INFORMATION GUIDELINES FOR PROPONENTS PREPARING COAL SEAM GAS AND LARGE COAL MINING DEVELOPMENT PROPOSALS (2018)

The Information Guidelines (latest release in May 2018) developed by the IESC, outline the information considered necessary to enable the IESC to provide robust scientific advice to government regulators on the water-related impacts of coal seam gas and large coal mining development proposals.

The Information Guidelines have been considered during the preparation of this report, including a summary checklist against the requirements presented in **Appendix A**.

2.3 APPROACH TO THE GATEWAY PROCESS

The Gateway process includes an assessment of potential impacts on water resources by the NSW Minister for Primary Industries and the Commonwealth IESC. The State assessment is focused on the "*minimal impact considerations*" prescribed in NSW's AI Policy (NSW Government 2012) (Section 2.1.2). Assessment of impacts on BSAL must include, amongst other matters, consideration of "*any impacts on highly productive groundwater (within the meaning of the Aquifer Interference Policy)*" (Mining SEPP Clause 17H [4] [iv]).

The minimal impact considerations of the AI Policy are expressed as a number of prescriptive criteria that apply to 'highly productive' groundwater sources, 'less productive' groundwater sources, dependent ecosystems, culturally significant sites, connected water sources (for a stream that is a reliable water supply), and other production bores. Less productive groundwater sources are not the primary focus under the Strategic Regional Land Use Policy Guideline for Gateway Applicants (2013) (i.e. consistent with the BSAL criteria). The AI Policy requires estimation of "*all quantities of water that are likely to be taken from any water source during and following cessation of the activity and all predicted impacts associated with that activity...*". The estimation is to be based on a "*simple modelling platform*" that the Minister determines to be "fit-for-purpose", where the model makes use of the "*available baseline data that has been collected at an appropriate frequency and scale*".

It is clear from the AI Policy that a risk management approach should be adopted. The level of effort in the assessment should be proportional to the likelihood of impacts and the potential consequences of those impacts.

However, some of the other reasons why the groundwater assessment for the Gateway process is only intended to be preliminary include:

- The assessment would not have the benefit of information usually provided by associated disciplines (especially surface water hydrology, geochemistry and ecology studies); although in this case, baseline datasets are available in EL 5460.
- Often the available data for hydrogeological conceptualisation and model calibration would be limited; although in this case there is an extensive dataset available for EL 5460.
- There is a limited 90-day period for assessment by the Gateway Panel, who must obtain the advice of the NSW Minister for Primary Industries and the IESC within that period; although in this case the Gateway Panel, NSW Minister for Primary Industries and IESC have assessed and advised on previously proposed open cut mining activities pertaining to EL 5460.
- There is to be no public consultation or exhibition for comment of submitted documents.

In combination with the above reasons, it is concluded that it would be time and cost prohibitive to offer the same level of detail and effort that is normally expended in an Environmental Impact Statement (EIS); therefore, an appropriate level of groundwater modelling and assessment has been applied for the Gateway process.

This assessment relies on numerical modelling (**Section 4**) to assess potential risks of mine development in terms of the AI Policy and Gateway process requirements.

Focus is placed on assessment of the baseflow/leakage interactions with the Hunter River, and associated 'highly productive' alluvium, and Saddlers Creek and associated 'less productive' unconsolidated alluvial sediments, with quantification of likely mine inflow to the Maxwell Underground, groundwater heads generally and drawdowns at registered bores in accordance with the AI Policy. The groundwater takes from each designated Water Source in the relevant WSPs are quantified and interpreted in terms of licensing requirements. Gateway process requirements are listed and cross-referenced in **Table 3.**

Table 3 Gateway Process Requirements

REQUIREMENT	SECTION REFERENCE
Estimates of all quantities of water that are likely to be taken from any water source on an annual basis during and following cessation of the activity.	**Section 8**
A strategy for obtaining appropriate water licence/s for maximum predicted annual take.	**Section 8**
Establishment of baseline groundwater conditions including groundwater depth, quality and flow based on sampling of all existing bores in the area potentially affected by the activity, any existing monitoring bores and any new monitoring bores that may be required under an authorisation under the Mining Act 1992 or the Petroleum (Onshore) Act 1991.	**Sections 3, 6 & 10.4**
A strategy for complying with any water access rules applying to relevant categories of water access licences, as specified in relevant water sharing plans.	**Section 8**
Estimates of potential water quality, level, or pressure drawdown impacts on nearby water users who are exercising their right to take water under a basic landholder right.	**Section 6**
Estimates of potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources.	**Section 6.6**
Estimates of potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems.	**Section 6.2**
Estimates of potential for increased saline or contaminated water inflows to aquifers and highly connected river systems.	**Section 6.7**
Estimates of the potential to cause or enhance hydraulic connection between aquifers.	**Sections 4.6, 5.1.6, & 6**
Estimates of the potential for river bank instability, or high wall instability or failure to occur.	Not Applicable
Outline of the method for disposing of extracted water (in the case of coal seam gas activities).	Not Applicable
Assess the project against the criteria specified in 'Table 1 – Minimal Impact Considerations for Aquifer Interference Activities' in the Aquifer Interference Policy.	**Section 6.9**

Source: NSW Government (2013).

Groundwater modelling has been conducted cognisant of the standards documented in:

- Murray-Darling Basin Committee (MDBC) Groundwater Flow Modelling Guideline (MDBC, 2001); and
- Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012).

For the purposes of this Preliminary Groundwater Assessment, the *Principle of Superposition* has been applied to estimate cumulative effects from nearby mining operations (see **Section 6.5**). This principle is a simple concept that states that the solutions to individual parts of a problem can be added to solve composite problems (Reilly *et al*. 1984). Hence, rather than include nearby mines in what would become a much larger and complex model, model results from other mines (e.g. drawdown at a specific location) can be added to the drawdown at that location estimated as the result of the effects from the Project model. That is, the complex result (total drawdown from all nearby systems) can be estimated from the summation of any 'contributing' results (drawdown) from separate systems. This approach is consistent with the expectation of a "simple modelling platform" for an Application for a Gateway Certificate.

Detailed simulation of cumulative effects from nearby mines would be conducted for the EIS groundwater assessment.

3 HYDROGEOLOGICAL SETTING AND CONCEPTUALISATION

This section provides a summary of the Project area hydrogeology and the conceptual hydrogeological model adopted by HydroSimulations.

The general setting of the Project and model areas is shown in **Figure 8**.

3.1 TOPOGRAPHY

The Project area and surrounds generally undulate between approximately 100-200 metres (m) Australian Height Datum (AHD) along the major drainage lines and rises up to a maximum of about 600 mAHD on hills and ridges (**Figure 8**, **Figure 9**). Topography is more elevated and variable (more sharply incised) to the south and south west of the Project area, with most of the Project area below about 300 mAHD.

3.2 RAINFALL

Rainfall (P) data were obtained for 12 Australian Bureau of Meteorology (BoM) weather stations surrounding the Project. The median annual rainfall at each station, as calculated by the BoM, has been used to develop a contour plot of rainfall in the regional area. These stations have a minimum period of record of 45 years, averaging 87 years per station. **Table 4** lists station information. Average annual rainfall contours are shown in **Figure 9.**

Annual rainfall ranges from more than 680 millimetres (mm) at higher elevations in the southwest of the model area, to less than 570 mm in the Saddlers Creek catchment valley, near the northern boundary of EL 5460. Rainfall is topographically controlled, but the variation is small compared to the change in elevation. At EL 5460 the average annual rainfall is about 570 mm at the northern boundary, increasing to about 610 mm in the south. The closest station to EL 5460 is 061018 (Muswellbrook, Edderton) but it has a considerably shorter period of record (74 years), than the one used for analysis (061016, Denman, Palace Street), with 131 years of data coverage.

A rainfall station was installed to the west of the Project by Malabar for the Spur Hill Mine (site ‘SHM’, **Figure 9**) in 2012. The gauge reads hourly rainfall and other weather parameters; however, its period of record is too short for statistical analysis. A comparison of median rainfall for the SHM site and BoM 061016 (**Figure 10**) shows a similar temporal pattern, but the values differ from the long-term medians for BoM 061016, mostly lower except for November. Inspection of the data indicates quite high rainfall periods in late 2014/ early 2015 at the BoM 061016 site, in line with the high November SHM values, while the longer 061016 data set reduces the effect of single values.

Other weather stations were installed for the Drayton Mine: WS09 (1989) and WS12 (1981), (**Figure 9**). WS09 has some erroneous data which needs resolution. WS12 has useful data for the period 1981 to at least 2015. The median monthly rainfall for WS12 has been included on **Figure 10** and shows a good relationship to the BoM data (‘Denman’, 061016). However, due to the uncertainly of precise locations and station data, and the comparative brevity of record, the BoM site is preferred for analysis. Subject to improved data and station information, these sites should provide additional local baseline data for the EIS.

The cumulative departure from mean (CDM or Residual Mass) rainfall trend for Denman is presented in **Figure 11**. These data show that the long-term trend in rainfall in the upper Hunter Valley comprises a long period of lower than average rainfall between 1900 and 1946, followed by a period of average to moderately higher than average rainfall. The period from 2012 to 2018 indicates about average then declining values, which agrees with the SHM data (2012 to 2018) being lower than the long-term medians.

Table 4 Median Annual rainfall at 12 BoM Stations in the Regional Area and the SHM Site

Station		Location		Elevation	Annual rainfall (P) (mm)	
Name	BoM ID.	Easting MGA	Northing MGA	mAHD	Average	Median
Aberdeen (Main Road)	61000	301114	6439270	183	601.4	603.5
Denman (Palace St)[1]	61016	282576	6414151	105	596.2	606.7
Muswellbrook (Edderton)	61018	296216	6413161	168	566.6	566
Muswellbrook (Lower Hill)	61053	300747	6428659	143	620.4	611.4
Aberdeen (Rossgole)	61065	285747	6441764	543	741.8	734
Jerrys Plains Post Office	61086	303577	6402525	87	644.5	644.2
Doyles Creek (Wood Park)	61130	293037	6400749	113	647.6	659.6
Muswellbrook (Lindisfarne)	61168	288671	6422468	160	596.2	608
Muswellbrook (Spring Creek Castle Vale)	61192	286663	6434129	259	660.3	665.1
Baerami Creek (Bronwyn Park)	61204	360356	6397323	205	683.7	698.1
Sandy Hollow (Goulburn Drive)	61235	270765	6419791	137	617.3	609.9
Gungal (Merryfields)	61324	265685	6429682	182	636.9	648.8
SHM	NA	285726	6415925	NA	532	NA

[1] Data is from 01-01-1889 to end 31-12-2017 from SILO (State of Queensland 2018) and may differ slightly from BoM statistics.

3.3 EVAPORATION

The closest climate stations within 100 km of the Project area with reasonable amounts of pan evaporation data are Scone SCS (Station 61089, about 35 km to the northeast, elevation 216 mAHD, with 17½ years of data between 1970 and 2018[1]) and Lostock Dam (Station 61288, about 65 km to the east, elevation 200 mAHD, also with 17.5 years of data between 1970 and 2018[1]).

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[1] While the stations opened in 1873 (Scone) and 1889 (Denman, Lostock), evaporation pans were not installed until 1970.

Table 5 lists the median rainfall (1873/1889 to 2018) and monthly pan evaporation (1970 to 2018) for the sites. While the periods of record are different, the temporal variability of the rainfall will be much greater than that of pan evaporation, and so a longer record is beneficial.

Both rainfall and evaporation follow a simple sinusoidal trend which is a maximum in January and December, with virtually no lag between trends. A rainfall deficit occurs for all months of the year (for median rainfall), for all evaporation station data.

Table 5 Median Pan Evaporation and Rainfall

Month	Median monthly rainfall (mm)			Median Monthly Pan Evaporation (mm)		
	Denman, Stn. 061016	Scone, Stn. 061089	Lostock Dam, Stn. 61288	Denman	Scone	Lostock
January	62.1	62.8	100.3	217	213	185
February	47.0	46.9	97.8	167	171	149
March	36.5	48.1	95.8	147	148	122
April	30.9	31.5	65.6	104	98	90
May	26.8	26.1	48.6	70	65	69
June	31.9	34.2	53.0	53	49	64
July	29.2	33.0	45.6	62	60	76
August	27.2	32.8	35.8	87	86	102
September	32.0	31.2	40.3	114	113	135
October	43.7	44.2	59.4	157	152	159
November	50.4	51.0	77.5	180	181	168
December	57.2	58.5	93.6	213	216	195

Pan evaporation is about three times greater than rainfall during the summer months and about two times greater during the winter months at Denman and Scone, indicating a semi-arid climate. This effect is less pronounced at Lostock, which is some 60 m higher than the other sites, with almost double the rainfall.

The annual average Areal Actual Evapotranspiration shown on BoM mapping is approximately 650 mm at the Maxwell Underground area. The BoM defines Areal Actual Evapotranspiration as that evapotranspiration that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average.

The CSIRO performed a short-term study to demonstrate and test innovative evaporation monitoring equipment at the former Drayton Mine from November 2016 to January 2017 (inclusive), using an open water (pit lake) site which relates to an evaporation pan (McJannet *et al.* 2017). The reported average daily evaporation, 7.98 mm, is higher than the long term daily average for Denman (BoM 061016) of 4.4 mm, but within the Denman range of 0.2 to 16 mm/ day.

While short term results would be expected to differ from long term averages, the authors noted that the evaporation rates were 'very high', reflecting:

- The timing of the trial in the summer months.
- Strong winds at the location (40% higher than at a nearby weather station).
- Heat from spontaneous combustion occurring around the pit lake.

The CSIRO results do not, therefore, depart from those expected from long term BoM data.

3.4 SURFACE DRAINAGE

The Maxwell Underground area is located within the Saddlers Creek and (to a lesser extent) Saltwater Creek surface catchments. The surface areas are drained by Saddlers Creek and its tributaries to the west and Saltwater Creek and its tributaries to the east. Both creeks drain toward the Hunter River in the south. Two minor gullies within the Project area also drain directly to the Hunter River in the south.

The Maxwell Infrastructure area is located within the Ramrod Creek catchment in the north, with a small proportion within the Bayswater Creek catchment to the east (however runoff from mined areas no longer drains offsite).

3.4.1 HUNTER RIVER

The Hunter River is located to the south of the proposed mining area. The thalweg (i.e. centreline) of the river channel is 525 m south of its closest point to EL 5460 (**Figure 9**). The Hunter River at Liddell, downstream of the Project, has an estimated catchment area of 13,400 km^2. The Hunter River is a regulated river supplying water from Glenbawn Dam to a range of industrial and agricultural users as well as town water supplies (WRM Water & Environment Pty Ltd 2015).

The nearest stream flow gauging stations to the site are listed in **Table 6**, with locations shown in **Figure 9**. Stream flow statistics (20-year period from 1993 to 2013) for the Hunter River gauges are presented in **Figure 12**. This shows that flows are broadly similar between Muswellbrook and Denman, but are generally lower at lower flows (and higher at higher flows) downstream at Liddell.

The flow-duration relationship at Liddell indicates that flow is non-zero all of the time, which is characteristic of regulated river systems (WRM Water and Environment Pty Ltd 2015).

Areas prone to flooding along the Hunter River in the vicinity of EL 5460 have been assessed previously by WRM Water and Environment Pty Ltd (2015), based on a flood study of the Hunter River developed by Muswellbrook Shire Council.

The Maxwell Underground is beyond areas prone to flooding along the Hunter River.

Table 6 Stream Flow Gauging Stations – Hunter River and Saddlers Creek

Gauge Number	210002	210055	210083	210031	210043	210151
Gauge Name	Hunter River at Muswellbrook Bridge	Hunter River at Denman	Hunter River at Liddell	Goulburn River at Sandy Hollow	Saddlers Creek at Bowfield	Hunter River DS Saddlers
Catchment Area (km^2)	4,220	4,530	13,400	6,810	78	NA
Easting (MGA)	301170	284705	304905	271713	292813	290670
Northing (MGA)	6429172	6415039	6403439	6418714	6410996	6405964
Average Flow (ML/day)	818	677	1,132	476	3.4	69
Period of record	1907-2017	1959-2017	1969-2017	1954-2017	1956-1982	2015-2016
Zero-gauge elevation (mAHD)	136.24	102	60.96	113.45	26.11	79.64

3.4.2 SADDLERS CREEK

Saddlers Creek is a small, ephemeral tributary that runs along the western edge of CL 229, continues through the north-west of EL 5460 and joins the Hunter River near the southwestern corner of EL 5460.

Saddlers Creek has been truncated in its upper reaches by previous open cut mining activities in CL 229. Prior to commencement of mining in the area, Saddlers Creek had a catchment of about 97.1 km^2. Approximately 15% of the pre-mining catchment no longer drains to Saddlers Creek (WRM Water and Environment Pty Ltd 2015).

The creek has a generally well-defined channel that has a thick covering of long grass across a broad base. There are several pools on the base that would hold water of a period following rainfall (WRM Water and Environment Pty Ltd 2015).

Several minor gullies drain into Saddlers Creek across the Maxwell Underground area.

The (current) Department of Industry (DoI)-Water[2] operated a monitoring site noted in **Table 6** above, Site No. 210043, which provided data from 1956 to 1982. As baseline information for the period of record, **Figure 13** shows the Discharge Rate Duration Curve and **Figure 14** shows the low flow frequency analysis prepared by the then NSW Office of Water (NOW).

Natural water quality fluctuations are evident by long-term datasets available from the adjacent Mt Arthur Mine (surface monitoring sites SW02, SW03 and SW04 shown on **Figure 9**), which is shown in **Figure 17.**

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[2] Formerly NSW Office of Water (NOW)

The figure shows Electrical Conductivity (EC, µS/cm) and monthly rainfall values for the period from 1998 to 2015. The EC values are generally high (irrigation and saline beneficial use category, greater than 1,500 mg/L TDS, see **Table 7**), and reduces by dilution after rainfall events such as in November 2011.

A description of available alluvial (shallow) groundwater level data is provided in **Section 3.6**. Re-establishment of the Saddlers Creek Gauging Station for the ongoing monitoring of flows is discussed further in **Section 10.5**.

It is noted that the Northern Sydney Basin Bioregional Assessment for the Hunter subregion (Herron et al. 2018) notes that Saddlers Creek is naturally saline, and that as groundwater is typically more saline than surface runoff, any potential reductions in baseflow (i.e. groundwater inputs) could decrease stream salinity.

Table 7 Quality Guidelines for Groundwater Resources in NSW (MDBC 2005)

Beneficial Use	Salinity, EC (µS/cm)	Description
Potable	Up to 800 µS/cm (~500 mg/L TDS)	Suitable for all drinking water and uses
Marginal Potable	800-2,350 µS/cm (~500-1,500 mg/L TDS)	At the upper level, this water is at the limit of potable water, but is suitable for the watering of livestock, irrigation and other general uses
Irrigation	2,350-7,800 µS/cm (~1,500 mg/L - 5,000 mg/L TDS)	At the upper level, the water requires shandying for use as irrigation water, or to be suitable for selective irrigation and watering of livestock
Saline	7,800-22,000 µS/cm (~5,000 mg/L - 14,000 mg/L TDS)	Generally unsuitable for most uses. It may be suitable for a diminishing range of salt-tolerant livestock up to about 10,500µS/cm (~6,500 mg/L TDS) and some industrial uses
Highly Saline	>22,000 µS/cm (~14,000 mg/L TDS)	Suitable for coarse industrial processes up to about 31,000 µS/cm (~20,000 mg/L TDS)

Flood modelling of Saddlers Creek has been previously undertaken by WRM Water and Environment Pty Ltd (2015). Comparisons with the estimated design flood levels under pre-mining conditions show that the Maxwell Underground mine entry area is beyond the probable maximum flood (PMF) extent.

3.4.3 SALTWATER CREEK

Saltwater Creek runs to the east of EL 5460 through (and downstream of) the Plashett Reservoir. Plashett Reservoir is a 65,000 ML storage that captures approximately 77% of the Saltwater Creek catchment and is integral to the operations at AGL's Bayswater Power Station (WRM Water and Environment Pty Ltd 2015).

Minor gullies drain the Maxwell Underground area to the south-east toward Saltwater Creek downstream of the Plashett Reservoir.

3.4.4 RAMROD CREEK

To the north of the Maxwell Infrastructure area, four minor gullies drain to the Ramrod Creek catchment. Ramrod Creek drains into the Hunter River immediately downstream of Muswellbrook.

The pre-mining upper reaches of Ramrod Creek have been truncated at the CL 229 boundary.

Recorded runoff quality in Ramrod Creek (Site 2221) has a median EC of 2,200 μS/cm (WRM Water and Environment Pty Ltd 2015).

3.5 GEOLOGY

The site is located in the Hunter Coalfield of NSW, a region of the Sydney Basin. The geology comprises interbedded sandstones, siltstones, and coal seams of the Wittingham Coal Measures and Newcastle Coal Measures. The surface geology is shown in **Figure 18** and a stratigraphy schematic is shown in **Figure 20**. The Wittingham Coal Measures in this area are overlain by what were once known as the Wollombi Coal Measures but which are now classified as the Newcastle Coal Measures. Sill and dyke intrusions have been identified from surface mapping, explorative drilling and aerial geophysical surveys.

Apart from the coal measures, extensive tracts of alluvium are present over most of the Hunter River channel reaches in the region. The alluvium consists of fine-grained unconsolidated sediments overlying medium to coarse gravels at the base. Alluvial thickness may reach up to 30 m or more, near the river channel (Environment and Natural Resource Solutions, 2012; Groundwater Imaging, 2012; Coffey, 2013).

The major regional structure in the Upper Hunter Valley is the Muswellbrook Anticline, trending generally north-south, just east of the town of Muswellbrook. In the axial region, the lowest Permian coal measures, the Greta Coal Measures, are exposed, and have been mined extensively at the former Drayton Mine. The Wittingham Coal Measures dip generally to the west or south-west on the western limb of the Muswellbrook Anticline.

A south plunging structure, the Calool Syncline is evident in EL 5460. The Denman Anticline is an anticlinal feature that exists in the south-eastern part of Spur Hill EL 7429. Regional faulting is predominantly northwest-southeast, but local faults strike east-west in the Mt Arthur North mine area.

The regional geological map shows the inferred location of a north-south trending geological structure, known as the Mt Ogilvie fault or structure (see **Figure 18**) Within the southern part of Spur Hill EL 7429, based on analysis of seismic data along with the difference in seam levels between drill holes to the east and west of this mapped structure, is a steeper westerly dip on the western limb of the Denman Anticline, rather than a significant contiguous north-south fault (McElroy Bryan Geological Services Pty Ltd (MBGS) and Geophysical Resources and Services (GRS) 2014).

Proposed mining operations are to target the Whynot Seam; Woodlands Hill Seam; Arrowfield Seam; and Bowfield Seam. These seams occur towards the top of the Jerrys Plains Subgroup in the Wittingham Coal Measures. Mackie (2003) described EL 5460 as being 'dominated by hardrock coal measures with minor colluvial and alluvial deposits along Saddlers and Saltwater Creeks.'

Extensive geological exploration has been undertaken by in the Project area (several hundred drill holes plus seismic and magnetic testing) to help define geological features such as seam floor/overburden thicknesses across the lease (**Figure 19**).

3.6 GROUNDWATER MONITORING NETWORK AND RELATED DATA

3.6.1 GROUNDWATER LEVELS AND PRESSURES

There is an extensive network of groundwater monitoring (government and mine-owned) and supply bores near the Project area. Groundwater monitoring at Malabar's Maxwell Infrastructure, Maxwell Underground and neighbouring Spur Hill Underground Coking Coal Project areas are outlined in the following subsections.

Excluding bores on land owned by Malabar, there are 147 registered bores within 10 km of the Gateway Application Area. Monitoring bore locations and registered landholder bores are shown on **Figure 22**.

The listed purpose of these bores is distributed as follows:

- Domestic/stock – 44 bores
- Irrigation – 25 bores
- Bores used for municipal water supply – 1 bore
- Industrial or dewatering bores (including mining purposes) – 4 bores
- Monitoring or test bores – 54 bores
- Bores with no listed purpose – 19 bores.

The bores used for irrigation typically have completed depths ranging from approximately 7 to 20 metres. **Appendix B** provides details of the registered bores within 10 km, excluding monitoring bores.

Figure 24 shows a map of baseline water table data derived from the abovementioned bores.

Maxwell Infrastructure

Malabar undertakes groundwater monitoring at the Maxwell Infrastructure in accordance with its approved Water Management Plan.

A number of bores have been destroyed over time as a result of mining activities. The groundwater monitoring network covering the Maxwell Infrastructure currently consists of 15 bores. Long-term data are available from all of these bores, with some bores providing data in excess of 30 years. **Table 8** provides a summary of the bore coordinates, depth, and monitoring period. Seven bores were installed in 1982, two were installed in 2000, and six were installed in 2005. All of the monitoring bores located at the Maxwell Infrastructure target the Permian coal measures.

Table 8 Monitoring Bore Construction Summary – Maxwell Infrastructure

Bore name	Easting (MGA94, z56)	Northing (MGA94, z56)	Ground Level (mAHD)	Total Depth (mbgl)	Data Range
F1024	305761	6419755	236.70	236	1982 - ongoing
F1162	304256	6420755	228.20	274	1982 - ongoing
F1163	301045	6415695	194.70	384	1982 - ongoing
F1164	304223	6420406	220.80	191	1982 - ongoing
F1167	305124	6421790	230.50	314	1982 - ongoing
F1168	305235	6420774	212.90	189	1982 - ongoing
R4171A	304821	6419129	229.62	138	2000 - ongoing
R4171B	304821	6419128	229.62	138	2000 - ongoing
R4214	304606	6416180	257.89	136	2005 - ongoing
R4220	304968	6416196	228.42	119	2005 - ongoing
R4224	305473	6416199	202.98	133	2005 - ongoing
R4241	305853	6416205	195.98	150	2005 - ongoing
R4243	304231	6416180	290.41	142	2005 - ongoing
R4258	304364	6420217	225.10	176	2005 - ongoing
W1102	300984	6416044	186.70	23	1982 - ongoing

Note: mbgl = metres below ground level

Maxwell Underground

Groundwater monitoring was first installed in the EL 5460 area in 1998. The monitoring network was progressively expanded and included 23 monitoring bores and seven vibrating wire piezometers (VWPs) including:

- six monitoring bores installed in 1998;
- eight bores installed between 2000 and 2003;
- two VWPs installed in 2010; and
- nine monitoring bores and five VWPs installed in 2011.

Tables 9 and **10** provide a summary of the network coordinates, depth, and monitoring period. Monitoring bores installed in the 1990s and early 2000s targeted the Permian coal measures, with the majority of these bores located within the footprint of the proposed mining areas. These bores would be removed progressively by mining.

The early network was augmented in 2011 by the addition of four sites (which have clustered bores) along the alignments of Saddlers Creek and the Hunter River. All of the VWPs target the Permian coal measures, and all but one of them are located between the coal deposit and the Hunter River.

The early network of monitoring bores (i.e. 1982 to 2003) was installed in exploration holes drilled into the Permian coal measures. Geological logs are available for the exploration drill holes, however no records of construction or screen intervals are available.

Table 9 Monitoring Bore Construction Summary – Maxwell Underground

Bore name	Easting (MGA94, z56)	Northing (MGA94, z56)	Ground level (mAHD)	Total depth (mbgl)	Monitoring bore screen interval (mbgl)	Start of Monitoring
DD1004	299798	6410922	217.38	105.74	-	Oct 1998
DD1005	298799	6410901	225.02	138.55	-	Oct 1998
DD1014	296799	6410864	183.4	90.48	-	Sep 1998
DD1015	298815	6409900	212.65	162.5	-	Oct 1998
DD1016	297801	6410882	201.15	126.4	-	Oct 1998
DD1025	298764	6411901	169.81	44.62	-	Aug 1998
DD1027	301133	6410960	235.82	252.75	-	July 2000
DD1030	301754	6408961	160.08	282.48	-	July 2000
DD1032	297143	6412495	140.25	276.46	-	July 2001
DD1041 - Deep	296202	6409476	187.32	387.32	-	July 2001
DD1041 - Shallow				-		
DD1043	295200	6409458	173.78	203	182-203	Apr 2003
DD1052	296274	6408513	183.12	127	105-127	Apr 2003
DD1057	295181	6410458	146.93	188	164-188	Apr 2003
MB1 -Alluvial	297933	6407459	81.01	11	8-11	Aug 2011
MB1 - Whybrow	297928	6407448	80.84	30	25-28	Aug 2011
DD1004	297930	6407453	80.89	60	51-57	Aug 2011
DD1005	294998	6411669	115.34	7	5-7	Aug 2011
DD1004	295004	6411675	115.43	30	20-29	Aug 2011
DD1005	297269	6412850	132.72	16	8.5-14.5	Aug 2011
DD1014	297328	6412729	137.34	30	27-30	Aug 2011
DD1015	300302	6406234	81.43	20	10-18	Aug 2011
DD1016	300307	6406231	81.34	60	42-47	Aug 2011

Table 10 VWP Construction Summary – Maxwell Underground

Bore name	Easting (MGA94, z56)	Northing (MGA94, z56)	Ground level (mAHD)	Total depth (mbgl)	Sensor positions (mbgl)	Start of Monitoring
RD1189 (SD1_DD001)	299896.4	6412419	208.63	322	Woodlands Hill Seam - 78.9 mbgl ZZBF Seam - 145.5 mbgl Warkworth Seam - 186.2 mbgl Mt Arthur Seam - 230 mbgl Piercefield Seam - 255.5 mbgl Bayswater Seam - 315 mbgl Wynn Seam - 322 mbgl	2010
RD1192 (RBR2)	296091.8	6409038	177.06	148.5	Wambo Seam - 61.2 mbgl Redbank Seam - 80 mbgl Blakefield Seam - 148.5 mbgl	2010
BLK6R12 (RD1220)	293653.1	6409558	186.25	135	Whybrow Seam - 25 mbgl Redbank Seam - 40.5 mbgl Whynot Seam - 86.5 mbgl Blakefield Seam - 113.7 mbgl	August 2011
VWP1 (RD1221) (RDW006A)	297925.7	6407444	80.96	155	Interburden - 21 mbgl Interburden - 40 mbgl Interburden - 73 mbgl Whybrow Seam - 87 mbgl Whynot Seam - 109.2 mbgl Blakefield Seam - 138 mbgl	August 2011
RBD1 (VWP) (DD1170)	295178.4	6409246	169.55	111.29	Whybrow Seam - 24.65 mbgl Redbank Seam - 33.55 mbgl Whynot Seam - 79.5 mbgl Blakefield Seam - 103.3 mbgl	April 2011
WND16 (VWP) (DD1188)	298121.5	6408842	130.58	126.16	Wambo Seam - 33.75 mbgl Whynot Seam - 59.25 mbgl Blakefield Seam - 90.15 mbgl Blakefield Seam - 110.5 mbgl	May 2011
WND26 (VWP) (DD1187)	299486.6	6409044	163.71	152	Whybrow Seam - 77.3 mbgl Redbank Seam - 84.6 mbgl Wambo Seam - 123.45 mbgl Whynot Seam - 144.25 mbgl	May 2011

Spur Hill Underground Coking Coal Project [EL 7429]

Groundwater monitoring to support exploration and environmental assessment activities for EL 7429 commenced in 2012. The monitoring network has been progressively expanded and now includes seven standpipe monitoring bores and five VWPs.

Tables 11 and **12** provide a summary of the network coordinates, screen interval, and monitoring period.

Table 11 Monitoring Bore Construction Summary – EL 7429

Bore name	Easting (MGA94, z56)	Northing (MGA94, z56)	Monitoring bore screen interval (mbgl)	Start of Monitoring
CB1	285517.0	6407737.0	7.4 - 10.4 (Hunter River Alluvium)	August 2012
RB2	286111.0	6416085.0	8 - 11 (Hunter River Alluvium)	August 2012
RB4	286017.0	6416066.0	8 - 11 (Hunter River Alluvium)	August 2012
SHD027	286915.4	6416030.7	214 – 226 (Whynot Seam)	November 2014
SHD028a	289168.9	6408422.8	113 - 119 (Whynot Seam)	November 2014
SHD028b	289172.7	6408420.8	60 - 69 (Redbank Creek Seam)	November 2014
N1	282187.0	6411761.0	8.7 (Hunter River Alluvium)	April 2017

Table 12 VWP Construction Summary – EL 7429

Bore name	Easting (MGA94, z56)	Northing (MGA94, z56)	Sensor positions (mbgl)	Start of monitoring
SHD003	287943.7	6417264.6	Whybrow Seam Overburden - 40 mbgl Whybrow Seam - 88 mbgl Whybrow Seam-Wambo Seam Interburden - 150 mbgl Whynot Seam - 183 mbgl Glen Munro Seam - 250 mbgl Woodlands Hill Seam - 287 mbgl Arrowfield Seam Roof - 330 mbgl Bowfield Seam - 370 mbgl	February 2013
SHD005	286139.4	6415822.0	Whybrow Seam Overburden - 85 mbgl Redbank Creek Seam-Wambo Seam Interburden - 165 mbgl Wambo Seam-Whynot Seam Interburden - 185 mbgl Whynot Seam - 202 mbgl Glen Munro Seam - 262 mbgl Woodlands Hill Seam - 313 mbgl Arrowfield Seam - 358 mbgl Warkworth Seam - 430 mbgl	February 2013
SHD006	288800.0	6408420.0	Whybrow Seam Overburden - 65 mbgl Whybrow Seam-Redbank Creek Seam Interburden - 100 mbgl Whynot Seam - 190 mbgl Glen Munro Seam Interburden - 270 mbgl Woodlands Hill Seam - 327 mbgl Arrowfield Seam - 370 mbgl Warkworth Seam - 418 mbgl	February 2013
SHD010	286873.7	6412265.3	Whybrow Seam Overburden - 50 mbgl Whybrow Seam Overburden - 90 mbgl Redbank Creek Lower Seam - 135 mbgl Whynot Seam-Blakefield Seam Interburden - 212 mbgl Blakefield Seam - 225 mbgl Glen Munro Seam - 267 mbgl Woodlands Hill Seam - 333 mbgl Igneous Sill (ISG1) - 383 mbgl	February 2013
SHD017	287032.5	6408365.0	Newcastle Coal Measures (WL4) - 175 mbgl Whybrow Seam - 263 mbgl Redbank Creek Upper Seam - 310 mbgl Wambo Seam Roof - 330 mbgl Blakefield Seam - 417 mbgl Warkworth Seam - 584 mbgl	February 2013

Monitoring in the Hunter River alluvium adjacent to EL 7429 commenced in 2012, and VWPs were installed in the Permian coal measures in late 2012 and early 2013. The monitoring program was augmented in November 2014 with the addition of standpipes for the Whynot seam and Redbank Creek seam.

Hunter River Alluvium

The available datasets and discussion of the groundwater-surface water interactions between the Hunter River and associated alluvium is detailed in **Section 3.6.4**.

Saddlers Creek Alluvial Sediments

Baseline groundwater level data are available for monitoring bores installed in the unconsolidated alluvial sediments along Saddlers Creek for the period June 2011 to December 2015 (AGE 2015). The bore locations are shown in **Appendix D, Figure D1,** location details are listed in **Appendix C**, and a subset of groundwater level hydrographs with rainfall CDM figures are shown in **Appendix D.**

The alluvial bores (MB1, MB2, and MB3 'Alluvial') all show stable hydrographs responding to climatic (rainfall) events. A snapshot of MB1 and MB2 alluvial hydrographs is shown in **Figure 15.**

The 'R' and 'F' series bores (**Appendix D**) have a longer time span and show a declining trend since the early 1990s, when mining (at the former Drayton Mine) began to intercept the groundwater table, showing declines of about 12 m and 80 m since 1982 respectively (AGE 2006). **Figure 16** shows a snapshot of R4241 and F1162 hydrographs.

3.6.2 GROUNDWATER QUALITY

Alluvial Aquifers

Hunter River Alluvium

Water quality within the Hunter River alluvial aquifer is known to be variable from fresh to moderately saline, with TDS concentrations ranging from about 400 mg/L to about 4,000 mg/L (AGE, 2012). The pH ranges from 6.9 to about 8.4. Groundwater within the Hunter River alluvium exhibits a higher quality compared with groundwater sourced from the underlying coal measures (AGE 2015).

Saddlers Creek Alluvial Sediments

Groundwater quality from the Saddlers Creek alluvial sediments has recorded TDS concentrations ranging from 5,700 mg/L to 6,100 mg/L (AGE 2012).

Permian Porous Rock Aquifers

Pre-mining groundwater quality data for coal seams was assessed for the Mount Arthur mine (AGE 2015). Results for single samples from boreholes intersecting coal seams are presented in **Table 13**.

Table 13 Pre-mining Water Quality (Mount Arthur Mine)

Date	December 1980	January 1981
pH	8.6	8.1
EC (µS/cm)	8,950	7,005

Other EC data relevant to the study area are summarised in **Figure 25**. These data were sourced from publicly available reports for surrounding mines (MER 2006; MER 2007; AGE 2012; AGE 2013). The data also suggest that groundwater in the Permian coal measures is generally more saline than that in the alluvium. EC data for the Hunter River alluvium reported by Coffey (2013; 4,900-6,490 µS/cm) agree with the ranges shown in **Figure 25**.

Groundwater EC data collected during the bore census for the neighbouring Spur Hill Underground Coking Coal Project (Heritage Computing, 2013) indicated an average Hunter River alluvium EC of 1,187 µS/cm on the floodplain (based on 11 samples), and 4,570 µS/cm on the colluvial slopes (i.e. more distal to the river; based on 3 samples). This suggests that the higher "alluvial" EC data from surrounding mines' reports summarised in **Figure 25** are likely dominated by samples either from smaller streams' alluvial deposits, and/or from the alluvials and/or colluvials located further from the Hunter River than those collected during the bore census for the Spur Hill Underground Coking Coal Project.

Kellett *et al*. (1989) used geochemical analysis to investigate the origins of solutes in groundwater in the Upper Hunter Valley. The study found that the high salinity of groundwater in the Permian porous rock unit is of connate (Permian marine) origin, with further solute input from the oxidation of sulphides in coal seams. They also found that Permian porous rock groundwater discharges up into the Hunter River alluvium, where it mixes with water derived from leakage from the Hunter River, and that the rock-derived salts accumulate in the groundwater sinks (i.e. due to evapotranspiration) around the margins of the Hunter River alluvium.

Kellett *et al*. (1989) also concluded that groundwater discharge up from the Permian porous rock unit (Wittingham Coal Measures) at Alcheringa (west of EL 5460) around the mapped location of the Mt Ogilvie structure and Denman Anticline is strong enough to have over-printed the geochemical signature of the Hunter River as the dominant water source within alluvial groundwater at this location. This suggests that:

- The vertical permeability of the fault is higher than the lateral permeability of the alluvium at this location; and/or
- There is a groundwater sink in the Hunter River alluvium at this location, the likely candidate being evapotranspiration of shallow groundwater. This sink could be generating a build-up of salts derived from Wittingham Coal Measures groundwater discharging upwards into the alluvials via the Mt Ogilvie structure.

Kellett *et al*. (1989) also noted strong upwelling of saline groundwater from the Wittingham Coal Measures at the northern end of the Mt Ogilvie structure (beyond the northern extent of the Project area).

3.6.3 HYDRAULIC PROPERTIES

Hydraulic Conductivity (K)

Previous work undertaken by AGE (2006, 2015), report:

- Leakage from spoil (at the former Drayton Mine) was assumed to be high, with hydraulic conductivity of 1 m/d, effective porosity of 20% and a recharge value of 30 mm (~5% of rainfall).
- Alluvium K: 8.6 m/ day, storage 20%.
- Colluvium and weathered zone K: 0.86 m/ day, storage 1%.
- Overburden K: 0.086 to 0.04 m/ day, storage 0.5%.

Hydraulic testing reported for the Drayton South Coal Project (AGE 2012) indicated ("hydraulic conductivity" reported only, no horizontal hydraulic conductivity (Kx) or vertical hydraulic conductivity (Kz) values for coal or regolith):

- Regolith testing indicated moderate hydraulic conductivity values between 0.1 m/day and 1.2 m/day.
- Low hydraulic conductivities prevailing within the coal measures with a median value less than 4.0×10^{-3} m/day calculated from falling head tests.
- Airlift yields measured during drilling established a median estimate of hydraulic conductivity of 6.0×10^{-3} m/day for the coal measures, which they noted was lower than other 'nearby mine' estimates.
- Permeability tests on core samples yielded a vertical hydraulic conductivity range for the interburden between 8.3×10^{-7} m/day and 3.4×10^{-3} m/day.

Figure 26 and **Figure 27** show model calibrated hydraulic properties from a later Drayton South Coal Project Application (AGE 2015, Kx and Kz; units are m/day, specific yield (Sy) is dimensionless, and the units for Specific Storage (Ss) are /m). Other background data are outlined below.

Field packer and laboratory core data from the Spur Hill Underground Coking Coal Project Preliminary Groundwater Assessment (Heritage Computing 2013), provide a useful lower bound on hydraulic parameters. Horizontal hydraulic conductivity from the investigations (**Figure 26**) ranges from 2×10^{-7} m/day to 1×10^{-3} m/day for the interburden, and from 1×10^{-4} m/day to 0.02 m/day for the coal seams.

Vertical hydraulic conductivity of the rock matrix based on core data (**Figure 27**) ranges from 1×10^{-7} m/day to 3×10^{-5} m/day. Observed horizontal to vertical hydraulic conductivity ratios range from 3 to 56 with a median of 11, defined using the arithmetic mean horizontal conductivity divided by the harmonic mean vertical hydraulic conductivity.

The Mt Ogilvie structure and Denman Anticline are not considered a major hydraulic barrier or conduit to groundwater flow, based on local scale geological modelling (MBGS and GRS 2014).

Dykes present within the coal measures are thought to locally enhance hydraulic conductivity along their upper and lower altered and fractured margins, but this is thought to be limited to a very local scale effect (Heritage Computing 2013). The main dyke rock mass appears to be almost impermeable.

Sills within and surrounding the coal measures will affect the vertical and horizontal conductivities of the system. However, the extent of these features is more refined than the modelled cells, and incorporation into the model has not been attempted in this Preliminary Groundwater Assessment report. The sills would be expected to locally restrict flows, and so their omission would, if anything, make the groundwater model results more conservative.

Specific Yield (Sy)

Specific yield (together with porosity and specific storage) usually decreases with depth. Specific yields for Sydney Basin sedimentary strata in the context of drainage due to longwall subsidence generally vary between 0.005 and 0.01. The Hunter River alluvium is expected to possess a specific yield in the range of 0.05 – 0.2.

Specific Storage (Ss)

The specific storage of Hawkesbury Sandstone in the Blue Mountains west of Sydney has been estimated to be about $1x10^{-6}$ m^{-1} (Kelly et al., 2005) in the upper zones where fracture flow is dominant. Results of long duration pumping tests in Hawkesbury Sandstone in western Sydney (Tammetta and Hawkes, 2009) indicated an average specific storage of $1.5x10E^{-6}$ m^{-1} for depths between ground surface and 300 m.

Summary

The data above are in general agreement with the calibrated hydraulic parameters from the groundwater modelling conducted (AGE 2015) and presented in **Table 14**.

Table 14 Calibrated Hydraulic Parameters from Drayton South (AGE 2015)

Geology	Parameter	Parameter value		
		Min	Mean	Max
Hunter River Alluvium	Kx	7.3×10^{0}	7.8×10^{0}	7.9×10^{0}
	Kz	3.2×10^{-3}	3.3×10^{-3}	3.4×10^{-2}
	Sy	5.0×10^{-2}	5.0×10^{-2}	5.0×10^{-2}
Saddlers Creek Alluvium	Kx	6.8×10^{-1}	7.9×10^{-1}	8.7×10^{-1}
	Kz	2.9×10^{-3}	3.4×10^{-3}	3.8×10^{-3}
	Sy	5.0×10^{-2}	5.0×10^{-2}	5.0×10^{-2}
Regolith	Kx	1.6×10^{-2}	2.4×10^{-2}	2.8×10^{-2}
	Kz	7.0×10^{-5}	1.1×10^{-4}	1.2×10^{-4}
	Sy	5.0×10^{-3}	5.0×10^{-3}	5.0×10^{-3}
Interburden	Kx	2.2×10^{-6}	8.6×10^{-4}	4.4×10^{-3}
	Kz	4.6×10^{-9}	2.8×10^{-5}	2.2×10^{-4}
	Sy	5.0×10^{-4}	5.0×10^{-4}	5.0×10^{-4}
	Ss	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}
Coal Seams	Kx	3.4×10^{-5}	2.4×10^{-2}	4.6×10^{-1}
	Kz	3.5×10^{-8}	2.0×10^{-4}	1.7×10^{-3}
	Sy	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}
	Ss	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}
Basement	Kx	1.0×10^{-7}	1.3×10^{-3}	9.4×10^{-2}
	Kz	2.6×10^{-10}	1.5×10^{-5}	9.4×10^{-4}
	Sy	1.0×10^{-5}	9.0×10^{-5}	1.0×10^{-4}
	Ss	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}

3.6.4 GROUNDWATER-SURFACE WATER INTERACTION – HUNTER RIVER

Figure 28 presents monthly statistics for the Hunter River between Muswellbrook and Liddell (100-year period, 1913 to 2013), conducted on 7-day moving averages to remove travel time effects (Heritage Computing, 2013). This shows that the Hunter River generally loses water along this reach (averaging around 17 ML/day). This analysis has been simplified, given the large number of ungauged tributaries and their larger catchment areas, for which inflows have not been accounted. Regardless, these data suggest that on average, for most of the time, the Hunter River loses large volumes of water to the underlying alluvium along this reach.

Hydrometric analysis of groundwater-surface water interaction was undertaken using groundwater levels in bore GW080077 and Hunter River stage elevations at the Denman gauge (#210055). The location of these sites is shown in **Figure 9**, and the analysis is presented in **Figure 29**. River water levels are consistently 2 m or more above adjacent groundwater levels, indicating a downward potential for river surface water to migrate into the Hunter River alluvium at this location. The comparison of alluvial and Permian rock groundwater EC against Hunter River EC also suggests that the river is the dominant source of water in Hunter River alluvium at this location. This analysis strongly supports the conclusions of other studies (Kellett *et al.*, 1989), and of the reach-scale mass balances outlined above, that the Hunter River is a losing stream to the south of the Project area.

It should be noted that the baseflow analyses of Coffey (2013) provide a qualitative and subjective estimate of baseflow, primarily along the Hunter River upstream of Muswellbrook because most gauged flows, even as far down catchment as Liddell, are primarily derived from this up-catchment area. The analyses shown in **Figure 12** and **Figure 28** discussed above, strongly suggest net losing conditions along the Hunter River between Muswellbrook and Liddell.

3.6.5 RIPARIAN VEGETATION

Riparian vegetation is present along Saddlers Creek and its tributaries. The riparian vegetation present has been highly modified from its original state and typically persists as very narrow and interrupted corridors along the drainage lines (Cumberland Ecology 2015).

Previous assessments by Cumberland Ecology (2015) found that the riparian vegetation types present are unlikely to be completely dependent on groundwater as the canopy trees are likely to draw on surface flows in streams and gullies and shallow soil water before accessing groundwater. The understorey of these communities is similar to the surrounding grassy understorey of non-GDE vegetation and is unlikely to be groundwater-dependent (Cumberland Ecology 2015).

GDEs associated with the Hunter River (including riparian vegetation) are discussed separately in **Section 6.2**.

3.6.6 STYGOFAUNA

Stygofauna are unlikely to occur in the Permian porous rock aquifer due to increasing depth (isolation), low hydraulic conductivity and generally high salinity (Eco Logical 2015). A field program conducted in 2011 across EL 5460 found no stygofauna in 17 Permian bores sampled (Eco Logical 2015).

Unconsolidated alluvial sediments associated with watercourses, such as the Hunter River and Saddlers Creek, provides more conducive habitat for stygofauna. In 2011 and 2018, Eco Logical (2015 and 2018) undertook sampling for stygofauna in the Hunter River alluvium and Saddlers Creek alluvium nearby to the Project. The surveys found (Eco Logical 2015 and 2018):

- Stygofauna present in the Hunter River and Saddlers Creek alluvium, namely;
    - one known stygofauna taxon (Syncarida: Notobathynella sp. crustacean) from the Hunter River alluvium;

  - two likely stygofauna taxa (Cyclopoida: diacyclops and Ostractoda crustaceans) in the Hunter River and Saddlers Creek alluvium; and
  - two potential, but unlikely, stygofauna taxa in the Hunter River (Acarina mite) and Saddlers Creek alluvium (Oligochaete worm).
- None of the known and potential stygofauna taxa are listed as threatened under the EPBC Act or NSW Biodiversity Conservation Act 2016.
- None of the known and potential stygofauna taxa collected are endemic to the study area, as all are widespread along aquifers associated with the Hunter River or associated tributaries.

3.6.7 GEOCHEMISTRY

Overburden and coal seam roof and floor samples from drill core material within EL 5460 have previously been subject to a geochemical test work program (including static and kinetic leach column tests) and geochemical impact assessment completed by RGS (2015). The test work program included sampling of the shallower overburden areas above the Maxwell Underground as deep as the Blakefield seam (and included the Whynot seam which is targeted for mining by the Project). In summation, the geochemical impact assessment relevantly found (RGS 2015):

- Overburden and most coal reject materials are expected to be classified as non-acid forming (NAF), with significant acid neutralising capacity (ANC) and very low oxidisable sulfur content.
- Overall, the risk of potentially significant water quality impacts from overburden and coal reject material is likely to be low.

A targeted geochemical test work program for the deeper strata targeted for underground mining by the Project (i.e. beyond the Blakefield seam) would be undertaken for the EIS.

3.7 GROUNDWATER FLOW SYSTEMS

There are two major hydrostratigraphic units (HSUs) within the study area:

- **Hunter River alluvium**. An alluvial aquifer associated with the Hunter River. It comprises silt underlain by gravel, reaching a thickness of 30 m or more near the Hunter River channel. The Hunter River alluvium is classified as a 'highly productive' groundwater source. The unconsolidated alluvial sediments associated with Saddlers Creek are considered separate to the Hunter River alluvium and classified as a 'less productive' groundwater source (**Section 2.1.2**).

- **Sydney Basin Permian porous rock units**. Classified as a porous rock “aquifer” of low water resource potential. It should be noted however that flow through fracture networks also occurs. This groundwater system is associated with the Newcastle and Wittingham Coal Measures, which comprise interlayered sandstone, siltstone, and coal seams to significant depth. The coal seams typically form the more permeable sub-units, whilst the interbeds form lower permeability resistors to groundwater flow. The Permian porous rock units are classified as a ‘less productive’ groundwater source (**Section 2.1.2**).

Groundwater is likely to flow between these two HSUs, although inter-aquifer flow rates are likely limited by the strongly contrasting permeability differences between the two units (i.e. most of the groundwater flowing through the alluvium is likely to have been derived from rainfall recharge and river leakage directly into the alluvials and is likely to primarily discharge directly out of the alluvium). Groundwater flows through the Permian porous rock aquifer, and discharges via the alluvium, creeks and evapotranspiration, at much slower rates than in the more permeable (by several orders of magnitude) Hunter River alluvium.

Previous work (Coffey 2013) indicated a potentiometric divide to the west of the Project area, from which flow across the Project area is most likely to be from north-west to south-southeast. This regime appears to be controlled by the primary discharge boundary of the Hunter River and/or its alluvium, which runs to the southeast beyond the southern boundary of EL 5460.

Harrison (1946) provides an early interpolated watertable for the Hunter River alluvium surrounding the site (**Figure 21**). Alluvial groundwater flows along the line of the river from the north to the southeast. In most cases, inflection of the potentiometric contours around the Hunter River in **Figure 21** (indicating a convex surface) suggests that the river acts as a source of water to the alluvium. The potentiometric surface is unlikely to have changed significantly since that time, due to the presence of the river and its surrounding incised land surface, which form the primary control on groundwater recharge and/or discharge, and hence groundwater flow directions and heads.

AGE (2015) reported that water levels in the Hunter River alluvium and Saddlers Creek alluvium were ‘generally 8 to 10m below ground levels’, with little change between 2008 and 2015.

Baseline water table levels (**Figure 24**) confirm these findings.

3.8 GROUNDWATER USE

Figure 22 shows the groundwater bores registered on DoI-Water’s database. There are 857 registered Government (Govt) groundwater bores within the model extent. Also shown are 103 bores from previous studies (Drayton South, AGE 2015; Mt Arthur, AGE 2013) and 15 former Drayton Mine bores (AGE 2015). Most of the groundwater usage in the area is from the Hunter River alluvium (bores registered in the Govt database). Comparatively few registered bores exist in the Permian porous rock aquifer or unconsolidated alluvial sediments of Saddlers Creek, likely due to its lower yield and poorer water quality.

3.9 CONCEPTUAL HYDROGEOLOGICAL MODEL

A pre-mining model diagram is presented in **Figure 30**.

3.9.1 RECHARGE

Recharge to the Hunter River alluvium is predominantly derived from leakage from the Hunter River, rainfall recharge and irrigation. Hydrograph fluctuation analysis of bore GW080077 suggests maximum recharge rates to the alluvium of approximately 100 mm/year, but more typically around 30 mm/year, assuming a specific yield of 0.1 and maximum / typical watertable fluctuations of 1 m / 0.3 m, respectively.

The Malabar owned property in the south (Llanillo property) has a licence of 90 units from the Hunter Regulated River Source, which is used for occasional irrigation of fodder crops and is therefore a small local recharge source. There is also irrigated pasture on the thoroughbred breeding properties to the south of the Hunter River. Some recharge to the alluvials also occurs from the underlying and adjacent Permian porous rock aquifer, as indicated by EC data and other geochemical data (Kellett *et al*. 1989). The dominant alluvial aquifer recharge source is however, leakage from the Hunter River.

Recharge to the Permian porous rock aquifer is much lower than to the alluvials because of its lower capacity to receive and transmit water (due to lower hydraulic conductivity and storage properties). The higher EC of the Permian porous rock aquifer compared to the alluvials supports this conclusion. Vibrating wire piezometer data (Heritage Computing 2013) showed no observable response to seasonal recharge events. Hence seasonal recharge to the Permian porous rock is expected to be close to zero – in the order of less than 5 mm/year.

3.9.2 DISCHARGE

Discharge from the Permian porous rock aquifer is primarily to the alluvium associated with the Hunter River and its tributaries but also to evapotranspiration from shallow groundwater in lower lying areas where the porous rock is sub-cropping or at outcrop. Discharge from the Hunter River alluvium is primarily via groundwater usage and evapotranspiration from shallow watertable areas.

Current hydraulic heads in the coal measures show minimal vertical or horizontal gradients. Drawdown from neighbouring mines to the north and east does not appear to have depressurised the Maxwell Underground area, but there are recorded mining effects near the Maxwell Infrastructure (due to past open cut mining activities).

With Project underground mining, vertical gradients would be created, and groundwater discharge into the underground mine workings would become a dominant discharge component of the water balance.

3.9.3 HYDRAULIC PROPERTIES

Hydraulic properties for the various stratigraphic units are based on a combination of measured data (**Section 3.6.3**) and the calibration parameterisations of surrounding mines' models (**Section 4.5**).

Gravels at the base of the mapped alluvium extents in the study area are expected to have a relatively high lateral hydraulic conductivity. The vertical leakance between the alluvium and Permian coal measures is not considered an integral parameter for analysis of reduction in discharge to the alluvium as vertical leakance could only appreciably affect the timing, not the magnitude, of potential impacts upon this component of the groundwater flow system.

The Mt Ogilvie structure is not considered to form a lateral barrier to groundwater flow, based upon interpretation of this structure as a roll-over feature, rather than a significant fault across which the coal measures have been vertically displaced and truncated (MBGS and GRS 2014). The feature appears to provide at least localised pathways for vertical groundwater flux from the Wittingham Coal Measures up to the land surface (see Kellett *et al*. 1989).

3.9.4 IMPACT OF MINING ON OVERLYING STRATA

A conceptual model of the hydrogeological system is illustrated in **Figure 31**. Possible mining effects include:

- Depressurisation and drawdown of subsurface water pressures/levels due to mine inflows (dewatering) extending some distances (e.g. laterally) from underground mining areas, altering flow patterns and groundwater storage.
- Fracturing of overlying strata above underground mining areas leading to alteration of nearer-surface groundwater flow patterns and aquifer storage.
- Drawdown of the water table, potentially reducing or interrupting flows in surface streams and reducing bore water levels.

The impact of mining on the permeability of caved overlying strata has been based on experience of monitoring and groundwater modelling gained to date, in other locations, combined with the most recent research available for subsidence impacts on aquifer and aquitard materials.

It is generally accepted that there would be a sequence of deformational zones produced by underground mining (**Figure 32**) usually described as:

- Deformed floor strata (Z).
- Mined seam (O).
- The caved zone (AA).
- The fractured zone, consisting of:
    - a lower zone of connective-cracking (A); and
    - an upper zone of disconnected-cracking (B).
- The constrained zone (C).
- The surface zone (D).

The rocks in the connective-cracking part of the fractured zone (A) would have a substantially higher vertical permeability than the undisturbed host rocks. This would encourage groundwater to move out of rock storage downwards towards the goaf. In the upper part of the fractured zone, where disconnected-cracking occurs, the vertical movement of groundwater should not be significantly greater than under natural conditions.

Depending on the width of the longwall panels, the depth of mining, and the presence of low permeability lithologies, there could be a constrained zone (C) in the overburden that acts as a bridge. Rock layers are likely to sag without breaking, and bedding planes are likely to open. As a result, some increase in horizontal permeability can be expected at least over the dimension of a longwall panel.

In the surface zone (D), near-surface cracking can occur due to horizontal tension at the edges of a subsidence trough. Cracking would be shallow (<20 m), often transitory, and any loss of water into the cracks would not continue downwards towards the goaf.

The strata movements and deformation that accompany subsidence would alter the hydraulic and storage characteristics of aquifers and aquitards. As there would be an overall increase in rock permeability, groundwater levels would be reduced either due to actual drainage of water into the goaf or by a flattening of the hydraulic gradient without drainage of water (in accordance with Darcy's Law).

At the base of the fractured zone, groundwater pressures would reduce towards atmospheric pressure.

Algorithms developed by Tammetta (Tammetta, 2013) and Ditton (Ditton and Merrick, 2014) provide estimates of the height of fracturing above longwall mines, which are indicated in the conceptual fracturing diagram (**Figure 32**).

The effects of multi-seam subsidence on the fracture height calculations has been estimated for the Project in consultation with geotechnical/subsidence experts (i.e. Ditton Geotechnical Services). It is understood that there are no specific case studies available with measured fracture heights based on borehole extensometer and vibrating wire piezometer data above longwall goafs in three or more seams.

The method used to define the nature of the fracturing and its effect on model parameters is discussed in **Section 4.6**, and summarised in **Figure 32.**

4 GROUNDWATER SIMULATION MODEL

4.1 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*. 2012) and the MDBC Groundwater Flow Modelling Guideline (MDBC 2001). As these are mostly generic guides, there are no specific guidelines on special applications, such as underground coal mine modelling.

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

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

Table 15 (based on Table 2.1, Barnett *et al*. 2012) summarises the classification criteria and shows a scoring system allowing model classification.

Based on **Table 15**, the groundwater model developed for this Preliminary Groundwater Assessment may be classified as Class 2 (effectively “medium confidence”), which is an appropriate level for this Project context.

MODFLOW-USG (for **U**n**S**tructured **G**rid, Panday *et al.* 2017), is an advanced version of the popular MODFLOW code developed by the United States Geological Survey (Harbaugh and McDonald 1996). MODFLOW is the most widely used code for groundwater modelling and is accepted as an industry standard.

MODFLOW-USG allows flexibility in grid design that can be used to focus resolution along rivers and around wells, or to subdiscretize individual layers to better represent HSUs (i.e. allow HSUs to end or pinch out).

The model complexity is adequate for simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system resulting from the proposed development.

Details of model setup are provided in **Table 16**.

Table 15 Groundwater Model Classification Table

Class	Data		Calibration		Prediction		Indicators		TOTAL
	Not much		Not Possible		Timeframe>>calibration		Timeframe>10x		
	Sparse		Large error statistics		Long stress periods		Stresses>5x		
	No metered usage	✓	Inadequate data spread		Transient prediction but steady state calibration		Mass balance>1% (or single 5%)		
1	Remote climate data		Targets incompatible with model purpose		Bad verification		Properties<>Field		1
							Bad discretisation		
							No review		
	Some	✓	Partial performance		Timeframe>calibration	✓	Timeframe=3-10x	✓	
	Poor coverage	✓	Long-term trends wrong		Long stress periods	✓	Stresses=2-5x	✓	
	Some usage info		Short time record		New stresses not in calibration	✓	Mass balance<1%	✓	
2	Baseflow estimates	✓	Weak seasonal replication	✓	Poor verification		Properties<>Field measurements	✓	12
			No use of targets compatible with model purpose				Some key coarse discretisation	✓	
							Reviewed by hydrogeologist		
	Lots		Good performance stats	✓	Timeframe~calibration		Timeframe<3x		
	Good aquifer geometry	✓	Long-term trends replicated		Similar stress periods		Stresses<2x		
3	Good usage info		Seasonal fluctuations OK		Similar stresses to those in calibration		Mass balance<0.5%		5
	Local climate info	✓	Present day data targets		Steady state prediction consistent with steady state calibration		Properties ~Field measurements		
	K measurements		Head and flux targets		Good verification		Some key coarse discretisation		
	Hi –res DEM	✓					Reviewed by modeller	✓	

Table 16 Groundwater Model Setup

Model aspect	Set-up	Details / key settings
Model code	MODFLOW-USG	(Panday *et al*. 2017)
Graphical User Interface (GUI)	Groundwater Vistas, Version 7	Environmental Simulations Inc.
Model area & units	51 km east to west, 35 km north to south, approximate area 1785 km^2	Length = metres, Time = days
Grid	Rectangular; regular	Total cells 278,460 Active Cells 263,718 cells, pinch out cells account for a 5.6% reduction, 117 x 300m rows, 170 x 300m columns
Grid rotation	None	
Layers and layer types	14 Layers	All layers unconfined (Type 3), see **Section 4.3**
Unsaturated flow	Pseudo-soil	
Solver	SMS	XMD HCLOSE = 0.001 m
Run modes	Steady-state calibration Transient verification Prediction	See **Section 4.8, 4.9 and 5**
Calibration data	Heads (piezometers; VWP[1])	See **Section 4.8**
Boundary conditions (Additional detail provided below in **Section 4.4**)	RCH	Aquifer recharge
	RIV	Rivers, ephemeral streams
	DRN	Mine drainage
	GHB	Boundary flow (some model edges)
	TVM	Temporal variation in aquifer conditions

[1] VWP – Vibrating wire piezometer

4.2 PREVIOUS GROUNDWATER MODELLING AND ASSESSMENTS

Groundwater studies have been undertaken for several nearby operations/projects in the Project area and broader study area, including:

- Saddlers Creek pre-feasibility studies (within the Maxwell Underground area) (MER 2003).
- Anvil Hill Project (now Mangoola Mine) (MER 2006).
- Drayton Mine (now Maxwell Infrastructure) (AGE 2006).
- Mount Arthur Underground (MER 2007).
- Mount Arthur Open Cut (AGE 2013).
- Spur Hill Underground Coking Coal Project (Heritage Computing 2013).
- Drayton South Coal Project applications (AGE 2012; 2015).

Reports and information from these other projects provided background data for this Project groundwater model discussed elsewhere, with the groundwater model created for the Spur Hill Underground Coking Coal Project Gateway Application providing the bulk of initial condition information.

It is noted that the Drayton South Coal Project previously proposed within EL 5460 is not proceeding.

AGE (2013) has previously reported that the Mount Arthur Mine developments (i.e. modifications, including open cut and underground mining) would result in small changes in leakage and drawdown for the alluvium, little change to mine pit inflows and on-going drawdown in the Permian coal measures.

The Spur Hill Underground Coking Coal Project preliminary groundwater model indicated that the proposed development met Level 1 minimal impact considerations of the AI policy for 'highly productive' water associated with the Hunter River alluvium, and level 2 minimal impact considerations for 'less productive' water in the Permian porous rock aquifer.

These results indicated that drawdown in the Permian coal measures could be expected as a cumulative effect. As noted earlier, potential cumulative impacts have been modelled as part of this Preliminary Groundwater Assessment modelling exercise using the Principle of superposition (see **Section 6.5**).

4.3 MODEL LAYERS AND GEOMETRY

Figure 34 shows the extent of the groundwater model domain, and details of model setup are shown in **Table 16**.

Because this Preliminary Groundwater Assessment is for the Gateway process, which requires a simpler than usual modelling approach, a laterally and vertically-coarser model grid than might normally be chosen for an EIS assessment has been used. This reduces the effort involved in the model build and reduces simulation runtimes. Based on the proposed width of the longwall panels at the Project (300 metres), a uniform grid size of 300 m has been selected.

The 14 model layers used to represent the regional stratigraphic section (**Figure 20**) are outlined in **Table 17**, and are based on the conceptual hydrogeology described in **Section 3**.

To supplement the detailed data available from the Malabar geological model for EL 5460, geological surface information from surrounding mines was extracted from publicly available reports (Heritage Computing 2013; AGE 2012; AGE 2013; AGE 2015; MER 2006) and the updated Geological Survey of New South Wales (GSNSW) geology model (Oliviera 2018).

The subcrop mapping of the 1:100,000 scale Hunter Coalfield Geological Map (NSW Department of Mineral Resources [DMR], 1993) was used to constrain the subsurface extent of each modelled geological surface.

The 25 m resolution Digital Elevation Model (DEM) from the Australian Government (Geoscience Australia, 2011) was used to define the modelled land surface.

The extent and depth of Hunter River alluvium (layer 1) was estimated using the information presented in surrounding mines reports (AGE 2015), the NSW government WSP, and government bore data. The depth of regolith (also layer 1) was estimated using the start of coring exploration data from the EL 5460 area, in conjunction with the regolith depth data elevation from CSIRO National Soil Attribute Maps (Wilford *et al.*, 2015).

Table 17 Model Layer Assignment

Layer	Lithology	Median Thickness (m)	Lumped Units
1	Alluvium / regolith	2	Alluvials, Colluvium, Regolith
2	Overburden	25	Whybrow Seam Overburden
3	Interburden	55	Mount Leonard, Althorpe & Malabar Formations, Whybrow, Redbank & Wambo seams
4	Whynot Seam	1.9	
5	Interburden	166	Mount Ogilvie Formation, Blakefield & Glen Munro seams
6	Woodlands Hill Seam	2.7	
7	Interburden	48	Mount Thorley Formation
8	Arrowfield Seam	2.9	
9	Interburden	30	Mount Thorley Formation
10	Bowfield Seam	2.9	
11	Interburden	34	Mount Thorley Formation
12	Warkworth Seam	4	
13	Interburden	248	Fairford and Burnamwood Formations
14	Basement	300	

The thickness of each modelled coal seam was extrapolated from the EL 5460 geological model's median seam thickness data.

Minimum model layer thickness was set to 0.0 m for all layers except layer 1, to allow layers to end (pinch out).

The resulting modelled geological surfaces are presented in **Appendix E**.

The model domain has been designed to be large enough to prevent boundary effects on model outcomes associated with mining-related stress on the groundwater environment because of mining at the Project.

The model extends beyond the subcrop trace of the deepest coal seam that is likely to be mined by the Project and/or surrounding mines in the future.

4.4 BOUNDARY CONDITIONS

The model domain and boundaries shown in **Figure 35** have been selected to incorporate any potential receptors (i.e. surface water bodies or GDEs) that could be adversely affected by mining. Following is detailed information on each of the modelled boundary conditions. Values used as initial conditions for the steady state calibration model are presented.

4.4.1 WATERCOURSES

Creeks and rivers throughout the model domain were modelled using MODFLOW's River (RIV) package. RIV is a form of the head dependent boundary condition which is appropriate for a stream which partially penetrates a layer and can receive water from an aquifer (gaining stream) or pass water to an aquifer (losing stream).

Head dependent boundary conditions require dimensional information regarding the boundary within a given cell, a boundary head and a conductance term, C (L^2/ T), where:

$$C = KA/B$$

and K is hydraulic conductivity of the boundary material

A is the area of the boundary

B is the thickness or width of the boundary (e.g. vertical stream bed thickness)

Table 18 lists these parameters for the steady state calibration model.

Table 18 River Package Parameters

Boundary	Water depth (m)	Width (m)	Conductance (m^2/ day)
Hunter River	1	20	6
Goulburn River	1.5	10	3
Saddlers Creek	0.5	2	0.6
Ramrod Creek	0.5	2	0.6
Other Creeks	0.5	2	0.6
Lake Liddell	0.5	300	0.6
Plashett Reservoir	0.5	300	0.6
Other reservoirs	0.5	300	0.6

The river and creek widths were estimated using satellite observations on Google Earth and are consistent with previous modelling (Heritage Computing 2013). The conductance values assigned to each river and creek are based on a constant bed thickness of 0.1m, with a clayey hydraulic conductivity property of 0.0001 m/d (also consistent with Heritage Computing 2013). The height of water was kept constant for each modelled river or creek, from its upstream reach to its downstream reach, with different observed heights of water being assigned to the various waterbodies included in the model. The water depth of modelled reservoirs close to the mining area was assigned a value of 0.5 m, which minimises the reservoir's interaction with the underlying aquifer to remain conservative regarding any mining impacts.

4.4.2 RECHARGE

Recharge is a form of constant flux boundary condition in MODFLOW, managed by the RCH package, treated by Groundwater Vistas (GWV) as a property. As such RCH requires a flow rate for each stress period, spatially variable as required, applied to the topmost model layer or uppermost active model layer.

The recharge characteristics of the system (**Section 3.9.1**) indicate that the alluvial materials are the most important contributor. These materials are identifiable spatially and categorized as one recharge zone. It was not possible to define other outcrops at the scale appropriate to the Gateway process model, hence the rest of layer 1 (non-alluvial areas, porous rock) comprise the second zone.

For the steady state model, the values defined in **Section 3.9.1** for the different zones were applied to the topmost layer. In this way a realistic representation of the recharge (different amounts of rainfall infiltration) relating to topography and surface conditions could be applied while keeping the model compact and functional. Resulting recharge rates of 31.0 mm/year (8.49E-05 m/day) and 3.0 mm/year (8.21E-06 m/day) were applied to the alluvial and non-alluvial areas respectively.

4.4.3 EVAPOTRANSPIRATION

Evapotranspiration is a form of head dependent flux boundary condition in MODFLOW, managed by the EVT package, which is treated by GWV as a property. Evapotranspiration can be applied to the topmost model layer or the uppermost active model layer. The EVT package only includes evapotranspiration from the saturated zone. The EVT package requires maximum rate and extinction depth values. The evapotranspiration rate maximum is for the water table at the top of the uppermost model layer and decreases linearly as the water table height drops below the surface until it equals zero at the extinction depth. The extinction depth is the depth below which evapotranspiration will not occur, defined, for example, by a plant rooting zone depth.

For the steady state calibration, the extinction depth in the model was set to 2m, and the maximum evapotranspiration rate was set to 500 mm/year (0.00137 m/d) (Heritage Computing 2013).

4.4.4 SURROUNDING GENERAL HEAD BOUNDARIES

Areas forming the edge of the model domain (primarily in the west, north and south) were assigned as MODFLOW General Head Boundaries (GHBs). This allows for groundwater throughflow. GHBs simulate groundwater flow into and/or out of the model domain according to a specified head and conductance.

Specified GHB heads were assigned based a combination of the most recently calibrated head values from the Spur Hill Underground Coking Coal Project groundwater model (Heritage Computing 2013) and recorded water levels at NSW government bores.

Each GHB cell was assigned a conductance value based on the layer host hydraulic property, cell thickness and area. The same process was applied from layer 1 to layer 14.

4.4.5 GROUNDWATER USE

No additional wells were included into this Gateway process model. AGE (2015) note that "groundwater extraction from the Hunter River alluvium is limited in the immediate vicinity of the Project". This has also been confirmed at neighbouring properties during the initial consultation undertaken as part of the contemporary bore census (**Section 10.4**).

There is no significant groundwater extraction specifically within Maxwell Underground area, apart from stock and domestic use.

4.4.6 NO FLOW BOUNDARIES

No-flow boundaries are also called inactive cells, with both titles being self-explanatory. These cells are used when some feature implies that there is no flux to or from the model at and beyond the feature.

No-flow boundaries (inactive cells) are shown in **Figure 35** in the southeastern and northeastern corners of the model area. These areas represent topographic divides in the form of ridge lines (geomorphic divide) and river channels. Both features imply that surface or near surface flow will not be flowing across the boundary. Deeper (groundwater flows) in the system are directed to the east following the boundary of the Hunter River valley (**Section 3.7**).

4.5 HYDRAULIC PROPERTIES

Previous studies and investigations within the region (MER 2007), in conjunction with core and packer testing data collected for the Spur Hill Underground Coking Coal Project, provided the initial basis for hydraulic property parameters used within the modelling component of this Project for the coal seams and interburden.

The hydraulic properties in **Table 19** are initial (indicative) hydraulic conductivities for the various stratigraphic units incorporated into the groundwater model. These were based on a combination of the measured data and the calibration parameterisations of surrounding mines' models.

Table 19 Initial Hydraulic Properties of Stratigraphic Units

Layer	Description	Zone	Kx (m/day)	Kz (m/day)
1	Alluvium	101	4.29	2.52E-02
1	Regolith	102	1.00	6.17E-04
2	Whybrow overburden	2	1.01E-04	4.74E-06
3	Whynot overburden	3	7.72E-04	1.50E-04
4	Whynot seam	4	1.00E-04	1.66E-06
5	Woodlands Hill overburden	5	6.22E-06	1.26E-06

Layer	Description	Zone	Kx (m/day)	Kz (m/day)
6	Woodlands Hill Seam	6	2.93E-02	2.93E-05
7	Arrowfield overburden	7	8.52E-07	7.05E-07
8	Arrowfield seam	8	5.10E-02	5.10E-04
9	Bowfield overburden	9	1.00E-05	3.26E-06
10	Bowfield seam	10	1.40E-03	4.30E-04
11	Warkworth overburden	11	1.00E-05	2.30E-06
12	Warkworth seam	12	3.41E-02	9.85E-05
13	Underburden to Ramrod Creek Seam	13	7.53E-05	1.33E-06
14	Underburden to Branxton Formation (Greta Coal Measures)	14	7.53E-05	1.33E-06

4.6 SUBSIDENCE AND FRACTURED ZONES

4.6.1 MULTI-SEAM FRACTURING

Section 3.9.4 provides background and conceptual information on the impact of mining on the properties of overlying strata, which is summarised in **Figure 32**.

As noted in **Section 3.9.4**, there are no published case studies relevant to above seam fracturing for the multi-seam nature of the Project. However, Ditton (pers. comm.) considered multi-seam subsidence data from North Wambo, Liddell and Cumnock Collieries, and concluded that a multi-seam correction can be derived from the incremental subsidence due to mining of individual seams. Li *et al*. (2007) found that the maximum cumulative subsidence resulting from mining of two seams is equivalent to about 85% of the combined seam thicknesses (assuming the areas of maximum subsidence are superimposed). Best and worst-case estimates of fracture heights may be assessed by adopting the predictions for single seam outcomes (best case) and cumulative outcomes based on multi-seam subsidence (worst-case).

The additional subsidence is converted into an 'effective' mining height increase, ΔT1. The ΔT1 term can be estimated as:

- No additional subsidence (best case).
- A summation of the effects of all the underlying seams, calculated by adding 'mining height increase' components based on incremental subsidence for underlying seams.
- A summation of the effects of all the underlying seams (worst case), calculated by adding 'mining height increase' components based on conservative summing of the mining heights of underlying seams.

Finally, the upper seam mining height T1 is increased to T1' by ΔT1 and used to estimate the multi-seam A-Zone fracture height A1' using the Ditton algorithm.

This method provides a range of potential fracture height values, summarised in **Figure 32**, with the maxima representing the most conservative estimate, and 95%A being the value with a 95% degree of confidence (95% confidence that actual A predictions would be less than this value).

4.6.2 STACKED DRAIN MODEL

MODFLOW-USG includes a new Connected Linear Network (CLN) Process to simulate the effects of multi-node wells, which could represent a fracture network above modelled longwall mining panels. However, some modellers have found the CLN package to be detrimental to model performance. Although the CLN package was not used in the model, a method of applying the formula used in the CLN package to calculate the drain conductance of a series of drains aligned vertically (stacked) in the fractured zone above a mined model cell has been developed by AGE (pers. comm.) and was implemented.

Drain elevations are set to the base of each cell within the fractured zone, with the relevant drain conductance (related to the height above the longwall panel) applied and remaining active for the duration of mining activity. Once mining is complete, new hydraulic conductivities representing the collapsed strata are applied.

Drains are not applied to layer 1, as this can cause interference with RCH and EVT boundary conditions. Where fracturing to surface occurs, or superficial cracking is represented, layer 1 can be given increased hydraulic conductivities, as indicated in **Figure 32**.

The layer below the deepest mined cells (deformed floor strata) can also be given increased hydraulic conductivities (**Figure 32**).

The 'fracture conductance' is related to an effective fracture aperture, which, due to a cubic power relation, has a log-linear relation to height above the longwall panel.

An example of some fracture conductance (VCOND) results is shown in **Table 20**. Relevant parameters for the examples are:

- Model cell size 300 m (for this Project).
- Cell (vertical) thicknesses and heights (above mined cell) affects the calculations and varies depending on location:
    - 9m (height=9m), arbitrary top layer, < 10m (Cell VCOND defaults to 100 m^2/day if thickness is less than 10 m to ensure drainage just above seam).
    - 10m (height=19m); 51m (height=70m); 100m (height=170m).
    - 150m (height=320m), to resemble depth to top of Bowfield Seam of about 330 m (average thicknesses and depths shown in **Figure 32**).
- Vertical hydraulic conductivities have been taken from calibrated model values representing the interburden layers at appropriate depths (**Table 20**).

This approach establishes reasonable relativities between conductances at different altitudes above a mined seam, but the absolute conductance values require scaling to match observed or anticipated mine inflows.

Table 20 Example Stacked Drain Conductances

Thickness (m)	Height (m)	Vertical Hydraulic Conductivity Kz (m/day)	Fracture Aperture (m, A)	Drain or Fracture Conductance (m^2/day, VCOND)
9	9	3E-02	4.4E-02	100
10	19	3E-02	3.5E-02	0.7847
51	70	1.5E-03	1.9E-02	0.1854
100	170	1.3E-05	8.5E-03	0.0028
150	320	1.0E-06	8.8E-04	0.0003

As indicated in **Figure 32**, values for fractured zone conductances were guided by the example in **Table 20**:

- Fractured zones have an effective (logarithmic) ramp function for VCOND, as per the example calculation, scaling from 'high' (>1) to about 0.1 (0.1854) over a range of about 0 to 50 m (note that Tammetta/Ditton fracture heights indicated in **Figure 32** imply all interburden areas between the Whynot and Bowfield seams are fractured).
- Mined seams VCOND set to 1 – an order of magnitude greater than fractured zone.
- Interburden (fractured zones) above Bowfield and Arrowfield seams are less than 50m thick, VCOND set to 0.1.
- Interburden (fractured zone) above Woodlands Hill seam is 166 m thick, and therefore VCOND could be reduced. Given the potential multi-seam effects and Tammetta/Ditton fracture height calculations, VCOND is also (conservatively) set to 0.1.
- Overburden above the Whynot seam thickness is about 55 m (average, layer 3), indicating VCOND of about 0.1.
- Layer 2 overburden will be subject to fracturing at greater than the 50m range, and so VCOND is set to 0.01. It is noted that the Whynot seam is bord and pillar mining, so fracturing would not necessarily be fully transmitted, despite being treated as such in multi-seam calculations.

4.6.3 MODEL SIMULATION

The layer definition within the groundwater model has allowed each mined coal seam to be represented individually. Interburden separates each target coal seam in the model. Because the target coal seams begin in model layer 4, there is flexibility in the model to simulate the fractured zone to various heights. This ensures that the impact of progressive caving and fracturing associated with the mining is adequately represented. **Table 21** shows layer properties defined by fracturing above mined cells (average layer heights [top] in mine affected area are shown in **Table 21**).

Table 21 Layer Properties Defined by Fracturing in the Mined Areas

Layer	Top (Average) (m)	Description	Deformation Category	Fracture Zone Heights (m)			Drain Cell
				Tammetta	Ditton		
				A	A	B	VCOND (m^2/day)
1	0	Regolith	D	Kz increased			
2	2	Whybrow overburden	C, B				0.01
3	27	Whynot overburden	A, B				0.1
4	82	Whynot seam	O	18 – 175	60 –258	66 – 288	1.0
5	83.9	Woodlands Hill overburden	A				0.1
6	249.9	Woodlands Hill seam	O	214	155	190	1.0
7	252.6	Arrowfield overburden	A				0.1
8	300.6	Arrowfield seam	O	254	203	246	1.0
9	303.5	Bowfield overburden	A				0.1
10	333.5	Bowfield seam	O	257	209	253	1.0
11	336.4	Warkworth overburden	Z				
12	370.7	Warkworth seam					
13	374.4	Underburden					
14	622.4	Underburden					

The number of cells affected by fracturing (stacked drain cells) varies in both time and space, being controlled by mine progression over time across the mining zone in the different layers. To manage this complexity, a series of (six) zones was developed to represent groups of cells subject to fracturing to differing heights above different respective mine levels, for which the drains could be turned on or off at the appropriate time in the model. **Figure 33** shows a schematic of the developed zones. While **Figure 33** does not show the detail of individual model cells, it accurately represents the zones and shows the complexity of the procedure.

Further investigations into the impact of mining on the hydraulic properties of overlying strata would be conducted as part of the EIS process.

4.7 MODEL VARIANTS

Both steady-state and transient models were developed for use in this Preliminary Groundwater Assessment as summarised below:

- Steady-state model of pre-mining conditions. Calibration against the observed pre-mining groundwater levels (**Appendix C**). This model was used to formulate transient model starting heads.
- Transient verification model for 18 years from January 2001 to December 2018. Verification against the groundwater hydrographs in **Appendix D**; and
- Transient predictive models for 27 years from January 2019 to December 2045 (following the verification period, started in 2019 to allow for first workings):
    - Null scenario, with no mining included, used in pre and post mining.
    - To the end of mining, including stacked drains.
    - 200 years post-mining recovery.
    - Dry climate predictive scenario.
    - Wet climate predictive scenario.

The steady-state and transient verification results are presented in the following sub-sections (**Sections 4.8 and 4.9**).

The results of the transient predictive model runs are presented in **Section 5**.

4.8 STEADY-STATE CALIBRATION

4.8.1 APPROACH

Steady-state calibration was performed manually initially to check for model stability, and then improved by use of parameter estimation. PEST (Parameter ESTimation) is a software tool allowing improvement of model parameter estimates by matching of model outputs to measured values (Doherty 2018).

An automated sensitivity analysis was conducted on the Kx parameter using GWV. The automated sensitivity helped with the model calibration, running the model several times and estimating calibration statistics for different (Kx) parameters values.

The steady-state model was initially calibrated using groundwater levels from various areas, including the EL 5460 area, Spur Hill EL 7429, Mount Arthur Mine and NSW government bores across the model extent.

Pre-mining groundwater levels were used for the calibration process. Available pre-mining calibrated groundwater levels were used from publicly available reports for Mount Arthur and the Drayton South Coal Project (AGE 2013; AGE 2015).

The groundwater levels recorded at the VWPs, from the nearby bore census conducted for the Spur Hill Underground Coking Coal Project and groundwater levels from inactive and active NSW government bores were assigned as calibration targets (Heritage Computing 2013). Weights were assigned to the target bores to reflect different levels of confidence with the groundwater level measurements:

- VWPs were assigned a low weight (0.1) due to the difficulty in reproducing observed groundwater levels from a previous study (Heritage Computing, 2013) and to the possible inaccuracy of the vertical position of the VWP sensors.
- Greater weight (0.5) was assigned to the Mount Arthur Mine bores, due to the proximity of the bores and accuracy, noting that there are historical and ongoing mining impact over this area, which may result in difficulty matching bore targets used in the model. The bore census records from Spur Hill Underground Coking Coal Project and active NSW government bores were also assigned a weight of 0.5.
- Finally, the groundwater monitoring bores within the EL 5460 area and some inactive NSW government bores were attributed a weight of 1 (highest) due to their proximity to the proposed mining activity and the likelihood of reliable data in NSW government monitored bores.

The initial (indicative) hydraulic parameters are presented in **Table 19**. **Table 22** lists the hydraulic parameter estimates resulting from the automated model calibration with PEST.

Table 22 Hydraulic Parameters (All m/day) Resulting from PEST Calibration

Layer	Zone	Kx[1]	Kx	Kz	Kx/Kz	Recharge
1	Alluvium	4.29	42.91	5.80E-02	879	8.49E-05[1]
1	Regolith	1	10	6.17E-03	1621	8.21E-06[2]
2	Whybrow overburden	5.05E-05	2.67E-04	4.74E-05	6	
3	Whynot overburden	1.54E-03	1.54E-02	1.50E-03	10	
4	Whynot seam	2.0E-04	2.93E-04	1.69E-07	1737	
5	Woodlands Hill overburden	1.24E-05	1.26E-04	1.26E-05	10	
6	Woodlands Hill Seam	2.05E-02	0.16	2.93E-05	5516	
7	Arrowfield overburden	5.11E-07	7.05E-05	7.05E-06	10	
8	Arrowfield seam	1.27E-02	1.28E-03	5.59E-04	2	
9	Bowfield overburden	5.0E-06	3.11E-06	9.43E-07	3	
10	Bowfield seam	8.4E-04	5.35E-04	1.59E-04	3	
11	Warkworth overburden	5.0E-06	9.04E-05	9.04E-06	10	
12	Warkworth seam	1.70E-02	1.71E-03	1.62E-05	105	
13	Underburden to Ramrod Ck Seam	3.77E-05	2.55E-05	3.00E-07	85	
14	Underburden to Branxton Formation (Greta Coal Measures)	3.76E-05	6.36E-06	1.04E-06	6	

[1] Kx parameter after the GWV automated sensitivity analysis
[2] Representing about 5% and 0.5% of rainfall respectively

Comparison of **Table 19** and **Table 22** shows:

- Interburden Kx ranges are comparable, 10^{-2} to 10^{-7} m/day, Kz also comparable, 10^{-3} to 10^{-7} m/day.
- Coal seam Kx ranges comparable, 10^{-1} to 10^{-4} m/day, Kz also comparable, 10^{-4} to 10^{-7}m/day.
- Alluvial and Regolith Kx values were increased by about an order of magnitude to 10^{1} m/day by PEST calibration, while alluvial Kz values were increased by about 2.5 times (still 10^{-2}) m/day, and Regolith Kz values were increased by PEST from 10^{-4} to 10^{-3} m/day.

Target bores for the steady-state calibration are listed in **Appendix C** showing measured values and model estimated values after the PEST calibration run.

4.8.2 RESULTS

The Australian Groundwater Modelling Guidelines (Barnett *et al* 2012) note that goodness of fit (between observed and predicted values of some parameter) is often measured using a simple statistic such as the root mean squared error (RMS), and the scaled root mean squared error (SRMS). The SRMS is the RMS divided by the range of measured data, and therefore connects the statistical error to the measured data set. These values are reported by GWV and are used in discussion of model calibration 'results'.

Steady-state head calibration performance is good with 7.5% SRMS (weighted) (**Table 23**), which is below the target 10% SRMS suggested in the MDBC Groundwater Flow Modelling Guideline (MDBC 2001).

Table 23 Steady-State Head Calibration Statistics

Performance Statistic	Value
Number of Observation Bores	100
Number of Data Points	100
Root Mean Square (m)	11.04
Scaled Root Mean Square (SRMS) (%)	7.47

Figure 36 shows a comparison of observed and predicted calibration bore water levels. Ideally, the comparison points would lie on the identity line (slope = 1) shown in the figure, indicating equality, or identical values. The points in **Figure 36** show a very good fit to the identity line over the complete range of measurements, with a slight overestimation indicated. The poorest matches are related to the observations from the VWPs at the neighbouring Spur Hill EL 7429 to the west.

Figure 37 shows calibration observed bore water levels and model residuals. Residuals (predicted subtracted from observed) are the basis of RMS and SRMS, and so also indicate goodness of fit.

Figure 37 highlights a tendency to overestimation (negative residual). However, there is no bias shown across the water level depth range or between measurements from different areas.

Figure 36 and **Figure 37** indicate an acceptable calibration performance, in agreement with the SRMS value from **Table 23.**

Figure 38 presents a map of the head calibration error ("Bore GWL Residual") throughout the model domain. The better results (all +/- 5m residual) are within the alluvium (or adjacent to watercourses where alluvium is likely, if not mapped). One bore (GW21, a considerable distance from the Project area) is showing a relatively high (>10 m) residual within the alluvium. Within EL 5460 the residuals are generally good (< +/- 10m) except for MB3 (Regolith), which would warrant further investigation at the EIS stage (i.e. with a refined model grid). The remaining areas are also generally good (< +/- 20m, mostly < +/- 10m), with the lack of underestimates (+ve residual) agreeing with the calibration data presented above. The slight overestimation translates to estimated water levels and fluxes, confirming that this Gateway process model is a conservative predictor.

4.8.3 WATER BALANCE

The water balance reported by MODFLOW-USG includes predicted inflows and outflows for various components of the model. The Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) suggest that a value less than 1% total predicted inflow and outflow discrepancy should be achieved, while greater than 5% would be unacceptable.

The water balance output shown in **Table 24** has a 0.0% total flow discrepancy (to 2 significant figures), indicating very good model convergence.

Table 24 Calibrated Steady-State Water Balance

Component	Inflow (ML/day)	Outflow (ML/day)
Recharge (Direct Rainfall)	29.65	0
ET (Evapotranspiration)	0	43.72
Wells	0	0
Streams (Leakage/Baseflow)	1.58	14.50
Head Dependent Boundary (GHB)	30.86	3.87
Total	62.09	62.09

4.9 TRANSIENT VERIFICATION

The transient verification of the groundwater model was performed manually, covering the period from 1 January 2001 to 31 December 2018 in monthly steps (Stress period 1 to Stress period 216). Historical monthly rainfall was applied to each stress period (to the present day). An automated sensitivity analysis was performed on the Specific Yield (Sy) parameter in layer 1 to test the match between observed and simulated groundwater level fluctuations over the verification period.

Seven Government monitoring bores located in the Alluvium zone were included in the Transient Verification Target Bore list (**Appendix F**) to better estimate impacts on the 'highly productive' groundwater zone. The verification process has excluded groundwater levels affected by mining and therefore does not include any mining stress from neighbouring mines (e.g. Mount Arthur and former Drayton Mine). The bore hydrographs shown in **Appendix F** include the Government monitoring bores, monitoring bores within EL 5460 and Spur Hill EL 7429 VWPs. Hydrographs from Mount Arthur Mine were not included as they were affected by mining, and the bore census records from the Spur Hill Underground Coking Coal Project were not included as they only have a single observation value.

4.9.1 RESULTS

The initial (representative) values and adopted values for storage parameters are shown in **Table 25**. In keeping with the Gateway Application guidelines and expectation of a "simple modelling platform", full transient calibration is deferred to the EIS stage.

Table 25 Indicative (Initial) Storage Properties of Stratigraphic Units Before and After the Transient Verification

Layer	Description	Zone	Initial Values		Calibrated Values	
			Ss (m^{-1})	Sy	Ss (m^{-1})	Sy
1	Regolith	1	0.0001	0.01	0.001	0.002
1	Alluvium	2	0.0001	0.01	0.001	0.05
2	Whybrow overburden	3	0.0001	0.01	0.001	0.05
3	Whynot overburden	4	0.0001	0.01	0.001	0.01
4	Whynot seam	5	0.0001	0.01	1E-5	0.03
5	Woodlands Hill overburden	6	0.0001	0.01	1E-5	0.01
6	Woodlands Hill seam	7	0.0001	0.01	1E-5	0.03
7	Arrowfield overburden	8	0.0001	0.01	1E-6	0.01
8	Arrowfield seam	9	0.0001	0.01	1E-6	0.03
9	Bowfield overburden	10	0.0001	0.01	1E-6	0.01
10	Bowfield seam	11	0.0001	0.01	1E-6	0.03
11	Warkworth overburden	12	0.0001	0.01	1E-6	0.01
12	Warkworth seam	13	0.0001	0.01	1E-6	0.03
13	Underburden to Ramrod Creek seam	14	0.0001	0.01	1E-6	0.01
14	Underburden to Branxton Formation (Greta Coal Measures)	15	0.0001	0.01	1E-6	0.01

Verification (transient) model performance is good with 4.5% SRMS weighted error (**Table 26**), which is below the target 10% SRMS suggested in the MDBC Groundwater Flow Modelling Guideline (MDBC 2001).

Table 26 Summary of Verification Model Performance Statistics

Performance Statistic	Value
Number of Observation Bores	107
Number of Data Points	6,156
Root Mean Square (m)	8.28
Scaled Root Mean Square (SRMS) (%)	4.49

Observed and predicted bore water levels for the transient verification model, as well as the weights the various bores were given during the transient verification runs, are shown in **Figure 39**. Reflecting the calibration model, the points in **Figure 39** show a very good fit to the identity line over the complete range of measurements, with again a tendency for overestimation indicated.

Figure 40 shows observed bore water levels and calibration model residuals. **Figure 40** once again shows some overestimation (negative residual). However, there is no bias shown across the water level depth range or between measurements from different areas. The diagonal pattern highlights the difficulty in matching temporal VWP heads.

Figure 41 shows a map of predicted water table levels after the verification runs, before mining commences, and **Appendix G** shows the verification hydrographs.

4.9.2 WATER BALANCE

The water balance output shown in **Table 27** has a total flow error of less than 10E-05%, again indicating good model convergence.

Table 27 shows a total input of 65.6ML/day, dominated by rainfall recharge (44%) and boundary inflow (47%), with inflow from storage providing 7% and leakage from streams to the aquifer 2%.

Inflow from rainfall is about 3% higher than the steady-state simulation values while leakage from streams is 1% higher and boundary inflow is about 0.5% lower.

Outflow from the model (65.6 ML/day) is primarily from evapotranspiration (68%), with lesser amounts contributed by baseflow to rivers and streams (22%), outflow to storage (4%) and boundary outflow (6%).

Outflow to the boundary and evapotranspiration have increased by about 6% and 2% respectively compared with the steady-state simulation values, and baseflow to the streams has increased by 1%.

Over the 18 years of the verification period, there is a predicted storage loss of 2.1 ML/day which is consistent with about 3% lower rainfall recharge than the long-term average adopted for the steady-state simulation.

Table 27 Transient (Verification) Model Water Balance Averaged over 18 Years

Component	Inflow (ML/day)	Outflow (ML/day)
Storage	4.5	2.4
Recharge (Direct Rainfall)	28.8	0
ET (Evapotranspiration)	0	44.5
Wells	0	0
Streams (Leakage/Baseflow)	1.6	14.6
Head Dependent Boundary (GHB)	30.7	4.1
Total	65.6	65.6

4.9.3 SENSITIVITY ANALYSIS

The sensitivity of the verification model to the storage parameter Specific Yield (Sy) was tested with three model runs, varying the calibrated Sy for the Alluvium (0.05) and Regolith strata (0.03) as shown in **Table 28:**

- Run 1, increased Sy in Alluvium (x 2) and Regolith strata (x 1.667) = improved RMS and RMS% by 0.01 (both).
- Run 2, alluvium unchanged, decreased Sy in Regolith strata (x 0.333) = worsened RMS by 0.01 but did not alter RMS%.
- Run 3, alluvium unchanged, decreased Sy in Regolith strata (x 0.067) = did not alter RMS or RMS%.

Table 28 Automated Sensitivity Analysis Runs and Associated Results

Run #	Sy Alluvium	Sy Regolith	RMS (%)	RMS (m)
1	0.1	0.05	4.48	8.27
2	0.05	0.01	4.49	8.29
3	0.05	0.002	4.49	8.28

The results above indicate that Specific Yield (Sy) had little effect on the resultant percentage RMS.

Decreasing Sy in Alluvium from 10% to 5% and Sy over the Regolith from 5% to 0.2% improved the match to the transient (seasonally varying) groundwater level data observed at the target bores, despite having marginally worse (0.01%) overall RMS results than run #1.

The parameter values in run #3 were selected for the final transient verification exercise.

The models and results outlined above indicate that the constructed groundwater model is suitable as a basis for mining predictions, in reproducing the observed groundwater levels across the range of historical observations.

5 PREDICTIVE MODELLING

5.1 MINING

5.1.1 MINE SCHEDULE

A schematic of the stress period setup for the Project groundwater model is provided in **Figure 42**. The prediction period runs for 27 years of active mine life (26 years of mining with 2019 included for infrastructure development), followed by 200 years of post-mining recovery. For this preliminary groundwater assessment, the first 18 years of the model were set to monthly stress periods (2001 to 2018), followed by yearly stress periods for the duration of mining (2019 to 2045) and four 50-year stress periods of post-mining recovery finishing in December 2245.

5.1.2 MODELLING IMPLEMENTATION

The potential impacts of the development were assessed by making comparisons between baseline (null) predictive runs (with no Project) and impacted predictive runs with the Project simulated using mining stresses as per **Figure 42**.

The underground mining and dewatering activities are defined in the model using drain cells within the mined coal seams, with drain elevations set to 0.1 m above the base of the coal seam. These drain cells were applied wherever workings occur and were progressed through time increments coincident with the stress period durations.

The stacked drains representing the fractured zones (see **Section 4.6**) were implemented based on the zone system outlined in **Section 4.6** and **Figure 32.** The series of zones define areas where fracturing would occur, based on the cells being progressively mined according to the mine schedule. That is, drains were turned on for cells above cells which are mined, at the start of mining, to the layer predicted to be fractured as outlined in **Section 4.6.2**. A schematic of the stacked drain zones is shown in **Figure 33.** The 'cells' in **Figure 33** are not intended to accurately depict model cells or mining progression. The diagram does, however, show the approximate areas of each zone, representing the areas of fracturing that are turned on progressively as mining progresses from layer 4 to layer 10, and for cells above the mined cells as specified by the fracturing model.

The main roadway headings were activated in advance of the active mining, but only in the layer being mined.

5.1.3 WATER BALANCE

The average water balance output over the entire model area for the predictive model at the end of mining is shown in **Table 29**. The results are similar to those from the verification run (**Table 27**), with the logical exception of the outflow to the drains. The 'error' term of 2.9E-04 % discrepancy is well below the acceptable error value of 1% (mass balance closure, Barnett *et al.* 2012).

Table 29 Mining Predictive Model Water Balance Averaged over 27 Years

Component	Inflow		Outflow	
	(ML/day)	%	(ML/day)	%
Storage	3.5	5	1.2	2
Recharge (Direct Rainfall)	28.9	45	0.0	-
Head Dependent Boundary (GHB)	30.9	48	3.9	6
ET (Evapotranspiration)	0.0	-	43.1	66
Streams (Leakage/Baseflow)	1.6	2	14.4	22
Drains and Wells	0.0	-	2.4	4
Total	64.9	100	64.9	100
Inflow – Outflow	1.9E-04			
Percent Discrepancy	2.9E-04			

Comparison of the tables show:

- The net storage loss of 2.1 ML/day has increased to 2.4 ML/day while rainfall recharge remains about the same.
- Recharge and head dependent boundary conditions dominate inflow with minor increases of 0.1 ML/day to 45% and 0.2 ML/day to 48% respectively.
- Head dependent boundary outflow is reduced to by 0.2 ML/day to 3.9 ML/day (6%).
- Evapotranspiration still dominates outflow, but is reduced by 1.4 ML/day to 66%.
- Leakage from the rivers and creeks is unchanged at 2%.
- Baseflow to rivers and creeks has reduced by about 0.2 ML/day to 14.4 ML/day, which still represents 22% of outflow.
- The outflow mechanism applied for the mined cells and fractured zones (stacked drains) provide an outflow of 2.4 ML/day or 4%.

5.1.4 PREDICTED WATER LEVEL CHANGES

Table 30 shows the induced losses from connected water sources, for the whole model domain averaged over 27 years of mining. Flow from the model (outflow) to a river (baseflow) is negative, and flow from a river (leakage) to the model (aquifer) is positive (inflow).

Table 30 shows increased flow from the Hunter to the alluvium starting in mining year 11 and increasing as mining progresses to a maximum of about 0.1 ML/day at the end of mining. Saddlers Creek is losing water to the unconsolidated alluvial sediments starting at mining year 5, with the flow also increasing to 0.1 ML/ day as mining progresses. Leakage from the rivers to the alluvium during the mining averages at 0.09 ML/day, which agrees with the water balance result of negligible inflow change.

Table 30 Whole Model Predicted Induced Flows, Porous Rock, Alluvium, Hunter River and Saddlers Creek

Mining Year	Impact to Hunter River – Baseflow from Alluvium (ML/day)*	Impact to Hunter River – Leakage to Alluvium (ML/day)	Saddlers Creek – Leakage to Alluvium (ML/day)	Net Flow - Rivers to Alluvium (ML/day)	Alluvium Loss – Flow to Permian (ML/day)
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	-0.01	0.00	0.00	-0.01	0.01
5	-0.01	0.00	0.02	0.01	0.03
6	-0.01	0.00	0.03	0.02	0.04
7	-0.01	0.00	0.05	0.04	0.06
8	-0.01	0.00	0.06	0.05	0.07
9	-0.01	0.00	0.06	0.06	0.08
10	0.00	0.00	0.07	0.06	0.08
11	0.00	0.00	0.07	0.07	0.09
12	0.00	0.01	0.07	0.08	0.10
13	0.00	0.01	0.08	0.09	0.11
14	0.00	0.02	0.08	0.10	0.12
15	0.00	0.02	0.08	0.11	0.13
16	0.00	0.03	0.09	0.12	0.13
17	0.00	0.04	0.09	0.12	0.14
18	0.00	0.04	0.09	0.13	0.15
19	0.00	0.05	0.09	0.14	0.16
20	0.00	0.05	0.09	0.14	0.16
21	0.00	0.06	0.09	0.15	0.17
22	0.00	0.06	0.10	0.16	0.17
23	0.00	0.07	0.10	0.16	0.18
24	0.00	0.07	0.10	0.17	0.19
25	0.00	0.07	0.10	0.17	0.19
26	0.00	0.08	0.10	0.18	0.20
27	0.00	0.08	0.10	0.18	0.20
			average	**0.09**	**0.11**

* Negative values represent a numerical effect in the model.

Flows from the alluvium to the Permian porous rock aquifer also increase as mining progresses, as would be expected. The average losses over the mining period (0.11 ML/ day) indicate a small average loss from the alluvium to the Permian porous rock aquifer over the 27 years of mining of about 0.02 ML/ day.

Figure 43 shows the Alluvium loss during mining including the recovery period flux, and **Figure 44** displays flows in the Hunter River and Saddlers Creek. Including the recovery period fluxes.

As discussed above, the figures confirm the data presented in **Table 30**, and confirms the negligible changes to flows between the alluvium and the Hunter River and Saddlers Creek over the model area during mining, for the whole model domain. **Figure 46** shows the predicted water table contours at the end of 2045 without mining, and **Figure 47** shows the predicted water table contours at the end of 2045 including mining. **Figure 48** presents the predicted water table drawdown at the end of 2045 including the effects of mining.

The AI Policy stipulates that there should be less than 2 m head reduction at 'any water supply work'. The 2 m drawdown contour shown in **Figure 48**, is wholly within the boundary of EL 5460 and mine-owned land, and so would not impinge on any neighbouring water supply works.

Figure 49 to **Figure 53** show the water level drawdowns at the end of mining for layers 2, 4, 6, 8, and 10.

5.1.5 PREDICTED MINE INFLOWS

Throughout the predictive period, the fractured zones invoked in the groundwater model above the underground mining areas were progressed in accordance with the mine plans (**Figure 4**). As presented in **Table 21**, drain conductances, were set to 1m^2/d in seams, 0.1 m^2/d in interburdens and 0.01 m^2/d in discontinuous fractured or constrained zones. The properties of layer 1 were not changed during the prediction run (for the base case model).

Model predicted inflows for the Project are shown in **Figure 54**. Inflow is quite slow for the first 3 years, when only the Whynot seam (bord and pillar) is operating (0.05 to 0.15 ML/d). Inflow increases when the Woodlands Hill seam operations begin (first longwall), with large contributions from the seam (layer 6) and overburden (layer 5). The apparent overcontribution from layer 5 is partially due to the thickness of this layer. With an average thickness of 166m (in the mined zone), it is more than three times the thickness of any other layer. This effect continues while the Woodlands Hill seam is in operation, with the interburden progressively contributing more than the seam until maximum inflow is reached in 2027 at 3.7 ML/day.

After 2027, contributions from the Whynot seam (layer 4), Woodlands Hill seam (layer 6), and associated interburden/overburdens (layers 3 and 5) diminish, and overall inflow reduces despite the contributions from lower seam operations. Relatively higher inflows of (3.4 to 3.5 ML/day) persist from 2027 to 2036 while multiple seam operations are occurring. The combined inflow value at the end of mining is 2.6 ML/day, with an average from 2019 to 2045 of 2.75 ML/day (i.e. 1004 ML/year).

The maximum total inflow (3.7 ML/day) is slightly less than the predicted value of 4.8 ML/day for the previously proposed Spur Hill Underground Coking Coal Project (adjacent to this Project) (Heritage Computing 2013).

The difference between the average water balance drain outflow (2.4 ML/day, see above) and the average mine inflow data (2.75 ML/day) is likely to be related to different time steps reported by GWV for aggregating model reaches (zones related to drain cells etc.) used in flux calculations compared with the zone water budget. The error is manifest in an overestimation of average mine inflows (0.3 ML/day), which makes this a conservative estimate. A more refined method of modelling the fractured zone would be undertaken for the EIS model.

5.1.6 DRAIN CONDUCTANCE SENSITIVITY

The stacked drain model (see **Section 4.6.2**) was used to simulate the effects of fracturing from multi-node wells, representing a fracture network above modelled longwall mining panels. This model provided a set of conductances for the drains and zones of influence (fractured zones) for the model cells above each mined longwall cell, shown in **Table 21**, and **Figure 32** initially set to 1.0 for mined seams, 0.1 for interburden and continuous fractured zones and 0.01 for discontinuous fractured or constrained zone model cells. The surface (layer 1) properties were unchanged.

A series of model scenario runs was performed to test the sensitivity of the mine inflows predicted by the model to the drain conductance values:

1. Enhanced drain conductances, by an order of magnitude (with respect to the base case) to 10 m^2/day in seams, 1 m^2/day in interburdens and 0.1 m^2/day in discontinuous or constrained fractured zones.
2. Enhanced drain conductances, by an order of magnitude (with respect to the base case) to 10 m^2/d in seams, 1 m^2/d in interburdens and 0.1 m^2/d in discontinuous or constrained fracture zones and layer 1 vertical hydraulic conductivity (Kz) increased by a factor of 10 x the host value.
3. Reduced drain conductances, by an order of magnitude (with respect to the base case) to 0.1 m^2/d in seams, 0.01 m^2/d in interburdens and 0.001 m^2/d in discontinuous or constrained fractured zones.

Comparative results from the drain conductance sensitivity runs are presented in **Table 31**.

Table 31 Drain Conductance Sensitivity Results

Run #	2019 – 2045 Average Inflow		Comparison to Base Case
	ML/d	ML/year	(2.8 ML/d)
1	5.1	1,863	+ 82 %
2	4.9	1,790	+ 75 %
3	0.9	329	- 68 %

Comparison of the base case to run #1 (drain conductances increased by a factor of 10), shows (**Figure 54** and **Figure 55**):

- An increase in inflow (82%).
- Similar temporal patterns.
- Increased contribution by layer 3 (+12%) and layer 7 (+10%) at the expense of layer 5 (-10%) (all interburden).
- Reduced contributions from the seams in layer 4 (Whynot seam, -4%) and layer 6 (Woodlands Hill seam, -11%).
- Increased contribution from layer 8 (Arrowfield seam, +3%).
- Layer 9 and 10 contributions are negligible.

Variation from base case to run #2 (drain conductances increased by a factor of 10 and L1 Kz increased by a factor of 10) is very similar to run #1, with a minor change in total inflow (**Figure 54** and **Figure 56**).

Run #3 comparison to base case (conductance reduced by a factor of 10) shows (**Figure 54** and **Figure 57**):

- A reduction in inflow (68%).
- A reversal of contributions, with the seam contributions dominating the system.

The results demonstrate that the model is clearly sensitive to the conductance values assigned to various drain cells. The values used in the prediction run were selected as appropriate based on sound theoretical considerations (see **Section 4.6**). Further investigations into the impact of mining on the hydraulic properties of overlying strata (and the application of drain conductances) would be conducted as part of the EIS process.

5.2 POST MINING RECOVERY

At the end of mining, the stacked drain system was turned off, and the model was run for four fifty-year time steps, with enhanced permeability parameters in the fractured zone to model system recovery. **Table 32** shows the hydraulic properties applied to the fractured zone model cells. The properties of layer 1 were unchanged, as no drains had been used in that layer.

The initial Kz properties in the table were selected based on fractured zone properties used in the Spur Hill Underground Coking Coal Project Gateway process groundwater model (Heritage Computing 2013), which were then adjusted so that conditions at the start of the recovery model matched conditions at the end of the mining prediction model runs.

Table 33 shows the induced losses from connected water sources, for the whole model domain averaged over 200 years of recovery. All tables and figures show losses or gains with respect to the baseline (no mining) condition. Flow from the model (outflow) to a river (baseflow) is negative, and flow from a river (leakage) to the model (aquifer) is positive (inflow).

Table 32 Hydraulic Properties for the Recovery Model Scenario

Layer	Kz (Host) (m/ day)	Initial Kz (m /day)	Deformed Kz (m/ day)	Sy (Host)	Deformed Sy
1 (Alluvium)	5.80E-02	NA	NA	0.05	NA
1 (Regolith)	6.17E-03	NA	NA	0.002	NA
2	4.74E-05	1.41E-04	7.10E-05	0.05	0.05
3	1.50E-03	2.00E-03	1.60E-03	0.01	0.01
4	**1.69E-07**	**10**	**10**	**0.03**	**0.2**
5	1.26E-05	3.74E-05	1.80E-05	0.01	0.01
6	**2.93E-05**	**10**	**10**	**0.03**	**0.1**
7	7.05E-06	9.80E-06	9.80E-06	0.01	0.01
8	**5.59E-04**	**10**	**10**	**0.03**	**0.1**
9	9.43E-07	9.80E-06	9.80E-06	0.01	0.01
10	**1.59E-04**	**10**	**10**	**0.03**	**0.1**
11	9.04E-06	NA	NA	0.01	NA
12	1.62E-05		NA	0.03	NA
13	3.00E-07		NA	0.01	NA
14	1.04E-06		NA	0.01	NA

Table 33 Predicted Alluvium and River Fluxes During Recovery Period

Years After Mining	Impact to Hunter River – Baseflow from Alluvium (ML/year)	Impact to Hunter River – Leakage to Alluvium (ML/year)	Saddlers Creek – Leakage to Alluvium (ML/year)	Net Flow - Rivers to Alluvium (ML/year)	Alluvium Loss – Flow to Permian (ML/year)
50 (2096)	0	49.8	44.6	94.4	98.7
100 (2146)	0	45.8	37.8	83.6	87.2
150 (2196)	0	37.6	31.1	68.7	71.7
200 (2246)	0	28.7	25.6	54.3	56.7
Maximum Predicted Impact					
2080	0				98.8
2100		50.0			
2158			45.4		

Table 33 shows that the Hunter River continues to act as a net losing stream over the whole model area, with the flow rate increasing after the end mining to a maximum of 50.0 ML/ year (about 0.1 ML/day) in 2100. Saddlers Creek continues to lose water to the unconsolidated alluvial sediments throughout the recovery period, with the flow also increasing to a maximum of 45.4 ML/year (about 0.1 ML/day). Leakage from the rivers to the alluvium during the recovery period averages at 75.3 ML/year (about 0.2 ML/day), which agrees with the inflow change for the whole model domain during mining.

Flows from the alluvium to the Permian porous rock aquifer also increase after the end of mining. The maximum losses after the end of mining period is 98.8 ML/year (0.3 ML/day) in 2080.

Figure 43 shows the alluvium loss during mining and recovery. Note plot is ML/day, so the value for alluvium (for example), 56.7 ML/year in **Table 33** is approximately 0.16 ML/day for 2246 as shown on **Figure 43**.

Figure 44 displays flows in the Hunter River and Saddlers Creek. As above, flows on the diagram are in ML/day. **Figure 44** therefore shows end of mining fluxes to Saddlers Creek and the Hunter River of about 0.08 ML/day, and 0.07 ML/day respectively.

Figure 45 shows the predicted recovery period water levels for bore DD1016, within the Project area (**Figure 38**) extending to layer 5. The figure shows a virtually linear rise in (predicted) recovery water level of 80 to 90 m for 150 years after mining ceases, following which the rate of increases starts to slow, indicating a protracted full recovery which could continue for decades before complete stabilisation (about another 50 m).

5.3 CLIMATE VARIABILITY

The IESC Information Guidelines (IESC 2018) indicate that water balance information for post mining scenarios under a range of climatic conditions should be provided for coal seam gas and large coal mining development proposals. They further note that Australian Climate Futures Tool (CSIRO 2015) can guide the definition of these scenarios. The 'East Coast south sub-cluster', which comprises regions in the central part of the eastern seaboard of Australia. (Dowdy *et al*. 2015), provides several key messages, including that:

- Decreases in winter rainfall are projected with medium confidence. Other changes are possible but unclear.
- Increased intensity of extreme rainfall events is projected, with high confidence.

The potential effect of climatic changes was assessed by impact on the predicted mine inflows, being the parameter most related to mining activity.

Model scenarios were run based on three differing rainfall/recharge possibilities, based on 27-year period (to match the mining predictive model) annual rainfall sets in the total record (1889 to 2017, see **Section 3.2**):

1. Average rainfall conditions – the 27-year set with the average matching the average annual rainfall for all sets (base case).
2. Increased rainfall conditions – the 27-year set with the average matching the maximum average annual rainfall of any set.

3. Decreased rainfall conditions – the 27-year set with the average matching the minimum average annual rainfall of any set.

Other model parameters such as evapotranspiration were not changed from the mining predictive model values.

Table 34 presents inflow values for the various scenarios, and **Figure 62** shows a plot of the data. As the table and figure show, the predicted mine inflows are virtually identical, with the maximum change being about 0.01 ML/day, or about 0.3%. Climatic variation is therefore expected to have a negligible impact on flows in the system.

Further analysis based on climate model predictions would be undertaken for the EIS study, but this approach provides a good indicative result appropriate to a Gateway process assessment.

Table 34 Predicted Mine Inflows (ML/day) for Differing Climate Scenarios

Year	Base	Run 2	Change (base – run 2)	Run 3	Change (base – run 3)
2019	0.1	0.1	9.7E-06	0.1	4.7E-05
2020	0.1	0.1	-7.2E-05	0.1	1.9E-04
2021	0.2	0.2	-2.2E-04	0.2	3.4E-04
2022	1.6	1.6	-8.3E-04	1.6	9.1E-04
2023	1.8	1.8	-1.2E-03	1.8	1.3E-03
2024	2.2	2.2	-1.5E-03	2.2	2.1E-03
2025	2.8	2.8	-1.5E-03	2.8	2.3E-03
2026	3.0	3.0	-1.4E-03	3.0	2.8E-03
2027	3.7	3.7	-1.8E-03	3.7	3.5E-03
2028	3.6	3.6	-1.8E-03	3.6	3.7E-03
2029	3.5	3.5	-2.1E-03	3.5	4.0E-03
2030	3.4	3.4	-2.6E-03	3.4	4.3E-03
2031	3.5	3.5	-3.1E-03	3.5	4.0E-03
2032	3.5	3.5	-3.4E-03	3.5	3.7E-03
2033	3.5	3.5	-3.5E-03	3.5	3.5E-03
2034	3.5	3.5	-3.7E-03	3.5	3.4E-03
2035	3.5	3.5	-4.0E-03	3.5	3.1E-03
2036	3.5	3.5	-3.9E-03	3.5	3.2E-03
2037	3.4	3.4	-3.1E-03	3.4	3.6E-03
2038	3.4	3.4	-3.8E-03	3.4	4.3E-03
2039	3.2	3.3	-4.4E-03	3.2	5.2E-03
2040	3.1	3.1	-4.3E-03	3.1	6.4E-03
2041	3.0	3.0	-4.8E-03	3.0	7.4E-03
2042	2.9	2.9	-5.5E-03	2.9	8.4E-03
2043	2.8	2.8	-5.6E-03	2.8	8.6E-03
2044	2.7	2.7	-5.4E-03	2.7	8.9E-03
2045	2.6	2.6	-5.4E-03	2.6	9.7E-03

6 POTENTIAL IMPACTS TO WATER RESOURCES AND WATER-DEPENDENT ASSETS

6.1 FRAMEWORK FOR ASSESSMENT OF IMPACTS

This assessment focuses on the requirements of the AI Policy and the Gateway process. **Table 3** lists the report sections relevant to the various Gateway requirements.

The main potential impacts on the groundwater regime due to underground mining arise from changes in bulk rock mass permeability caused by the fracturing associated with longwall subsidence, and the pumping out of groundwater that enters the mine consequently. Effects on the hydrogeological system during and after mining operations have been evaluated as part of the impact assessment.

The description of the water-dependent asset register for the Hunter subregion (Macfarlane *et al*. 2016) of the Northern Sydney Basin Bioregional Assessment provides guidance for identification of ecological (e.g. surface water feature, groundwater feature [subsurface] and vegetation [GDE or potential habitat]), economic (groundwater management zone or area [surface area] and surface water management zone or area [surface area]) and sociocultural (e.g. cultural and social) assets. The following sub-sections have been prepared in consideration of the water dependent asset register and asset list for the Hunter subregion on 15 June 2017.

6.2 GROUNDWATER DEPENDENT ECOSYSTEMS

At the time of writing, the nearest 'high priority' GDE listed in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018) to the Project area is Wappinguy Spring, near Merriwa, more than 50 km to the north-west. Hence there are no known risks as a result of the proposed mine development to such 'high priority' GDEs (**Figure 7**). Similarly, there are no 'high priority' GDEs listed in the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (version current for 1 July 2016) within 20 km of the Project. At the time of writing the nearest 'high priority' GDE to the Project area is Parnell Spring in the Wollemi National Park to the south-southeast. There is no known risk of mine development to such 'high priority' GDEs.

The BOM hosts the National Atlas of Groundwater Dependent Ecosystems (GDE Atlas, accessible through the BOM website: http:\\www.bom.gov.au).

The GDE Atlas comprises maps that show the location of both known and potential GDEs across Australia, as well as ecological and hydrogeological information for each GDE. The GDE layers in the Atlas include GDEs identified in previous studies, and potential GDEs derived through new spatial analysis using existing feature layers and products developed from analysis of remotely sensed data.

GDEs derived in the analysis are mapped according to the following classifications:

- High potential for groundwater interaction.
- Moderate potential for groundwater interaction.

- Low potential for groundwater interaction.

Figure 63 shows a map of potential GDEs derived from the GDE Atlas for the Project area and surrounds. There are no areas of high or moderate GDE potential within the Project area. Areas of moderate or high GDE potential within the broader model area are restricted to reaches along the Hunter River and other rivers and creeks to the west and south of the Hunter River.

None of the creeks north of the Hunter River, such as Saddlers Creek and Ramrod Creek have moderate or high GDE potential areas. There are areas of low GDE potential within the Project area, along Saddlers Creek and Saltwater Creek.

According to the GDE Atlas glossary, GDEs with 'Low potential for groundwater interaction' are defined as having the following properties:

- Ecosystems that are unlikely to be interacting with groundwater.
- Either groundwater is unlikely to be present, or if groundwater is present, the ecosystem is unlikely to be using it.
- Either all datasets suggest groundwater interaction is unlikely, or the most reliable dataset suggests that groundwater interaction is unlikely.

A depth to water table map has been prepared (**Figure 24**) which demonstrates that areas within EL 5460 away from streamlines have standing water table depths predominantly at greater than 10 m, which supports the proposition that most ecosystems within EL 5460 are unlikely to be interacting with groundwater.

Further analysis of the potential impacts of the Project on GDEs, where present, would be considered in an EIS.

6.3 CULTURALLY SIGNIFICANT SITES

At the time of writing there were no listed groundwater-dependent culturally significant sites in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018). Hence there are no known risks of mine development to such sites.

6.4 SIMULATED IMPACTS ON GROUNDWATER LEVELS

The Project would cause depressurisation of the Permian strata. The Permian coal measures within the mine footprint are predicted to be essentially dewatered during mining of the target coal seams. Outside the mine footprint, depressurisation impacts on potentiometric pressures within Permian strata would occur.

The modelled potentiometric drawdown impacts of the proposed mine development are presented in **Figure 49** to **Figure 53** for model layers 2 (uppermost overburden), 4 (Whynot seam), 6 (Woodlands Hill seam), 8 (Arrowfield seam) and 10 (Bowfield seam). Each of these figures presents the maximum modelled potentiometric drawdown in each model layer at the end of mining. The areas where the model layer pinch out are shown as white areas on the plots. There are no drawdowns predicted in the Hunter River alluvium (layer 1) as there is no mining proposed directly beneath the alluvium.

Maximum drawdown in layer 2 occurs in and around the mining footprint, and rapidly diminishes, extending south with values of 2 to 4 m (at depth) below the Hunter River (**Figure 49**). In this area, the surface of layer 2 is about 15 to 20 m below the ground surface (**Appendix E**, **Figure E1**), and the layer thickness is over 100m, and so impact on overlying regolith and alluvium would be minimal.

Within the deeper layers drawdowns increase and the depressurisation effects spread to a greater extent around the mining footprint. Depressurisation to the east is restricted due the pinching out of layers.

Maximum depressurisation extents of >2m extend (at depths) approximately 9 km south, 3 km west and 6 km north of the EL 5460 boundary.

As already noted in **Section 5.1.4**, the predicted water table drawdown at the end of mining does not exceed 2m at any point beyond the EL 5460 boundary.

6.5 CUMULATIVE MINING IMPACTS

The cumulative impacts of the Project with surrounding mines and major water users in the vicinity have been considered as part of this study, in accordance with the requirements of the AI Policy.

As indicated on **Figure 1** , the Mount Arthur Mine (less than 10 km to the north) is the closest operating mine to the Project, along with the former Drayton Mine voids.

Information for the Mount Arthur Mine (open cut and approved underground) predicted impacts (AGE 2013) indicates water table drawdown (>2m) mostly on the northern side of Saddlers Creek (opposite bank to the Maxwell Underground) (**Figure 64**). There are no data points shown, but interpolated data (**Figure 64**) suggests drawdown is generally <2m to the southeast of Saddlers Creek.

Drawdown was also reported (Mount Arthur Underground, MER 2007) for coal seams (Piercefield and Glen Munro) underlying Saddlers Creek, but in the shallow (regolith) zone drawdown was less than 2m along Saddlers Creek, with a small area >2m to the south of Saddlers Creek in agreement with the report on the combined operations (AGE 2013).

Malabar is continuing to undertake work to enhance the geological understanding of the zone where EL 5460 meets the Spur Hill Coking Coal Project EL 7429. This improved understanding would be used to optimise the development plans for the Spur Hill Underground Coking Coal Project in the future. At this stage, it is not anticipated that the Spur Hill Underground Coking Coal Project would proceed as proposed in previous documentation.

Notwithstanding, the previously reported Spur Hill Underground Coking Coal Project (underground mining) data (**Figure 65**) shows small areas of maximum drawdown (2 to 5 m) in the alluvium and regolith in the central and northern part of EL 7429. The central area is about 5 km west of Saddlers Creek and a considerable distance from the Project area (at least 10 km west), and on the opposite bank of Saddlers Creek.

Cumulative impacts of mining have been evaluated using the Principle of Superposition (**Section 2.3**). The focus of the cumulative effects analysis was the water table drawdown, the parameter being the most appropriate for evaluating impact on the alluvium and regolith water resources, and any impact on rivers and creeks. The only potential for cumulative impact is therefore from the combined operations of the Maxwell Underground and the Mount Arthur Mine, as discussed above (AGE 2013).

For the purposes of this study, values were estimated from the available drawdown prediction map (**Figure 64**) for the Mount Arthur Mine, which were then added to predicted values from the Project Gateway process groundwater model. The cumulative drawdown results are shown in **Figure 66**.

Due to the localised nature of the drawdown fields, there are no areas of overlapping effects with significant drawdown from both mining developments (**Figure 66**). Drawdown from Mount Arthur Mine is negligible (<1 m) across most of the Maxwell Underground, with a small area on the northern boundary showing >2 m, and so no cumulative effects are apparent.

It is noted that the Drayton South Coal Project is not proceeding, and therefore is not considered in the cumulative effects.

6.6 POTENTIAL IMPACTS ON EXISTING GROUNDWATER USERS AND OTHER LICENSED WATER USERS

The simulated maximum (Project only) drawdown impacts on existing groundwater users in the region are presented in **Table 35**. The impacted bore locations are shown in **Figure 67**.

Table 35 presents the maximum (Project only) drawdowns for all registered bores within the model extent which are impacted due to a predicted cumulative total drawdown greater than 2 m, the AI Policy criterion. Cumulative drawdown reveals the cumulative effects of the Project and other nearby mining activities (see **Section 6.5**). The bores in **Table 35** are subdivided into those within 10 km of the Gateway Application Area and within the exploration licence (EL 5460).

Table 35 shows only two impacted bores within the exploration licence area (GW029655 and GW078709) and 27 in the wider model extent with greater than 2 m cumulative drawdown. Of these, only one bore (GW049223) has a drawdown due to the project > 2 m.

Details for the specific bores mentioned above are scant, but the Water NSW database provides the following information (all depths are below ground surface):

- GW029655:
  - Has a water bearing zone at about 23 m depth with one recorded water table at about 18 m.
  - Bore Depth is 25.3 m.
  - Water bearing zone is described as ‘Fractured’.
  - Has no alluvium recorded.
  - Is > 2km from reported alluvium.

- GW078709:
    - Has no information available, but is about 250 m from GW029655.
- GW049223:
    - Has water bearing zones at about 27 m, 37 m and 60 m, no reported water table.
    - ‘Soil, Clay’ and ‘Gravel River’ reported to 0.3 m, 12.2 m and 13.7 m respectively, underlain by shale then sandstone from 17 m, followed by shale, ‘Unknown’ clay (0.2m thick) and sandstone of various thicknesses.
    - Bore depth is 67.1 m.
    - Is close to/ within alluvium boundary.
    - Is located on land associated with Mt Arthur Mine.

Given this information, bores GW029655 and GW078709 are not drawing water from alluvial sources, and drawdown of < 2m will be unlikely to impact bore performance, with a water table standing at about 18 m from water bearing zones about 5m lower.

Bore GW049223 is also not drawing water from alluvial sources. Without water table information it is impossible to define the absolute effects of the predicted maximum drawdown of about 21 m. However, with water bearing zones starting at about 28m and concluding some 40m lower it is unlikely that this drawdown would affect the bore yield. Drawdown from other (nearby) mining activity is <2m at this bore.

Bores impacted by other mining activity in or near alluvial zones (GW059131 and GW024700) also have little or no information available from Water NSW. It is likely that these bores have been or would be subject to investigation by operators of the mining activity primarily responsible for drawdown effects. Information to better define these bores and any associated activity would be undertaken for the EIS.

Hence there would be negligible impacts on any bores located in the ‘highly productive’ Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) from the Project.

Table 35 Modelled Project Impacts on Registered Bores within the model extent (Excluding Monitoring Bores) with > 2m cumulative drawdown

WORK NO.	LICENCE	EASTING	NORTHING	PURPOSE	DEPTH (m)	MALABAR OWNED	DRAWDOWN DUE TO PROJECT (m)
	Within Exploration Licence EL 5460						
GW078709	20BL167443	290749	6412391	NOT KNOWN	50	NO	1.26
GW029655	20BL023405	290702	6412144	STOCK	25.3	NO	1.35
	Within 10KM OF THE Gateway Application Area						
GW029645	20BL023939	289066	6414082	NOT KNOWN	18.3	NO	0
GW029646	20BL023938	292841	6414900	NOT KNOWN	9.1	NO	0.15
GW029647	20BL023417	291005	6413906	STOCK/DOMESTIC	36.6	NO	0.14
GW029648	20BL023418	290875	6413873	STOCK/DOMESTIC	31.1	NO	0.13
GW029649	20BL023419	291321	6413790	NOT KNOWN	25.9	NO	0.14
GW029658	20BL023408	289462	6413936	STOCK	55.8	NO	0.08
GW029661	20BL023406	293054	6414688	STOCK	42.7	NO	0.20
GW031622	20BL024276	294440	6415949	STOCK	91.4	NO	0
GW031623	20BL023652	294122	6417453	STOCK	38.1	NO	0.01
GW031859	20BL024674	294633	6415460	STOCK	61	NO	0.06
GW032077	20BL024716	294266	6416778	STOCK	53.3	NO	0.20
GW032512	20BL024338	294386	6418629	STOCK	33.5	NO	0.01
GW033193	20BL026154	293686	6417043	STOCK	46.9	NO	0.15
GW033547	40BL026898	296176	6415461	STOCK	12	NO	0
GW033915	20BL024261	294185	6419509	STOCK	39.6	NO	0
GW045469	20BL103870	295550	6420532	STOCK	49.1	NO	0
GW049223	20BL106334	298120	6413682	STOCK	67.1	NO	20.78
GW078707	20BL167441	289548	6413537	STOCK	43	NO	0.11
GW078708	20BL167442	290888	6413226	STOCK	43	NO	0.07
GW078026	-	294351	6419981	STOCK/DOMESTIC	-	-	0
	Within Model Extent						
GW011295	20WA212203	290536	6425144	STOCK	29	-	0
GW024700	-	295573	6423275	STOCK	-	-	0
GW030745	-	296052	6422854	EXPLORATION/ RESEARCH	220	-	0
GW059131	20BL119201	294964	6424927	IRRIGATION	11.6	-	0
GW061636	20BL133914	291981	6426129	STOCK/DOMESTIC	42.7	-	0
GW073576	20BL166372	291596	6424675	STOCK/DOMESTIC	20	-	0
GW200003	20BL166521	291033	6425814	STOCK/DOMESTIC	21	-	0

6.6.1 OTHER LICENSED WATER USERS

Other water users near the Project area and surrounds include Godolphin Woodlands which has access to 3764.28 units from the Hunter Regulated River Source (WALs 1034, 1033, 1321, 789, 1271, 1020, 1215) and Coolmore which has access to 5,290 units from the Hunter Regulated River Source (WALs 11175, 13797, 616, 1311). As demonstrated in **Table 2**, Malabar also currently holds 1,423 units in the Hunter Regulated River Source, including a licence of 90 units which is used for irrigation of fodder crops or stock use.

As the Hunter River is a regulated river system (i.e. flow duration relationships show flow is non-zero all of the time), and given the licensed water volumes already held by Malabar are well in excess of the predicted leakage (maximum 50 ML/year) (**Section 5**), there would not be any impact on other licensed water users.

6.6.2 BASIC LANDHOLDER RIGHTS

Surrounding landholders exercising basic landholder rights are likely accessing water from shallow groundwater sources or surface water sources. The Project would have negligible impact on water users exercising their right to take water under a basic landholder right, given the modelled 2 m water table drawdown at the end of mining is not predicted to extend beyond the EL 5460 boundary (and is therefore primarily restricted to mine-owned land).

6.7 POTENTIAL IMPACTS ON GROUNDWATER QUALITY

Mining-induced changes to the hydraulic properties and depressurisation of the Permian porous rock strata in the mined area would result in mixing of potentially chemically different groundwater between overlying and underlying units. EC data for the coal measures from surrounding mines' publicly available reports suggests a mean EC of around 5,200 µS/cm (Heritage Computing 2013). As such, it is considered unlikely that mining-induced mixing of groundwater would result in changes to the beneficial uses of groundwater in the Permian porous rock units in or around the Project area during or following mining. The risk of these impacts decreases with distance from the active mining (goaf) area and enhanced rock mass fracturing.

In the long-term, increased leakage (albeit small) of surface water to the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) would result in a reduction in the salinity of the alluvial aquifer, which has an EC range of 1,187 to 6,490 µS/cm (**Section 3.6.2**), whilst the gauged Hunter River EC averages around 500 µS/cm at Denman. Average increased leakage from rivers and streams to the alluvium is predicted to be about 0.09 ML/day, which is insignificant compared to the background figure of average Hunter River loss of over 17 ML/day (**Figure 28**).

There is a predicted minor increase in leakage from the alluvium to the Permian porous rock aquifer, averaging 0.02 ML/day. This could potentially have a beneficial effect on the Permian porous rock water quality.

There are no simulated risks of reduced beneficial use categories of the alluvial water source because of the Project. Nor is there any predicted increase in the salinity of the Hunter River.

6.8 OTHER IMPACTS OF MINING

For the 'highly productive' groundwater source of the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone), the AI Policy requires that:

- There be no mining activity below the ground surface within 200 m laterally from the high bank, or 100 m vertically beneath the alluvial water source (whichever is the lesser).
- Not more than 10% cumulatively of the three-dimensional extent of the alluvial material to be excavated by mining activities beyond 200 m laterally from the high bank, or 100 m vertically beneath the alluvial water source.

No mining activity within the above specified proximities to the 'highly productive' alluvial groundwater source is proposed.

The proposed Maxwell Underground mining area does not include mining directly beneath the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone). The Hunter River channel is located approximately 525 m south-west of the Project longwalls at its closest point.

The Woodlands Hill Seam mined closest to Saddlers Creek within the Jerrys Management Zone of the Jerrys Water Source is at a distance of approximately 240 m and a depth of approximately 140 m (**Figure 4** and **Figure 6** and **Figure E2**). The next closest mined seam (Woodlands Hill) is more than 250 m below the ground surface.

No excavation of the 'highly productive' alluvial sediments associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) is proposed.

6.9 SUMMARY OF ASSESSMENT IN TERMS OF THE AQUIFER INTERFERENCE POLICY

Table 36 summarises the preceding discussion of potential impacts of the Project in terms of the AI Policy minimal impact considerations for the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) which is the focus of the Gateway process.

Based on the findings of the groundwater modelling and assessment, the Project meets the Level 1 minimal impact consideration classification of the AI Policy for 'highly productive' groundwater associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone).

Based on available data, the unconsolidated alluvial sediments associated with Saddlers Creek within the Jerrys Management Zone of the Jerrys Water Source are classified as a 'less productive' groundwater source (**Section 2.1.2**). The Permian porous rock groundwater sources within the Sydney Basin – North Coast Groundwater Source are also classified as 'less productive'.

These water sources are assessed against the AI Policy minimal impact considerations in **Table 36**, **Table 38** and **Table 39.**

Table 36 Summary of Aquifer Interference Policy Assessment – Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone)

Aquifer	Alluvial Water Source: Hunter Regulated River Water Source (Upstream Glennies Creek Management Zone)
Category	Highly Productive Groundwater Source
Level 1 Minimal Impact Consideration	Assessment
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	At the time of writing the nearest 'high priority' groundwater dependent ecosystem listed in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018) to the Project area is Wappinguy Spring, near Merriwa, more than 50 kilometres to the north-west. There are no listed groundwater-dependent culturally significant sites in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018). Hence there are no known risks of mine development to such 'high priority' groundwater dependent ecosystems or groundwater-dependent culturally significant sites. No drawdown is predicted in excess of the criterion within the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone). **Level 1 minimal impact consideration classification.**
Water Pressure 1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	Not applicable as only unconfined conditions in the alluvial water source. Therefore, only the above water table consideration is relevant. **Level 1 minimal impact consideration classification.**
Water Quality 1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. 1. (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. 1. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three-dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". 1. (d) Not more than 10% cumulatively of the three-dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".	There are no simulated risks of reduced beneficial use categories of the alluvial water source as a result of the Project. Nor is there any predicted increase in the salinity of the Hunter River. No mining activity within these specified proximities to the alluvial water source is proposed. No excavation of the 'highly productive' alluvial sediments associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) is proposed. **Level 1 minimal impact consideration classification.**

Table 37 Summary of Aquifer Interference Policy Assessment – Alluvial Water Source: Jerrys Water Source (Jerrys Management Zone)

<table>
<tr><td>Aquifer</td><td colspan="2">Alluvial Water Source: Jerrys Water Source (Jerrys Management Zone)</td></tr>
<tr><td>Category</td><td colspan="2">Less Productive Groundwater Source</td></tr>
<tr><td colspan="2">Level 1 Minimal Impact Consideration</td><td>Assessment</td></tr>
<tr><td colspan="2">Water Table

1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 m from any:

(a) high priority groundwater dependent ecosystem; or

(b) high priority culturally significant site;

listed in the schedule of the relevant water sharing plan.

OR

A maximum of a 2 m water table decline cumulatively at any water supply work.</td><td>At the time of writing, the nearest ‘high priority’ groundwater dependent ecosystem the Project area listed in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018) to is Wappinguy Spring, near Merriwa, more than 50 kilometres to the north-west. There are no listed groundwater-dependent culturally significant sites in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 (version current for 14 January 2018). Hence there are no known risks as a result of the proposed mine development to ‘high priority’ groundwater dependent ecosystems or groundwater-dependent culturally significant sites.

No drawdown is predicted in excess of the criterion at any water supply within the Jerrys Water Source (Jerrys Management Zone).

Level 1 minimal impact consideration classification.</td></tr>
<tr><td colspan="2">Water Pressure

1. A cumulative pressure head decline of not more than 40% of the “post-water sharing plan” pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.</td><td>Not applicable as only unconfined conditions in the alluvial water source. Therefore, only the above water table consideration is relevant.

Level 1 minimal impact consideration classification.</td></tr>
<tr><td colspan="2">Water Quality

1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.
1. (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.
1. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three-dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a “reliable water supply”.</td><td>There are no simulated risks of reduced beneficial use categories of the alluvial water source as a result of the Project. Nor is there any predicted increase in the salinity of the Saddlers Creek.

No mining activity within these specified proximities to Saddlers Creek is proposed.

Level 1 minimal impact consideration classification.</td></tr>
</table>

Table 38 Summary of Aquifer Interference Policy Assessment – Permian Porous Rock Groundwater Sources: Sydney Basin – North Coast Groundwater Source

Aquifer	Permian Porous Rock Groundwater Sources: Sydney Basin – North Coast Groundwater Source
Category	Less Productive Groundwater Source

Level 1 Minimal Impact Consideration	Assessment
Water Table 1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work. 2. If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies(5) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than 2m decline cumulatively at any water supply work then make good provisions should apply.	There are no 'high priority' groundwater dependent ecosystems (GDEs) listed in the WSP within 20 km of the Project. At the time of writing, the nearest high priority GDE listed in the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (version current for 1 July 2016) to the Project area is Parnell Spring in the Wollemi National Park to the south-southeast. There are no listed groundwater-dependent culturally significant sites in the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Source 2016. Hence there are no known risks as a result of the proposed mine development to 'high priority' groundwater dependent ecosystems or groundwater-dependent culturally significant sites. The maximum drawdown due to the Project at any bore within 10 km of the Gateway Application Area is greater than 2 m at one bore. It is unclear whether this drawdown will affect bore use. More than 2 metres cumulative drawdown is predicted at some water supply works when taking account of surrounding mining operations. As such, a groundwater management plan should be developed and implemented for the Project. This plan should define a groundwater monitoring strategy, groundwater level triggers, and a trigger action response plan. **Level 2 minimal impact consideration classification.**
Water Pressure 1. A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	The maximum drawdown due to the Project at any bore within 10 km of the Gateway Application Area is 0.2 m, however more than 2 metres cumulative drawdown is predicted at some water supply works when taking account of surrounding mining operations. As such, a groundwater management plan should be developed and implemented for the Project. This plan should define a groundwater monitoring strategy, groundwater level triggers, and a trigger action response plan. **Level 2 minimal impact consideration classification.**

Aquifer	Permian Porous Rock Groundwater Sources: Sydney Basin – North Coast Groundwater Source
Category	Less Productive Groundwater Source

Level 1 Minimal Impact Consideration	Assessment
Water Quality 1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.	There are no simulated risks of reduced beneficial use categories of the Permian porous rock groundwater source as a result of the Project. **Level 1 minimal impact consideration classification.**

In addition to the development and implementation of a groundwater management plan, the Project should monitor total mine inflows during the life of the Project. These water takes would be required to be reported on an annual basis to DoI-Water, and should be periodically used, in conjunction with the monitoring network data, to verify the groundwater modelling and the potential risks of mining activity identified in this and/or future EIS assessments.

The identified potential impacts on groundwater bores (**Section 6.6**) would require refinement and further assessment during the EIS assessments including, but not limited to:

- survey to confirm existence, location, and construction details (i.e. bore census [**Section 10.4**]);
- confirmation of actual water use and entitlements at the bore;
- detailed quantification of drawdown impacts and/ or likely bore specific impacts (by the EIS groundwater model assessment); and
- identification of mitigation/remedial options and (if required) contingency actions.

7 PREDICTIVE UNCERTAINTY (INCLUDING SENSITIVITY ANALYSIS)

Predictive uncertainty in the groundwater model and model results can be described by error statistics and sensitivity analysis.

The Australian Groundwater Modelling Guidelines (Barnett *et al.* 2012) provides two quantitative criteria for model classification and assessment:

- For a medium confidence model, which is an appropriate level for this Project context (**Table 15**), a mass balance error of <1% is stipulated, reflecting the water balance error for the entire model.
- The SRMS (error), being a simple statistic of goodness of fit between observed and predicted values, should be <10%.

Both criteria were met by the Project model, with mass balance errors of 2.9E-04 %, and SRMS values of 7.5% (steady state) and 4.5% (transient verification).

Sensitivity analysis allows the robustness of the groundwater model to parameter uncertainty to be tested. Whilst it would be prohibitive to run unlimited model runs with all variations in parameter and parameter combinations considered, at Gateway stage, testing of sensitivity to key parameter uncertainty is useful. One of the guiding principles of the Australian Groundwater Modeling Guidelines (Barnett *et al*, 2012) is that sensitivity analysis "should be performed".

Analyses for the Project model were conducted by testing sensitivity to:

- Specific Yield (Sy), tested with three model runs, varying the calibrated Sy for the Alluvium and Permian strata, with results shown in **Table 28.**
- The stacked drain model (see **Section 5.1.6**) conductances - for the drains and zones of influence (fractured zones), with results presented in **Table 31**.

The Specific Yield analysis showed that Sy did not have a significant impact on the resultant percentage SRMS (about 0.01% change), indicating the basic parameters of the groundwater model are appropriate for predictive modelling.

The model proved sensitive to the drain conductances (+82% to -68% mine inflow variation) as expected, with these factors being the key mining stress imposed on the groundwater model. While the conductances applied were theoretically sound, this aspect of the model would be investigated further in an EIS model.

The results outlined above indicate that the constructed groundwater model is suitable as a basis for predicting the effects of mining on the Project area and surrounds for a Gateway process.

8 LICENSABLE WATER TAKES

Based on the groundwater modelling results, the predicted average annual groundwater and consequential surface water take volumes required to be licensed over the life of the Project and post-mining are summarised in **Table 39**. These volumes are indicative only for the purposes of the Gateway process and would be refined during the EIS assessments. The predicted water take would be further refined during the progression of the Project to more accurately predicted the potential take and ensure adequate licences are held to account.

Table 39 Project Licensing Summary – Indicative Water Take Volumes

<table>
<tr><th rowspan="2">Water Sharing Plan</th><th rowspan="2">Management Zone / Water Source</th><th colspan="2">Predicted Annual Water Take Requiring Licensing for the Project (ML/year)</th><th rowspan="2">Licences Currently Held by Malabar (Total Units)</th></tr>
<tr><th>During Mining</th><th>Post Mining</th></tr>
<tr><td rowspan="2">North Coast Fractured and Porous Rock Groundwater Sources 2016</td><td>Sydney Basin – North Coast Groundwater Source</td><td>Avg. 1004
Max. 1347</td><td>Nil</td><td>Nil*</td></tr>
<tr><td>New England Fold Belt Coast Groundwater Source</td><td>Negligible</td><td>Negligible</td><td>1,387</td></tr>
<tr><td rowspan="2">Hunter Unregulated and Alluvial Water Sources 2009</td><td>Hunter Regulated River Alluvial Water Source</td><td>Avg. 40
Max. 73</td><td>Avg. 79
Max. 99</td><td>332</td></tr>
<tr><td>Jerrys Management Zone of Jerrys Water Source</td><td>Negligible</td><td>Negligible</td><td>Nil**</td></tr>
<tr><td>Hunter Regulated River Water Source 2016</td><td>Hunter Regulated River Water Source</td><td>Avg. 33
Max. 66</td><td>Avg. 75
Max. 95</td><td>1,423</td></tr>
</table>

* In the 2017/18 period, a total of 187 Aquifer WALs with a total share component of 67,794.5 units were available in the Sydney Basin – North Coast Groundwater Source.
** In the 2017/18 period, a total of 10 Aquifer WALs and 19 Unregulated River WALs with a total share component of 1,246 and 2,097 units respectively were available in the Jerrys Water Source.

Malabar currently holds adequate licences for 'highly productive' water associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone). Malabar also holds adequate licences in the Hunter Regulated River Source.

As demonstrated in **Table 39**, the total share components available in the Sydney Basin – North Coast Groundwater Source and Jerrys Water Source are well in excess of the predicted annual water take requiring licensing for the Project. Malabar would seek and obtain the appropriate water licences (as required) and/or comply with appropriate trading rules in accordance with the relevant WSPs.

Clause 39 of the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009 includes rules (specifically distance restrictions) for granting water supply works approvals.

Relevantly for the Project, the distance restrictions in clause 39 do not apply where (see clause 39[6]):

(a) a hydrogeological study undertaken by the applicant, and assessed as adequate by the Department, demonstrates that the water supply work will have no more than minimal impacts on the existing licensed taking of water from the water source;

(b) all potentially affected persons in the near vicinity of the water supply work, holding an access licence or having a right to take water under the Water Management Act 2000 have been notified by the applicant; and

(c) any approval granted contains conditions setting out a process for remediation in the event that any more than minimal impact on existing extraction from the water source occurs in the future.

There are no flow classes established for the Hunter Regulated River Alluvial Water Source under the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009.

9 MANAGEMENT, MONITORING, MODELLING AND MITIGATION

As previously noted (**Section 3.6**) Malabar has an extensive monitoring network over the Project area, including access to over 50 groundwater monitoring bores (including standpipes and VWPs), surface water monitoring sites and on-site meteorological stations. Available NSW government monitoring data (e.g. meteorological and flow gauging stations) are also used to add to the network.

Malabar is currently implementing an appropriate data gathering and management approach, with ongoing and future hydrogeological investigations (**Section 10**) capable of providing appropriate datasets for future EIS assessments, and subsequent management plans and licensing.

Following the grant of a Gateway Certificate, the groundwater model would be refined in greater details for the purposes of the EIS as outlined in **Table 40**. The scope of the Gateway process model is included for comparison.

Table 40 Proposed Scope for EIS Groundwater Model

Model Feature	Gateway Process	EIS
Spatial Scale	Coarse	Fine
Temporal Scale	Coarse	Fine
Model Extent	51 km x 35 km	51 km x 35 km
Stratigraphy	14 Layers	>14 Layers
Spatial Parameter Variability	No	Yes
Steady-State Calibration	Yes	Yes
Transient Calibration	No (Verification Only)	Yes
Prediction Period	27 years	27 years
Representation of Fractured Zone	Yes	Yes
Tracking of First Workings	Limited	Yes
Sensitivity Analysis	Preliminary (Sy and stacked drain conductance)	Extensive
Uncertainty Analysis	Preliminary (climate)	Extensive
Recovery Analysis	Yes	Yes
Cumulative Assessment	Law of Superposition	Simulation
Final Void / Rejects Seepage Analysis [Fate]	Limited	Yes
Mitigation Measures	No	Yes
Future Monitoring Program/Investigations	Yes	Yes
Outputs	AI Policy / Significant Impact Focus	Extensive Spatial and Time Series Plots and Tables
Licensing Volumes	Indicative	Firm Recommendations
Software	MODFLOW-USG	MODFLOW-USG
Report	Condensed	Substantial

The EIS groundwater model would also include modelling of the long-term water levels in the existing mined voids within ML 1531 and CL 229 (from the former Drayton Mine activities). These voids would be used for water storage and CHPP reject emplacement during the life of the Project.

Consistent with contemporary NSW Development Consents, a groundwater management plan would likely be required to be developed and approved for the Project. This plan should define a groundwater monitoring strategy, groundwater level triggers, and a trigger action response plan. The groundwater monitoring network would be designed to monitor for the potential drawdown risks to existing users' water supply works.

Furthermore, the Project would require a volumetric take (total mine inflow) metering program. These water takes would be required to be reported on an annual basis to DoI-Water, and periodically used, in conjunction with the monitoring network data, to verify the groundwater modelling and the potential risks of mining activity identified in this and/or future EIS assessments.

10 ONGOING AND FUTURE HYDROGEOLOGICAL INVESTIGATIONS

During the preparation of this report, Malabar has been developing and progressing in parallel a number of hydrogeological investigations to be used in support of the future EIS assessments, management plans (including development of triggers) and for licensing applications (where required). Each of the investigations is outlined below.

The investigations have also been guided by previous IESC advice for other projects (e.g. IESC 2015-069) and outputs of the Northern Sydney Basin Bioregional Assessment for the Hunter subregion. In particular, recommendations relating to:

- Saddlers Creek and associated water dependent assets;
- Hunter River and associated alluvium;
- Ramrod Creek; and
- Groundwater users.

10.1 TRANSIENT ELECTROMAGNETIC SURVEY OF UNCONSOLIDATED ALLUVIAL SEDIMENTS

A transient electromagnetic (TEM) survey (a geophysical exploration technique) would be used to assist to define the extent and depths unconsolidated alluvial sediments near Saddlers Creek and Hunter River Alluvium proximal to the Maxwell Underground.

The preliminary outputs of the TEM survey have confirmed the alluvial extent and depth estimated for the Gateway process groundwater modelling exercise. The results of the TEM survey would be used for refining the modelled extents of the unconsolidated alluvial sediments for the EIS and consequently partitioning of groundwater take for future licensing (i.e. within the Jerrys Management Zone of the Jerrys Water Source). The results of the TEM survey would be reported in the future EIS assessment.

10.2 DRILLHOLE TRANSECTS IN UNCONSOLIDATED ALLUVIAL SEDIMENTS

A shallow drilling program would be used to log the depths of unconsolidated alluvial sediments proximal to the Maxwell Underground. The results of the drillhole transects would be used to calibrate and complement the TEM survey, as well as provide the opportunity for the installation of additional shallow piezometer monitoring sites for future groundwater sampling programs.

The results of the drillhole transects would be reported in the future EIS assessment.

10.3 GEOLOGICAL DATASETS FROM ONGOING EXPLORATION REVIEW

The existing geological dataset within the Project area is comprehensive. Notwithstanding, Malabar would continue to augment and review the geological datasets within EL 5460, and the outcomes used in the development of the groundwater model (i.e. model layers and consideration of geological structure and sills) for the EIS assessments.

10.4 CONTEMPORARY BORE CENSUS

A contemporary bore census would be used to identify surrounding groundwater users and collect field observations and anecdotal information to validate available NSW government records and prior bore census records and assessments in the Project area and surrounds.

The results of the bore census would be reported in the future EIS assessment.

10.5 SADDLERS CREEK GAUGING STATION RE-ESTABLISHMENT

The surface water flow gauging station on Saddlers Creek would be re-established by Malabar. The additional datasets would be used to augment the historic stream water levels records between 1956 and 1981 on Saddlers Creek for the EIS assessments and be used for future monitoring programs.

Data collected over time would be used to provide quantitative flow regime information (including seasonal, climatic high and low flow periods, and contribution of baseflow) for Saddlers Creek to allow for ongoing assessment of the groundwater dependence and potential impacts (if any) on riparian vegetation along Saddlers Creek.

10.6 FINAL VOID GROUNDWATER MONITORING NETWORK

Malabar would establish a groundwater monitoring network surrounding the existing voids at the Maxwell Infrastructure area. The network would be used to validate previous groundwater drawdown predictions (i.e. development of localised groundwater sinks), as well as monitoring of potential seepage migrating away from existing rejects/emplacement areas towards the catchment of Ramrod Creek, if any.

Available groundwater monitoring datasets would be used in the development of the groundwater model for the EIS assessments, including assessments for the proposed placement of CHPP rejects in the existing East Void for the Project.

10.7 DATA SHARING AGREEMENTS

Malabar is establishing data sharing agreements with neighbouring operations (e.g. Mt Arthur Mine) to facilitate the shared use of the extensive groundwater (and surface water) monitoring datasets available in the region.

Available groundwater monitoring datasets would be used in the development of the groundwater model for the EIS assessments, and future monitoring programs.

11 EPBC ACT SIGNIFICANT IMPACT ON WATER RESOURCES ASSESSMENT

This report considers the impacts of the Project on groundwater resources, and if these impacts are significant according to the Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources (DotE, 2013).

The guidelines indicate that the Project must have 'a real or not remote chance or possibility that it will directly or indirectly result in a change to' the 'hydrology' or 'water quality' of the water resource. This change must be of 'sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users'. Third party users can include 'environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring'. Furthermore, 'Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the water resource which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts'.

Considering the aforementioned guideline and the results of the Gateway groundwater modelling and assessment (**Sections 3 to 10**), the Project is considered unlikely to have a significant impact on groundwater resources, because:

- The modelled 2 m water table drawdown at the end of mining is not predicted to extend beyond the EL 5460 boundary and, therefore, there would be negligible impact on other economic or social groundwater users beyond existing predicted impacts from other activities in the area.
- There would be no measurable impact on water quality in the Hunter River or the Hunter River alluvium.
- There are no known risks to 'high priority' GDEs or 'high priority' groundwater-dependent culturally significant sites identified by the NSW Government in relevant WSPs.
- The BOM GDE Atlas only identified areas of low GDE potential near the Project, therefore a significant impact on GDEs is unlikely.

Where relevant, the Information Guidelines for Proponents Preparing Coal Seam Gas and Large Coal Mining Development Proposals (2018) have also been used and a summary reconciliation is presented in **Appendix A**.

12 CONCLUSIONS

This report has been prepared for Malabar to provide a preliminary groundwater assessment of the Project for the purposes of the Gateway process. The assessment relies on numerical modelling of potential risks of mine development in terms of the NSW AI Policy and Gateway process requirements.

The groundwater model was written and operated within the Groundwater Vistas (GWV) interface, using MODFLOW-USG groundwater modelling software. This modelling was undertaken in consideration of the MDBC Groundwater Flow Modelling Guideline (2001), the Australian Groundwater Modelling Guidelines (2012), as well as the Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources (2013) and the Information Guidelines for Proponents Preparing Coal Seam Gas and Large Coal Mining Development Proposals (2018).

A comprehensive review of data, literature, conceptual hydrogeology, and other numerical groundwater models and assessments developed within and surrounding the Project area, was carried out as a basis for the model development. The report has also been prepared cognisant of the outputs of the Northern Sydney Basin Bioregional Assessment for the Hunter subregion, and prior advice for the Project area and surrounds provided by the IESC.

The complexity of the numerical groundwater model developed as part of this study is adequate for this preliminary groundwater assessment by simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system because of the proposed development. Based on the Australian Groundwater Modelling Guidelines (2012), the model is classified as Class 2, with a good steady-state calibration and verification (transient) performance of 7.5% and 4.5% scaled root mean square error respectively, both achieving the target for less than 10% suggested in the MDBC Groundwater Flow Modelling Guideline (2001).

The relevant criteria in relation to BSAL requires consideration of any impacts on 'highly productive' groundwater, within the meaning of the AI Policy (NSW Government 2012). The water associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) is classified as a 'highly productive' groundwater source.

Predictive modelling to assess the potential impacts to 'highly productive' groundwater source has been conducted with the following key results (for the Project only):

- Inflows to the underground mine workings are conservatively predicted in the Gateway process groundwater model to average approximately 2.7 ML/day (total) for the proposed mine life (2019 to 2045), peaking at 3.7 ML/ day in 2027, before declining to about 2.6 ML/day.
- The modelled 2 m water table drawdown at the end of mining is not predicted to extend beyond the EL 5460 boundary.

- Consequently, the predicted average groundwater take from the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) over the 27 years of mining is estimated to be approximately 40 ML/year, and about 79 ML/year post mining. [*Malabar currently holds licences up to a total 332 units in the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone)*]
- In turn, the estimated alluvial groundwater take results in a small average predicted licensable take from the Hunter Regulated River Source of approximately 33 ML/year during mining and 75 ML/year post mining (<0.02% of average recorded Hunter River surface water flow) [*Malabar currently holds licences up to a total 1,423 units in the Hunter Regulated River Source*].
- No measurable impact on water quality in the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) or the Hunter Regulated River Source.
- Potential impact to one privately-owned bore (drawdown greater than 2 metres) is predicted due to the Project.
- No known risks to ‘high priority’ GDEs or ‘high priority’ groundwater-dependent culturally significant sites listed in relevant Water Sharing Plans.
- No impact on Equine or Viticulture CIC through reduced access or availability to water resources, because:
    - There would be negligible drawdown on the groundwater table and the estimated groundwater take would be licensed in the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone); Malabar currently holds licences up to a total 332 units.
    - The predicted maximum licensable take from the Hunter Regulated River Source is 95 ML/year and Malabar currently holds licences up to a total 1,423 units.
    - There would be no measurable impact on water quality in the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone) or the Hunter Regulated River Source.
- Climatic variation is was shown to have a negligible impact on mine inflow predictions.

Based on the findings of the groundwater modelling and assessment, the Project meets the Level 1 minimal impact consideration classification of the AI Policy for ‘highly productive’ water associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone).

Based on available data, the unconsolidated alluvial sediments associated with Saddlers Creek within the Jerrys Management Zone of the Jerrys Water Source are classified as a ‘less productive’ groundwater source. The Permian porous rock groundwater sources within the Sydney Basin – North Coast Groundwater Source are also classified as ‘less productive’.

While ‘less productive’ groundwater sources are not the primary focus under the SRLUP Guideline for Gateway Applicants (2013), the minimal impact considerations of the AI Policy for the ‘less productive’ groundwater sources have been classified in this report (i.e. Level 2, as more than 2 metres cumulative drawdown is predicted at some water supply works). Accordingly, a groundwater management plan should be developed and implemented to define groundwater level triggers, and a trigger action response plan.

Following grant of a Gateway Certificate, the groundwater assessment and supporting numerical model would be refined and developed further to meet the requirements of the Secretary’s Environmental Assessment Requirement (SEARs) and the IESC Information Guidelines. This assessment would be presented in the EIS.

In conclusion, the Project would have “*no more than minimal harm*” on any water sources as a consequence of water being taken under licence in accordance with the Water Management Act 2000. Malabar currently holds adequate licences for ‘highly productive’ water associated with the Hunter Regulated River Alluvial Water Source (Upstream Glennies Creek Management Zone).

Furthermore, consideration of the potential impacts against the Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources (2013) concludes that the Project is unlikely to have a significant impact on groundwater resources.

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FIGURES

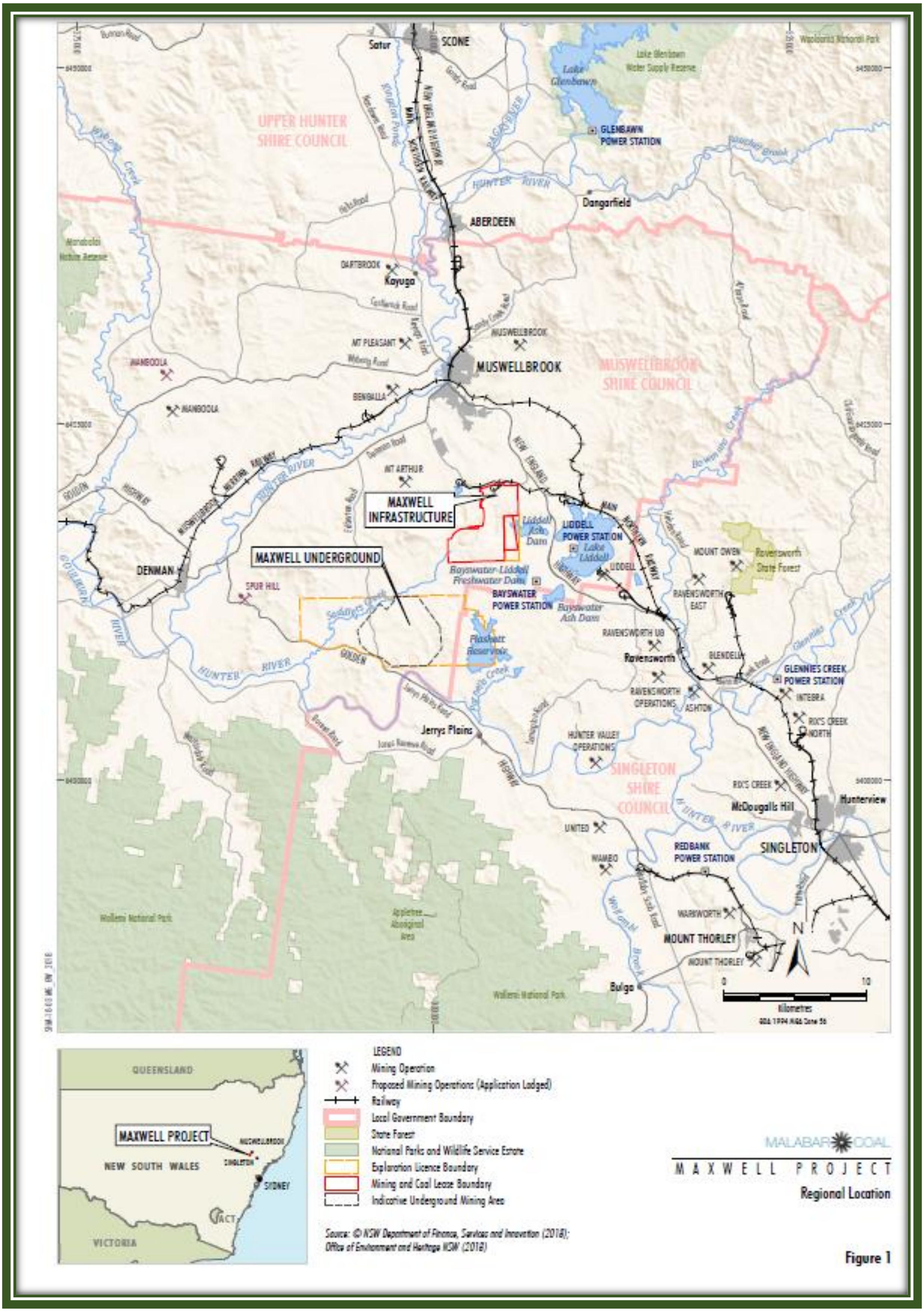

Figure 1 Regional location

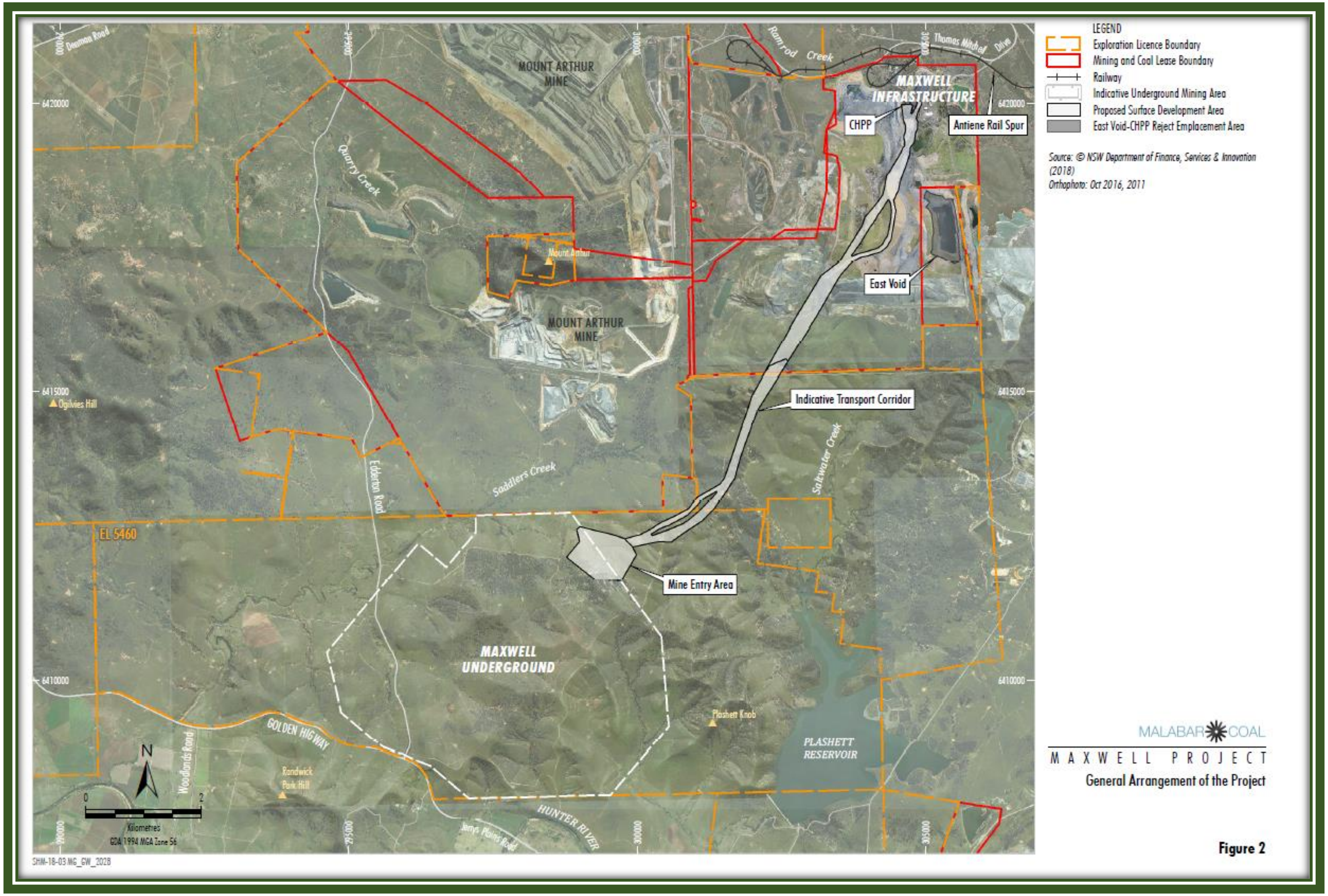

Figure 2 **General arrangement of the Project**

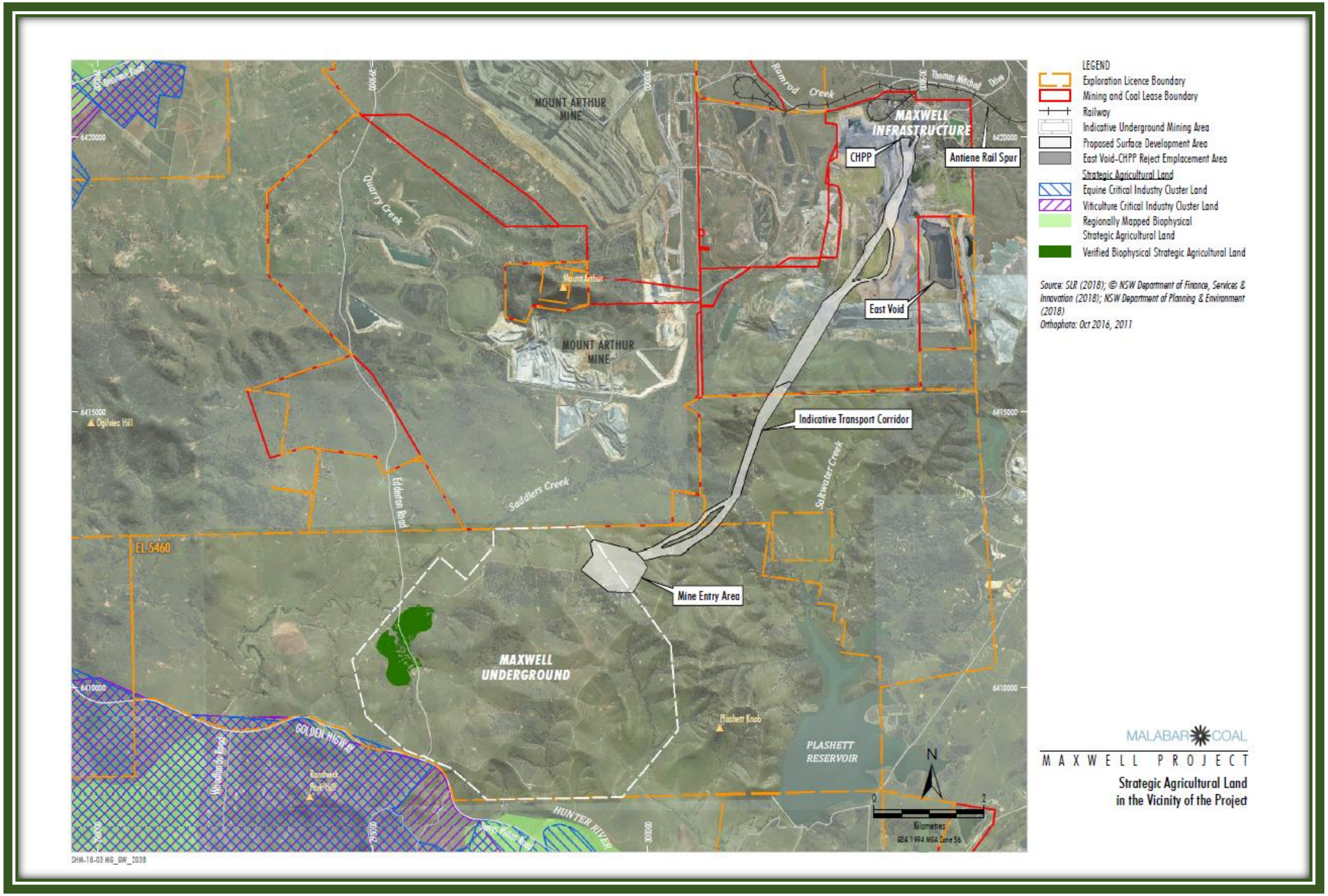

Figure 3 Strategic agricultural land near the Project

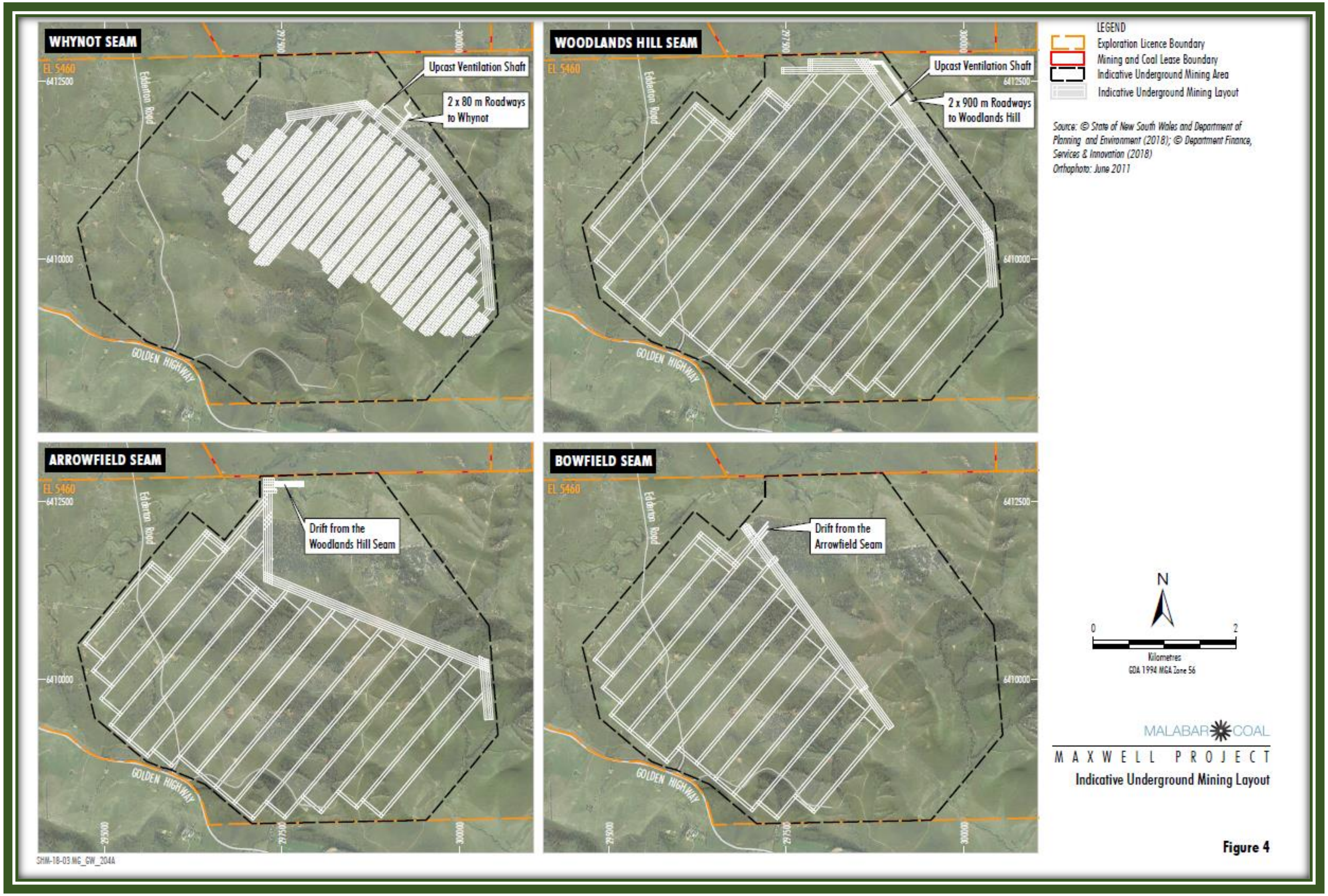

Figure 4 **Indicative underground mining layout**

Figure 5 CHPP reject emplacement area – East Void

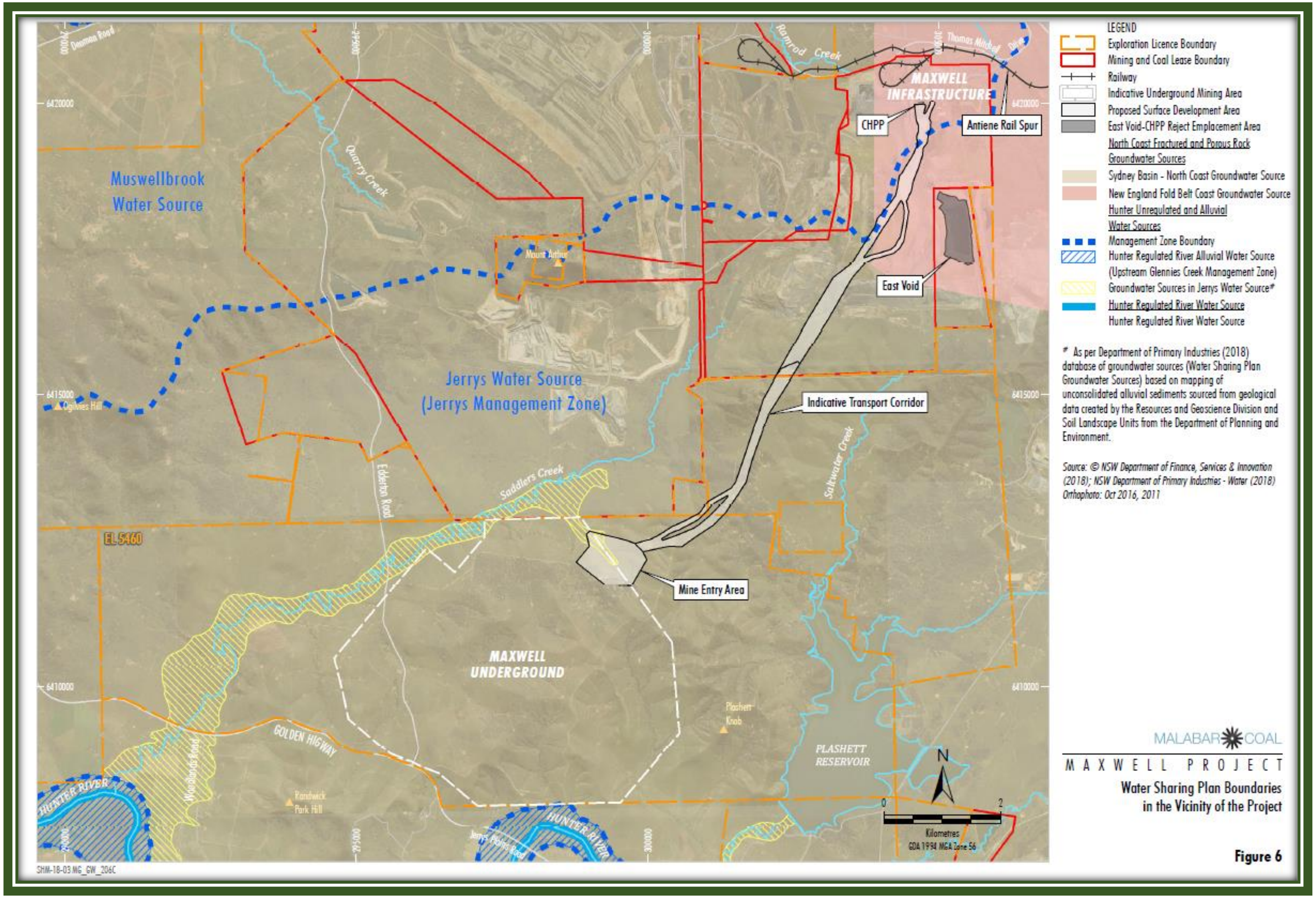

Figure 6 **Water sharing plan boundaries near the Project area**

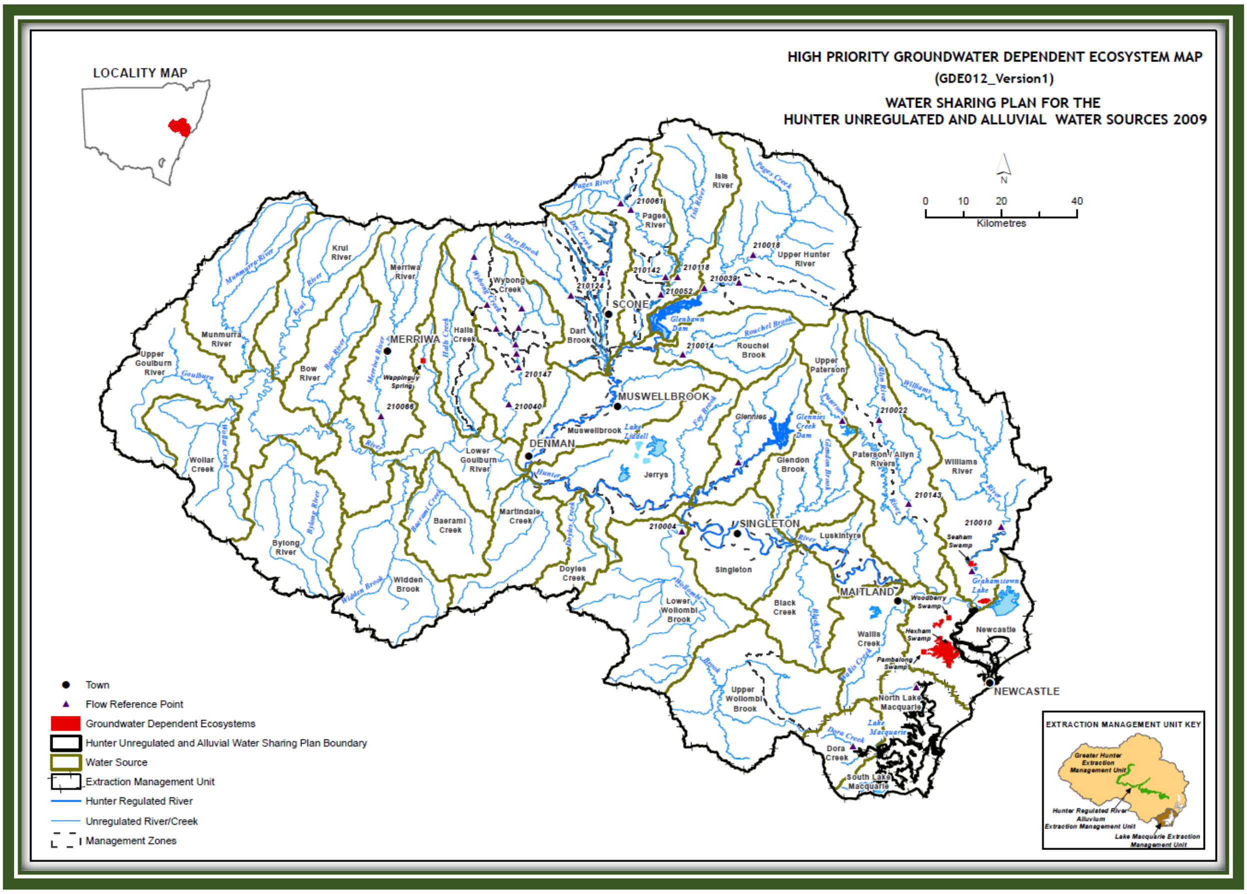

Figure 7 Map of 'High Priority' GDEs under Hunter Unregulated and Alluvial WSP

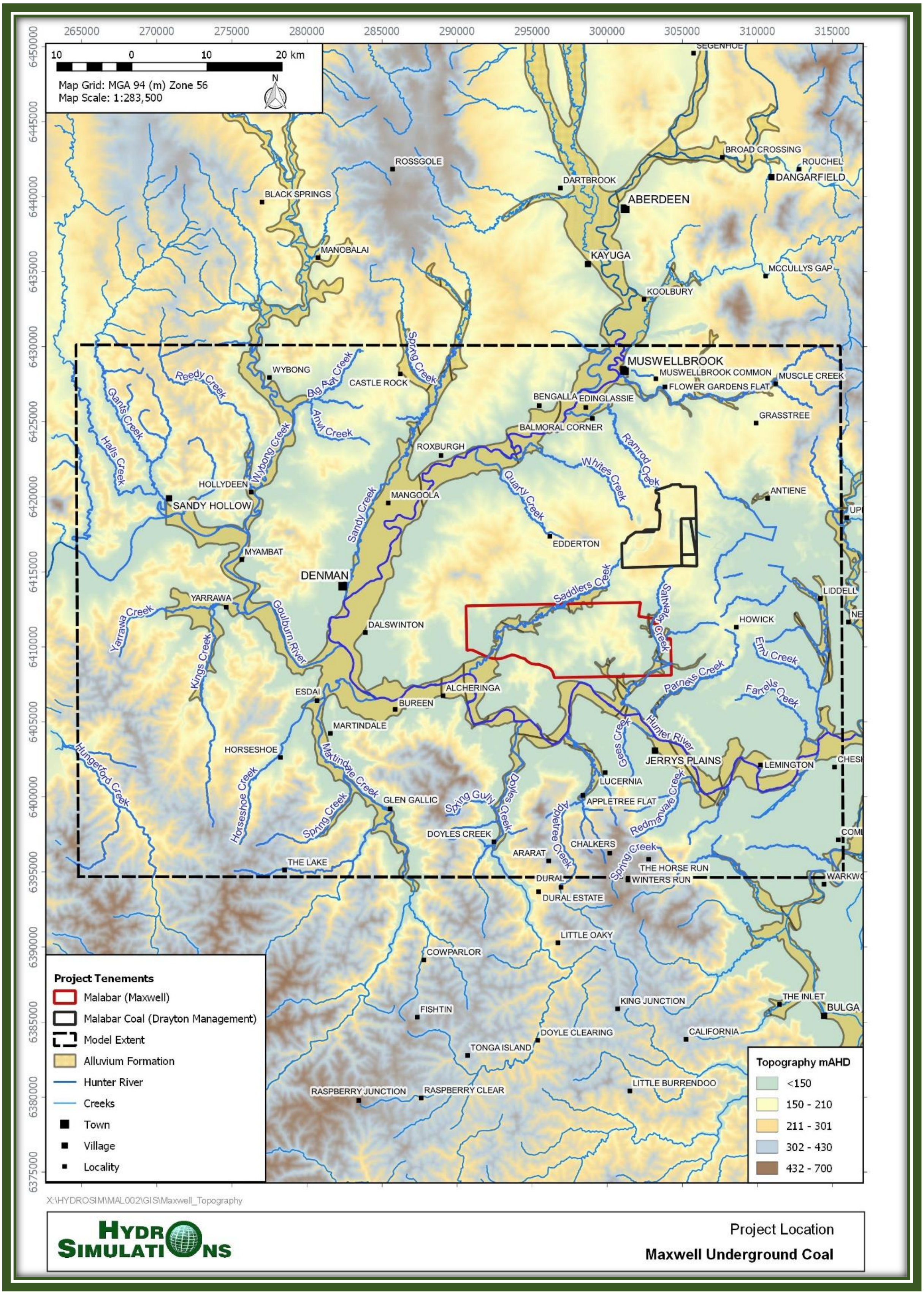

Figure 8 Model extent and regional topography

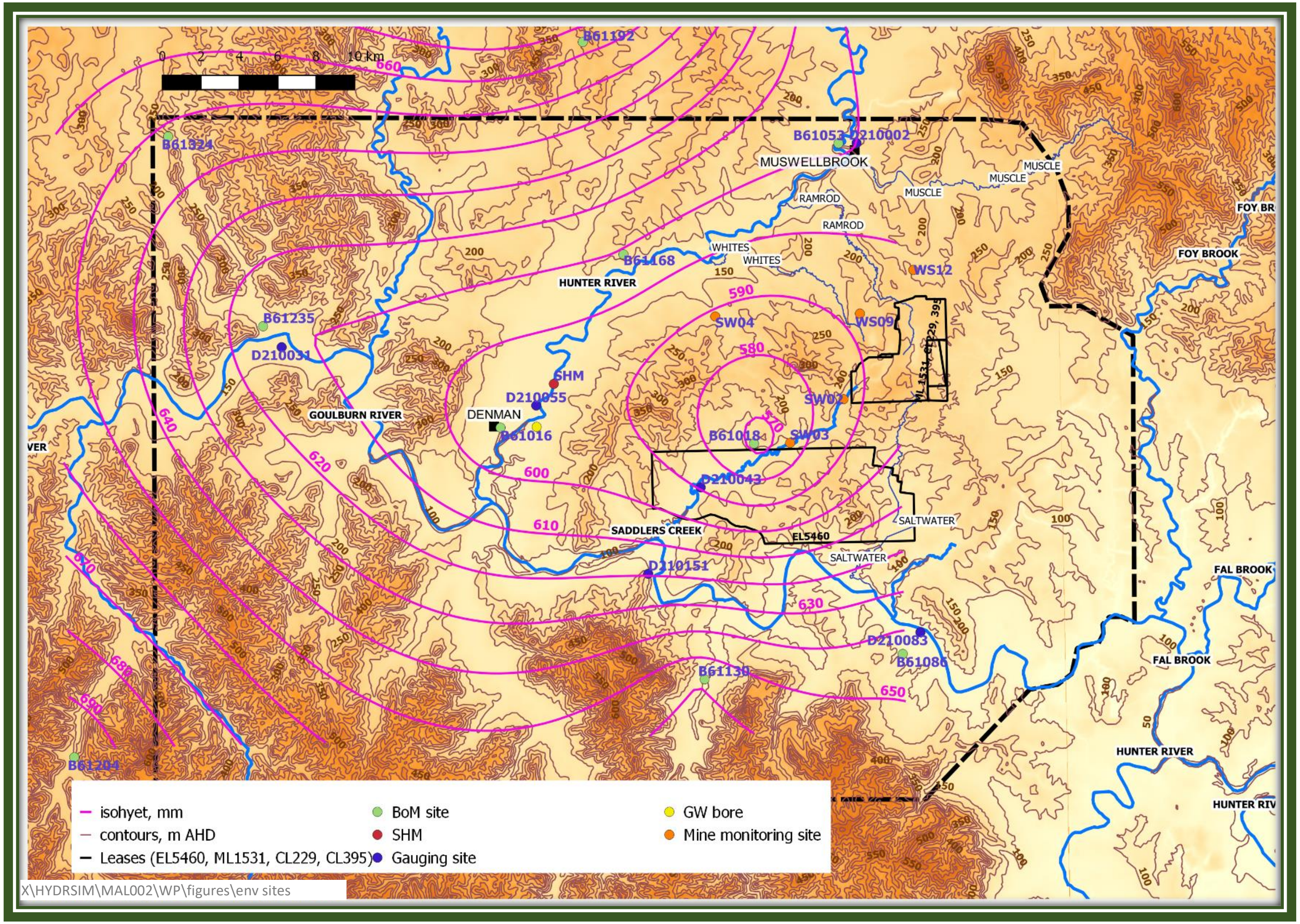

Figure 9 Average annual rainfall, climate and surface water monitoring sites

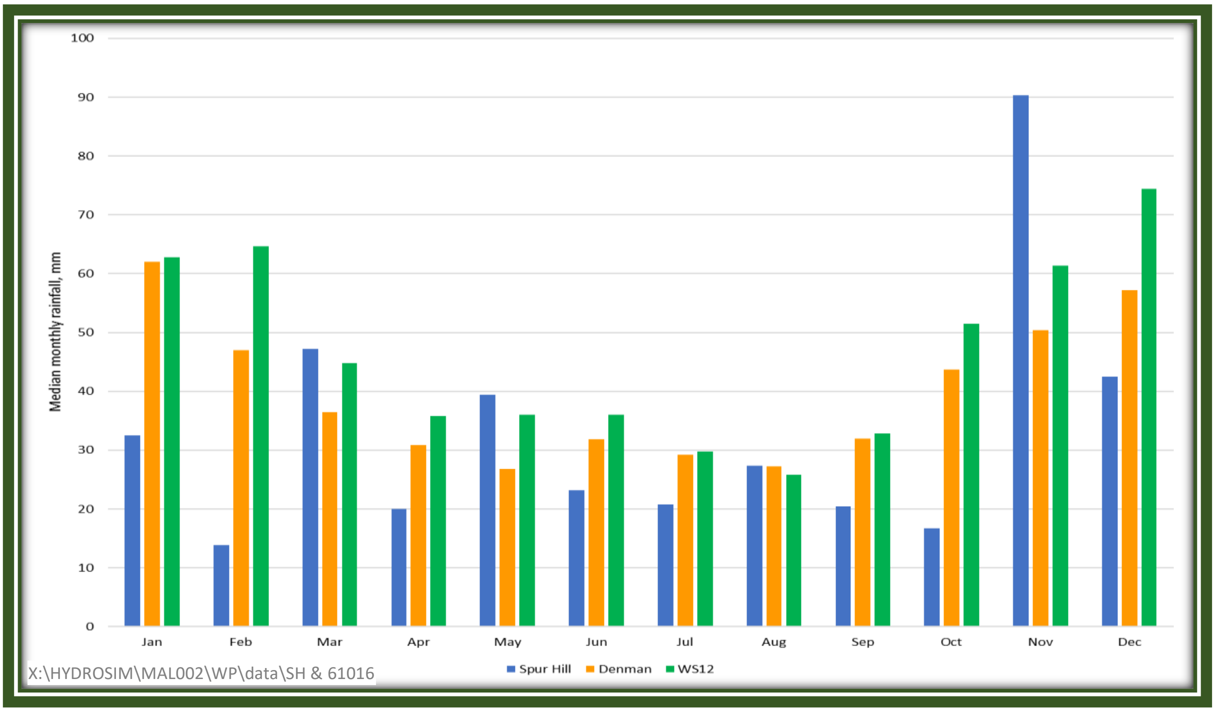

Figure 10 Denman and SHM median annual rainfall comparison

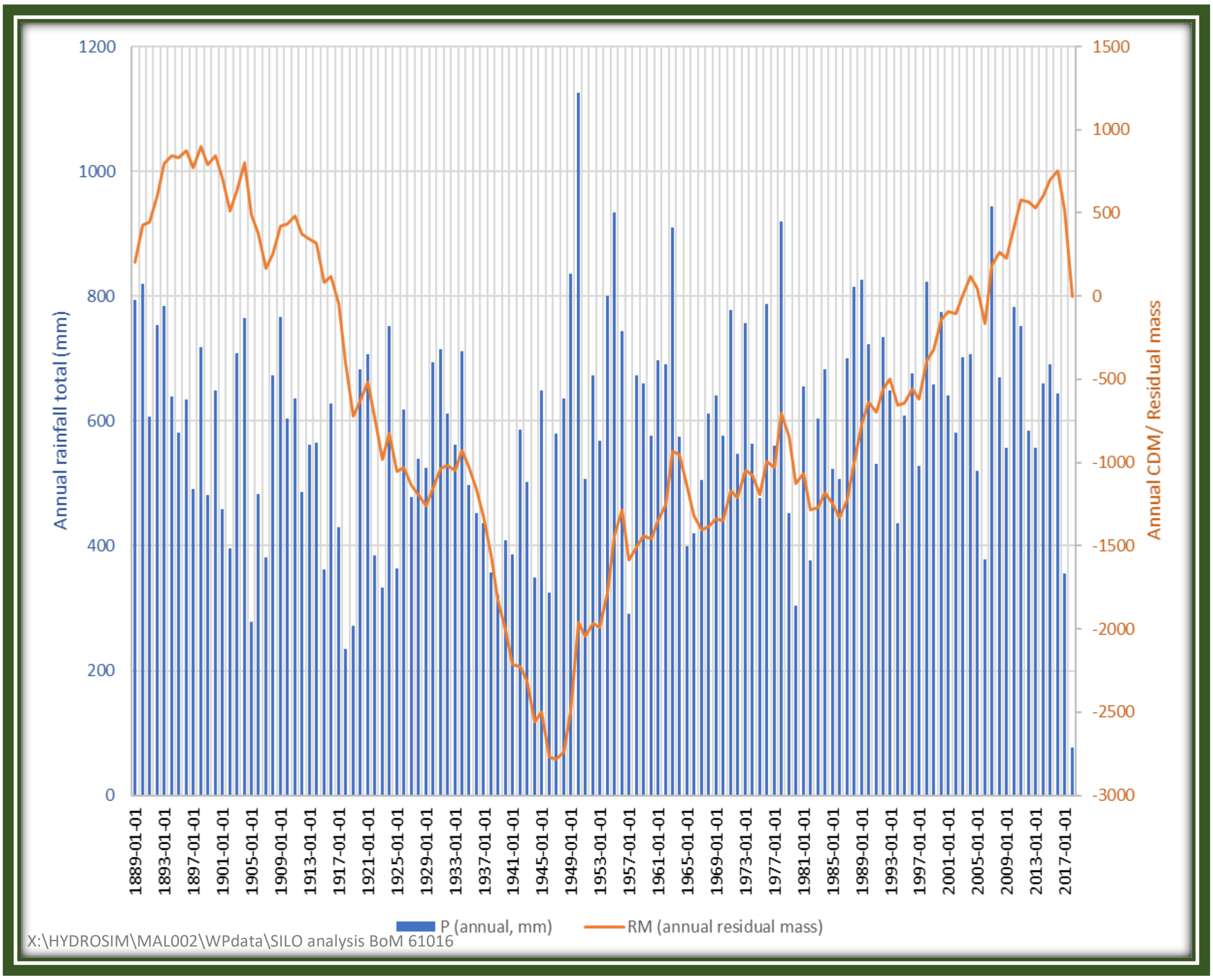

Figure 11 CDM/residual mass curve for BoM station 061016 (Denman, Palace Street)

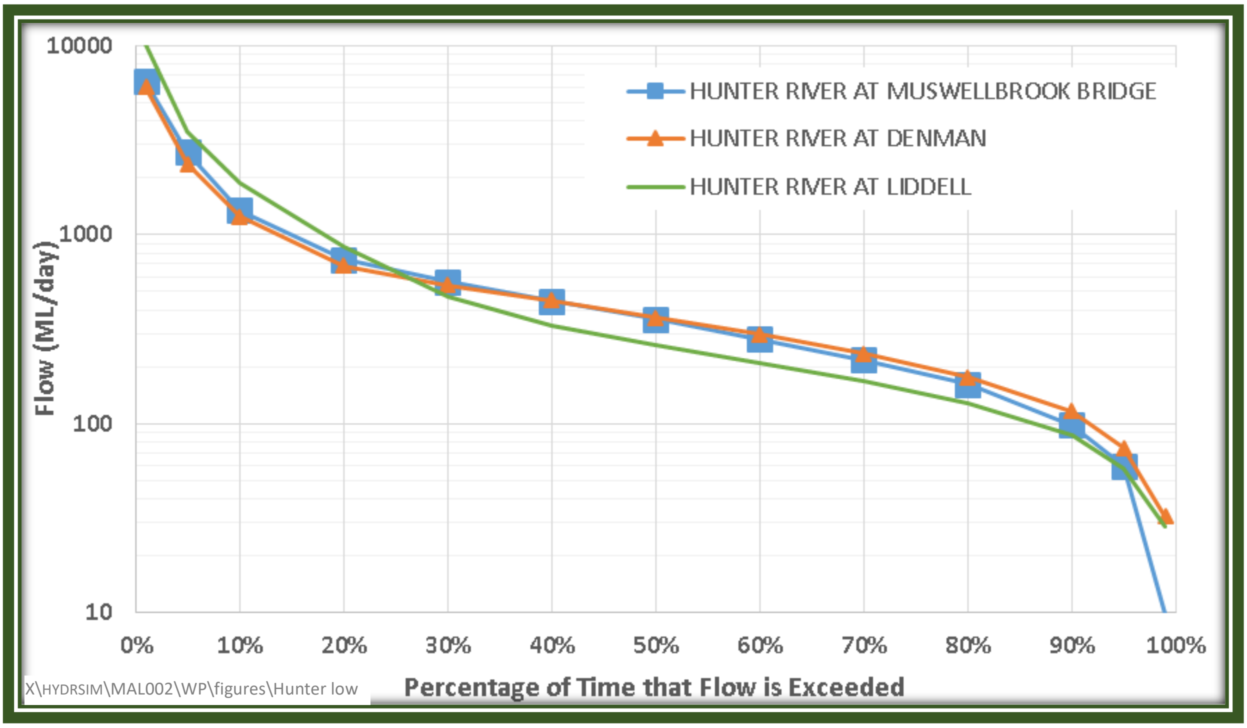

Figure 12 Flow exceedance, Hunter River near Denman

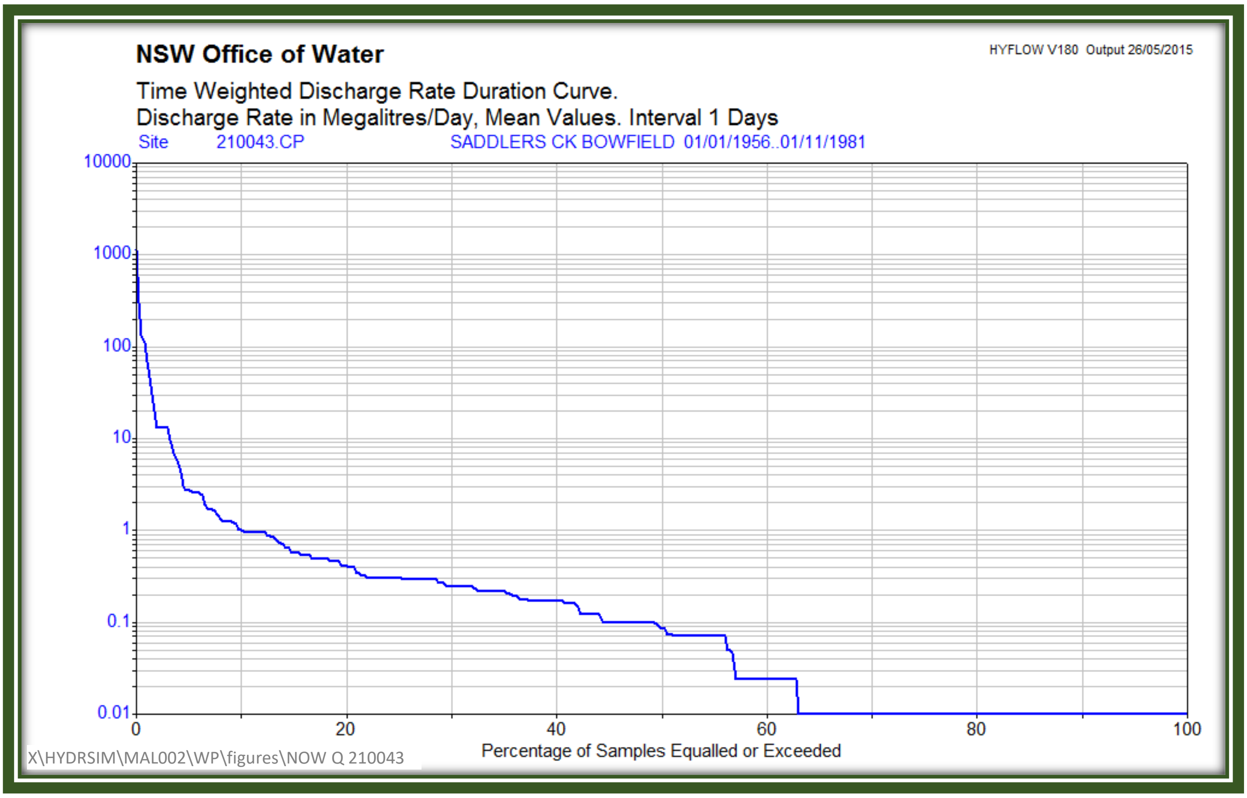

Figure 13 Discharge rate duration curve, Saddlers Creek

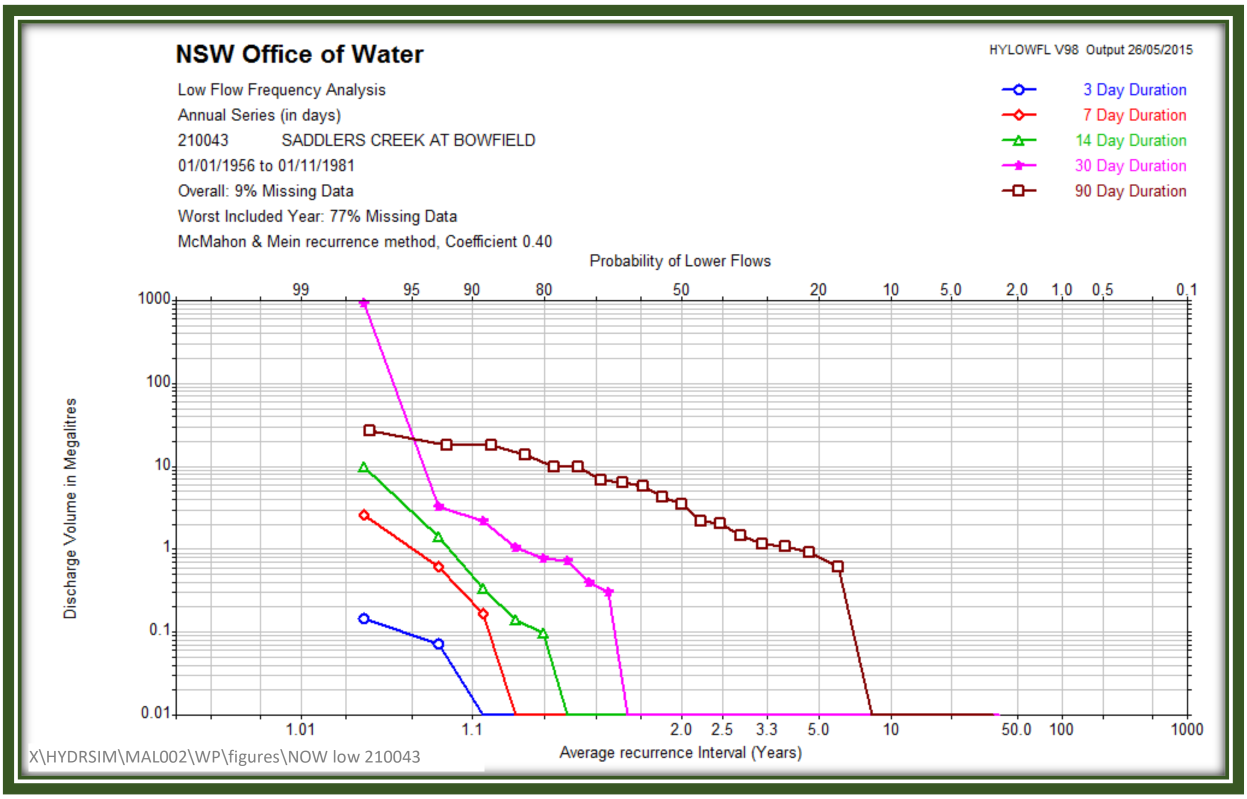

Figure 14 Low flow frequency analysis, Saddlers Creek

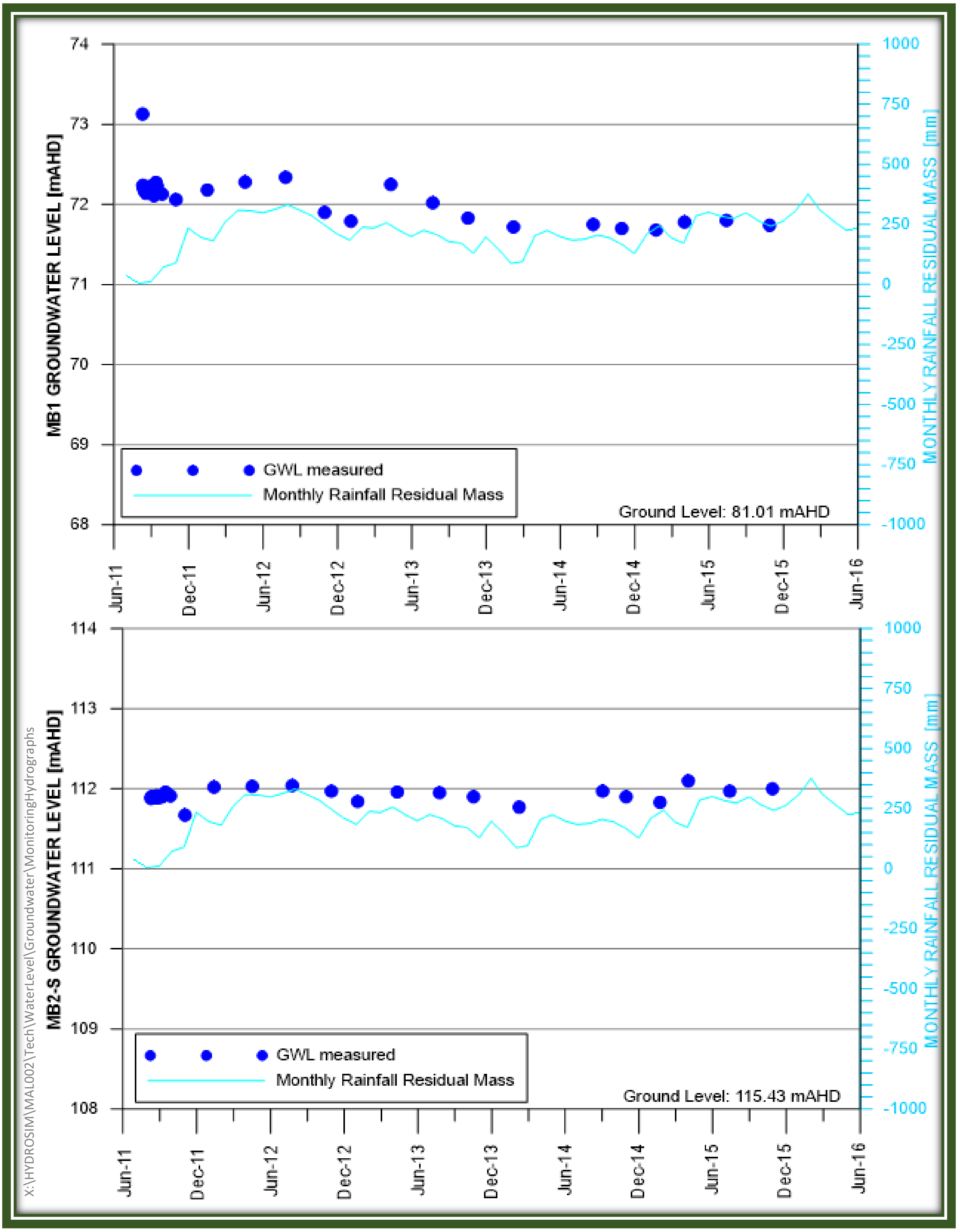

Figure 15 MB1 and MB2 alluvial groundwater level plots and monthly rainfall CDM (residual mass)

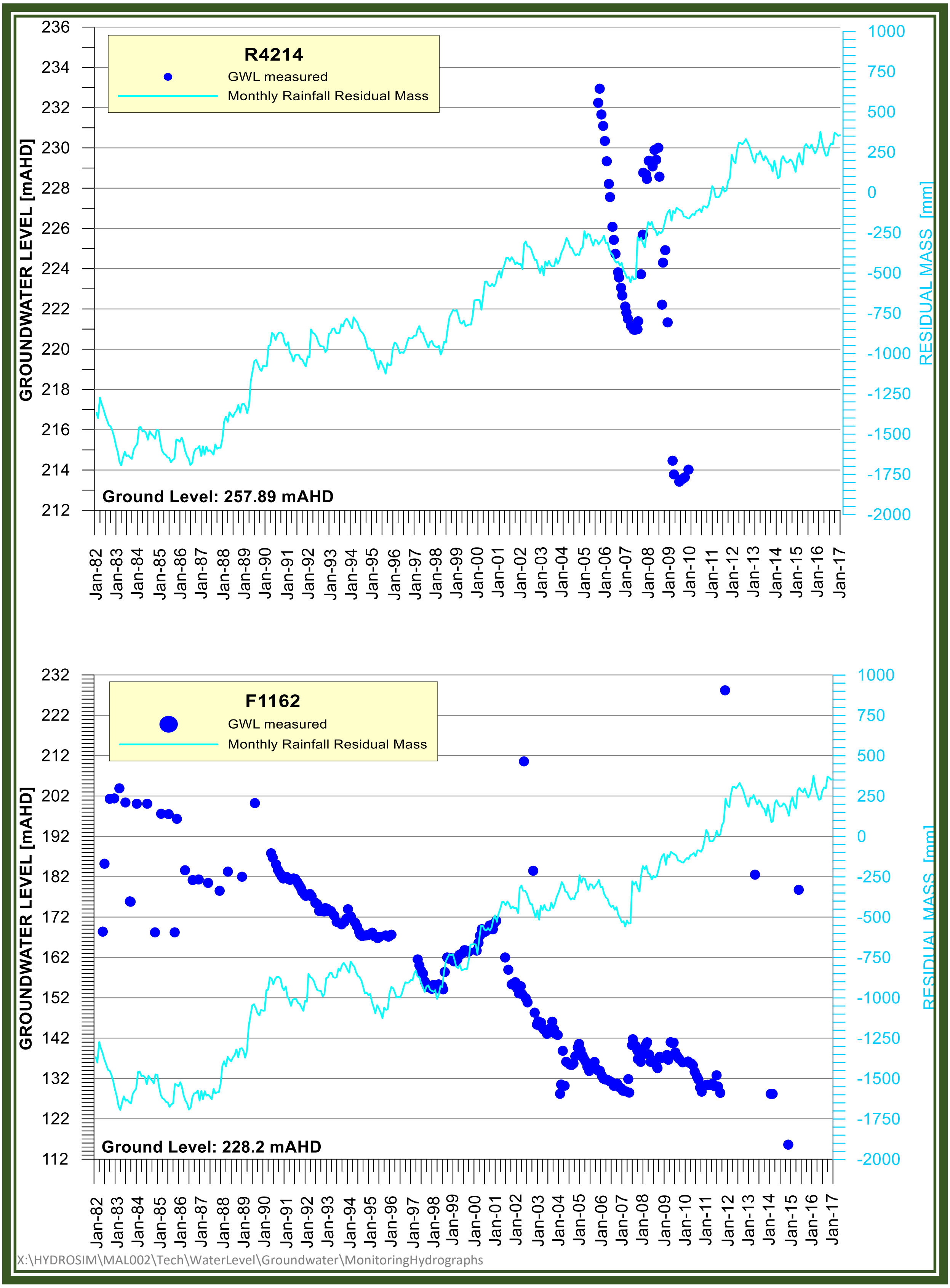

Figure 16 R2414 and F1162 groundwater level plots and monthly rainfall CDM (residual mass)

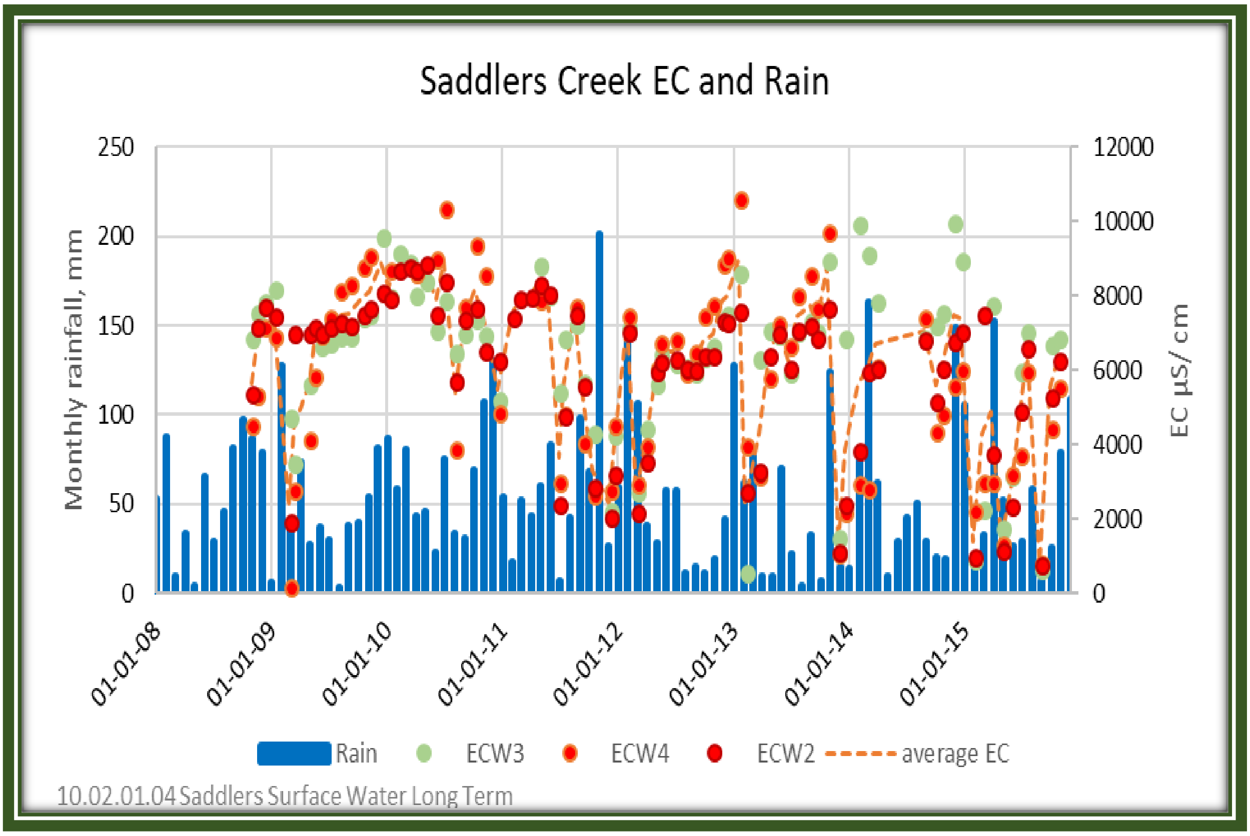

Figure 17 Saddlers Creek EC values for Mt Arthur monitoring sites 'SW02, SW03 and SW04', shown as ECW2, ECW3 AND ECW4 respectively, and monthly rainfall

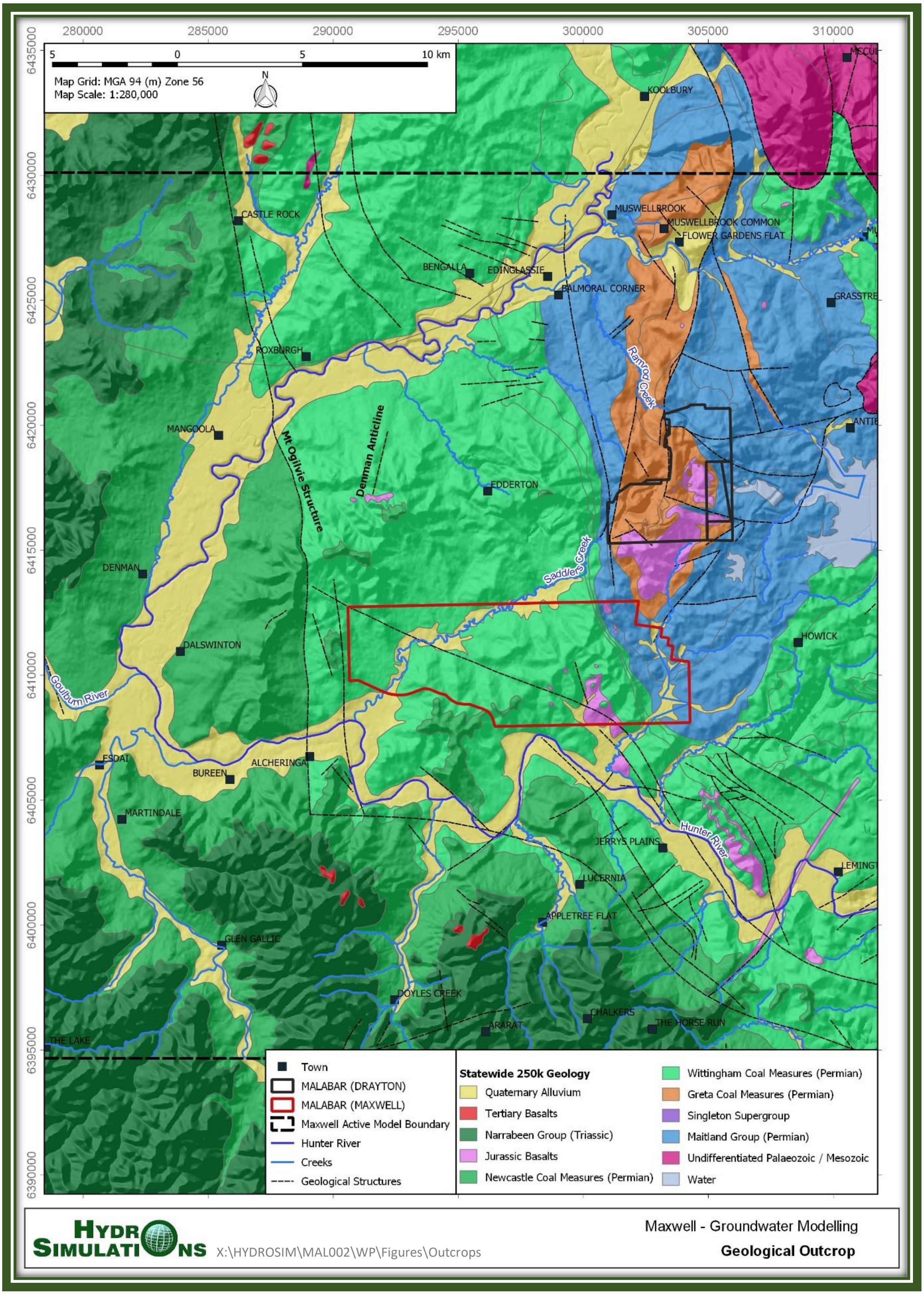

Figure 18 Geological outcrop

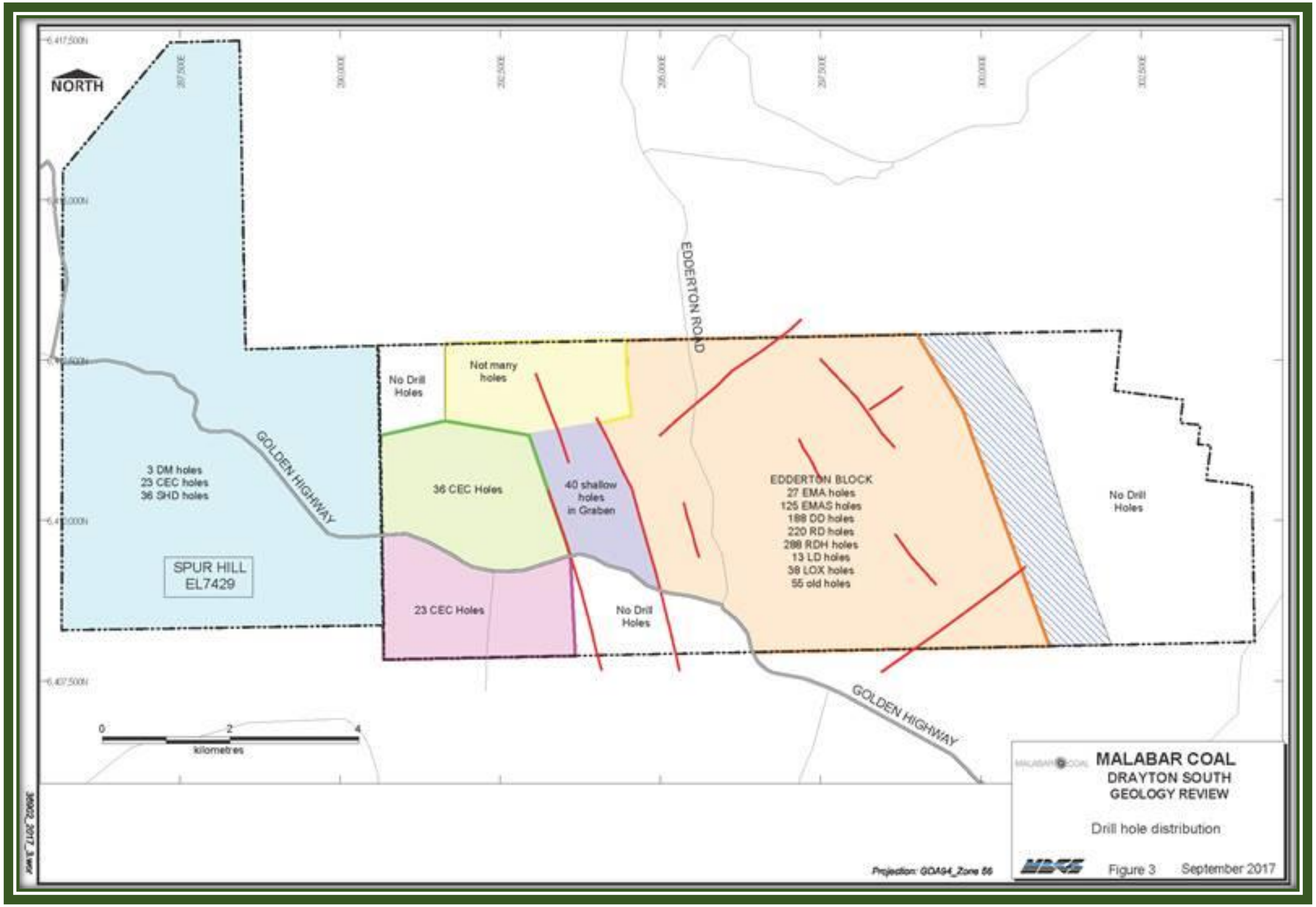

Figure 19 **Malabar drill hole distribution**

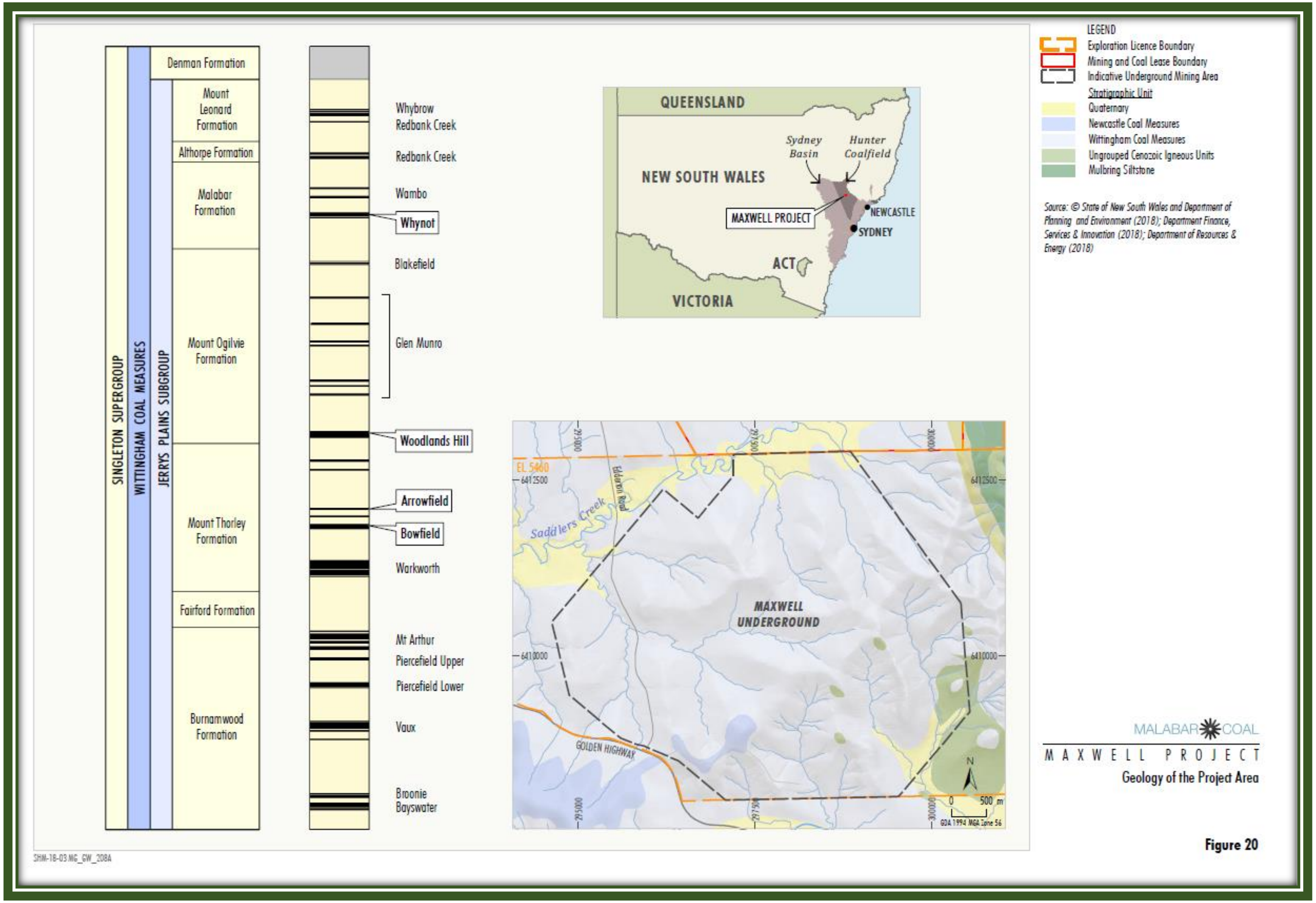

Figure 20 **Stratigraphy schematic**

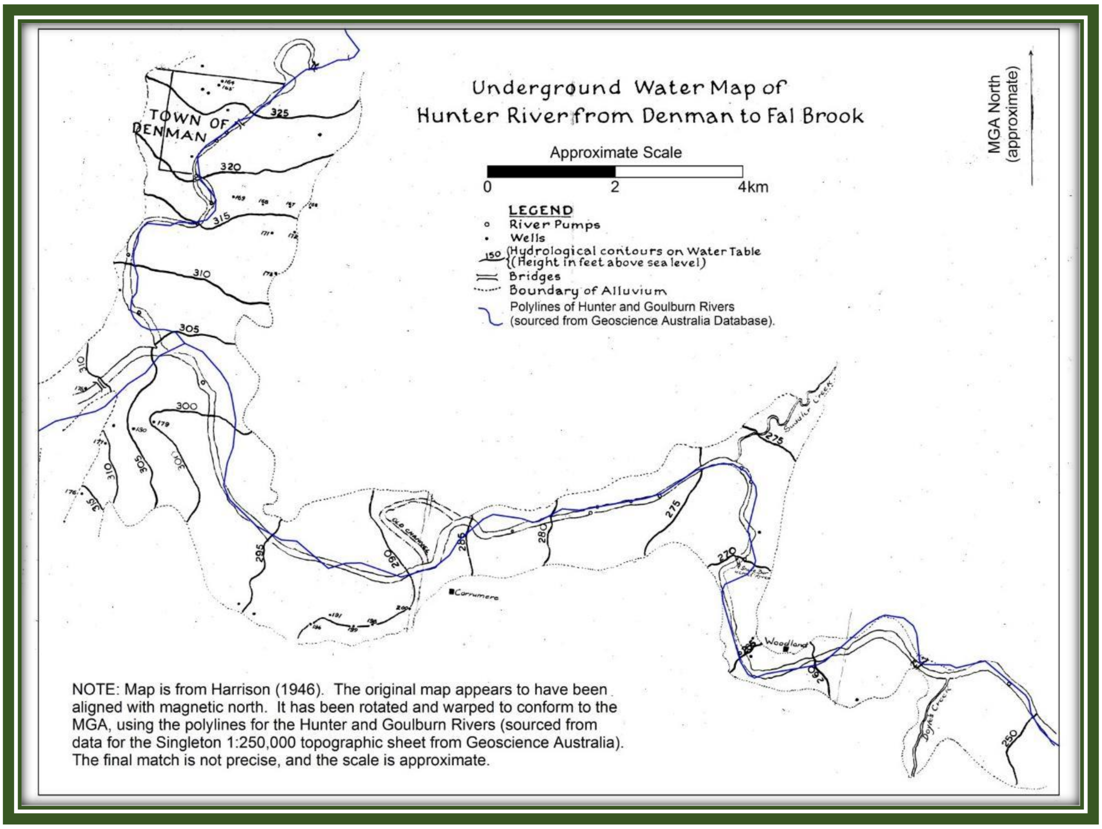

Figure 21 Interpolated water surfaces, 1946

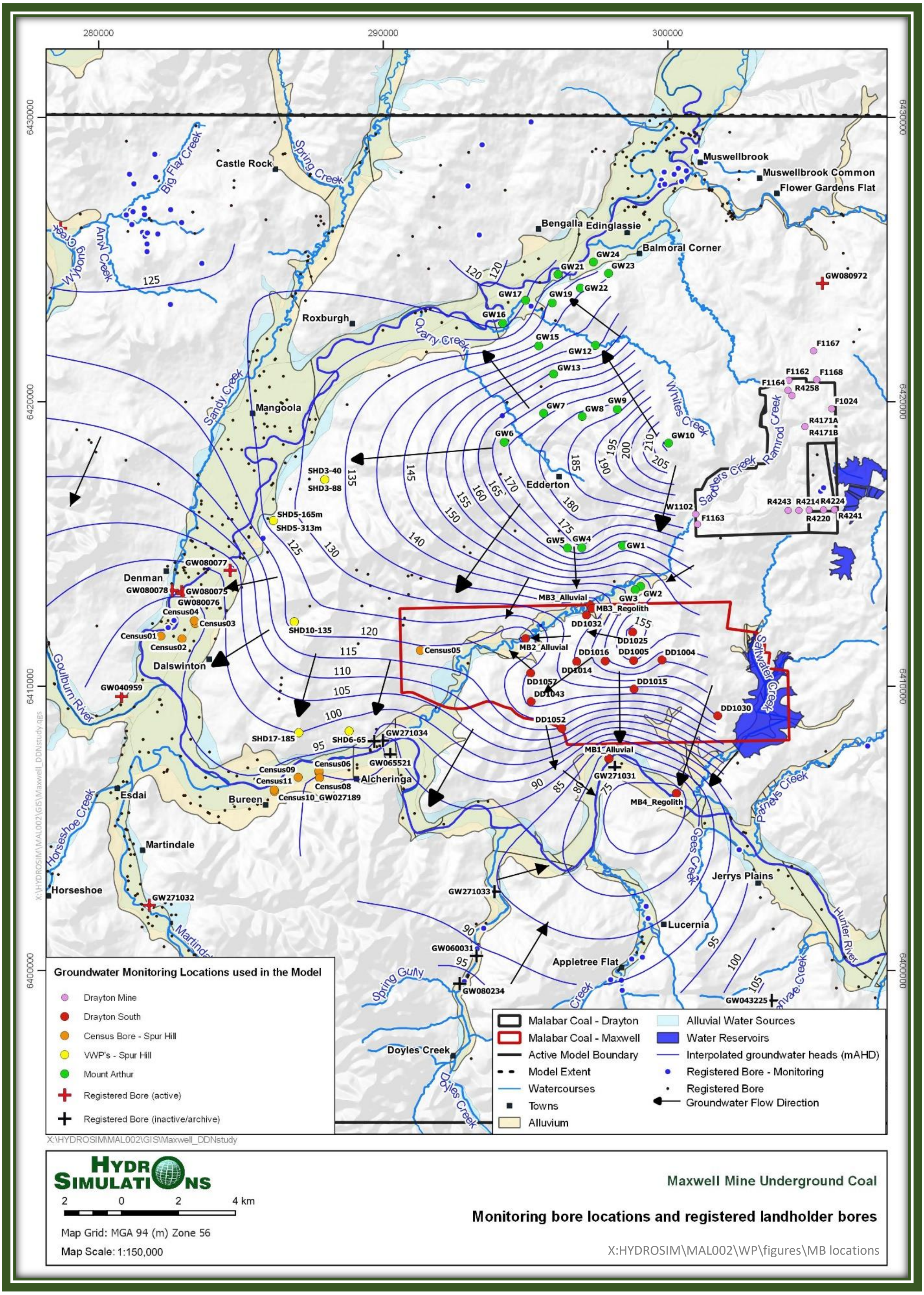

Figure 22 Monitoring bore locations and registered landholder bores

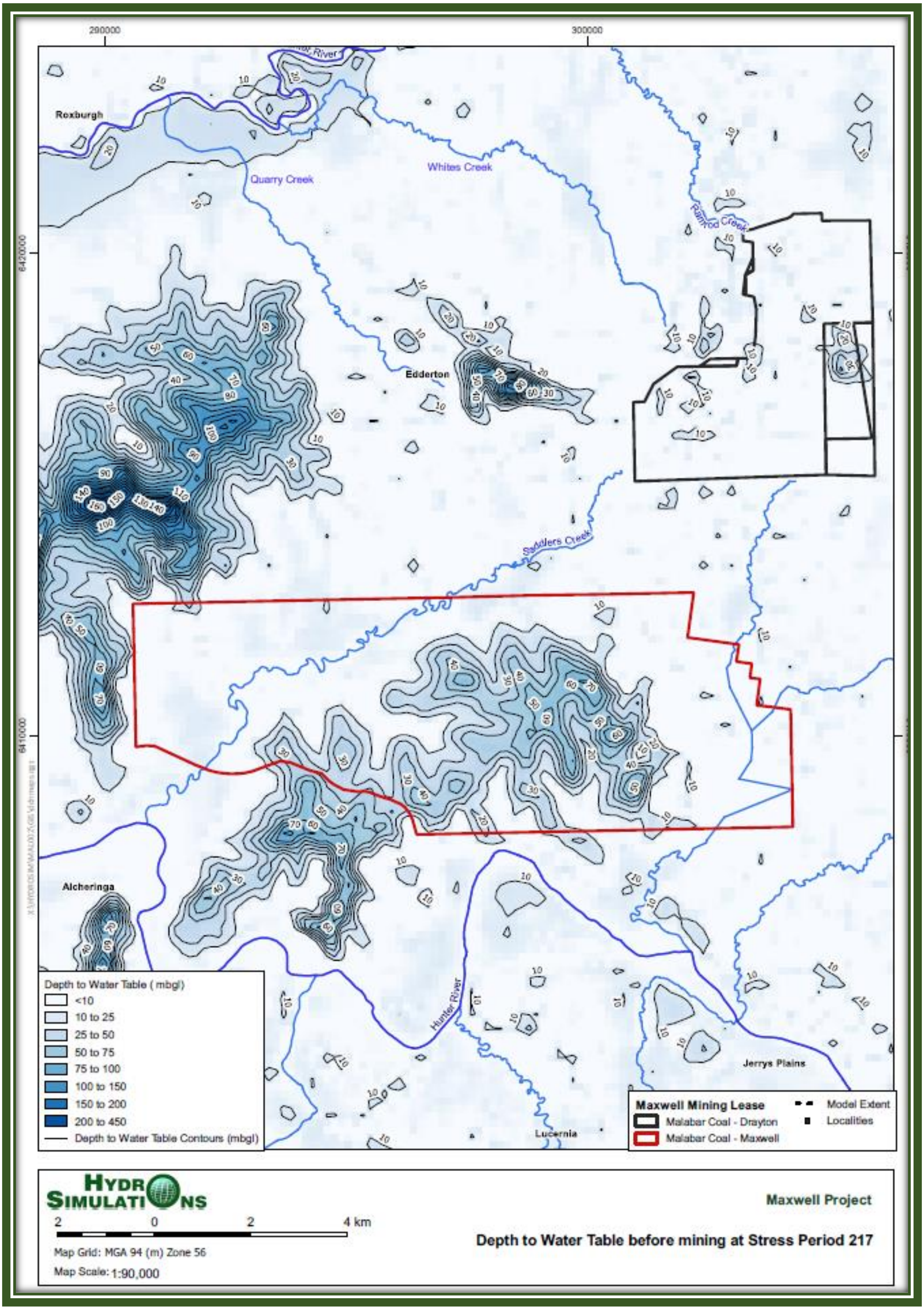

Figure 23 Predicted depth to water table (pre-mining)

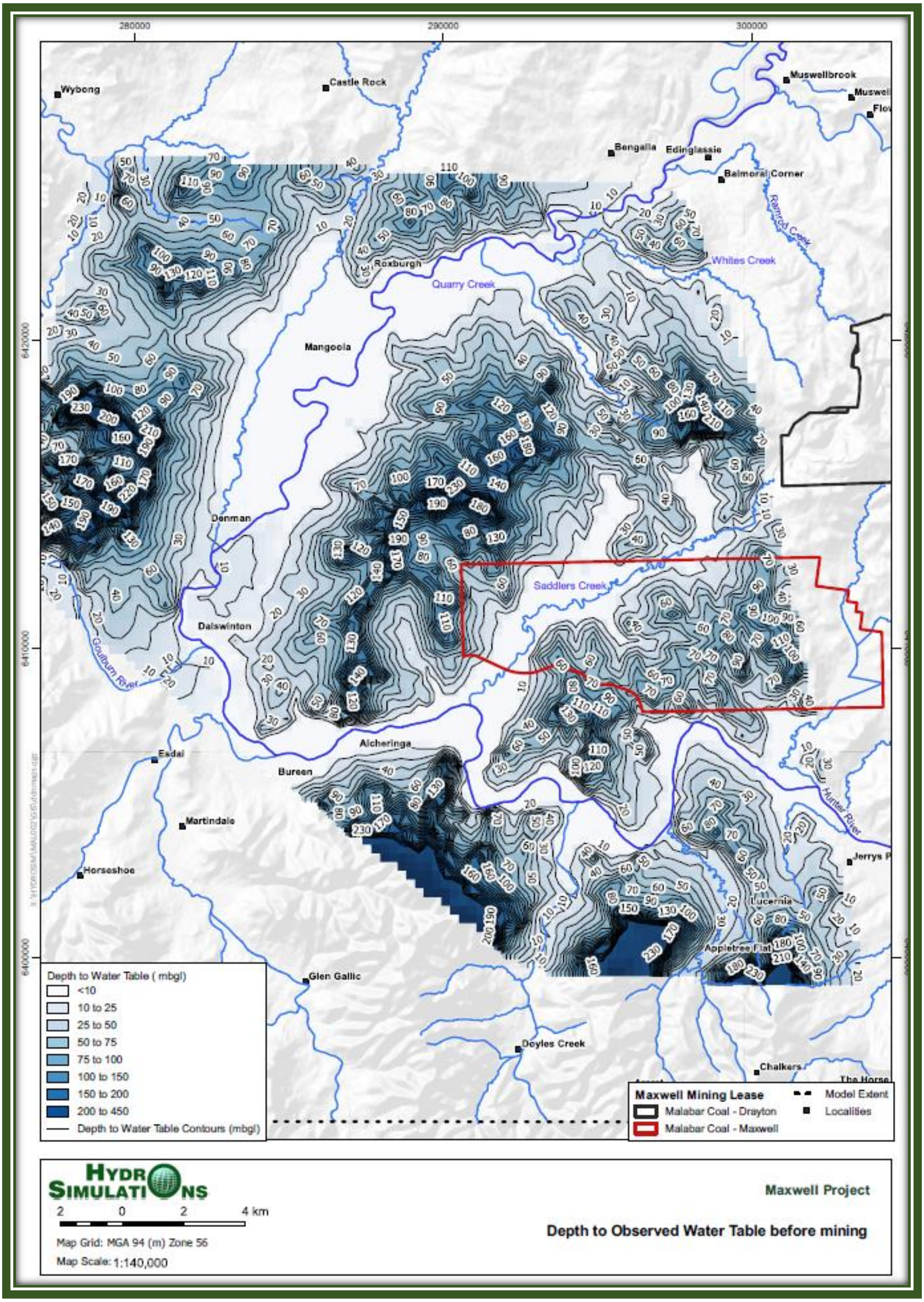

Figure 24 Depth to observed baseline water table

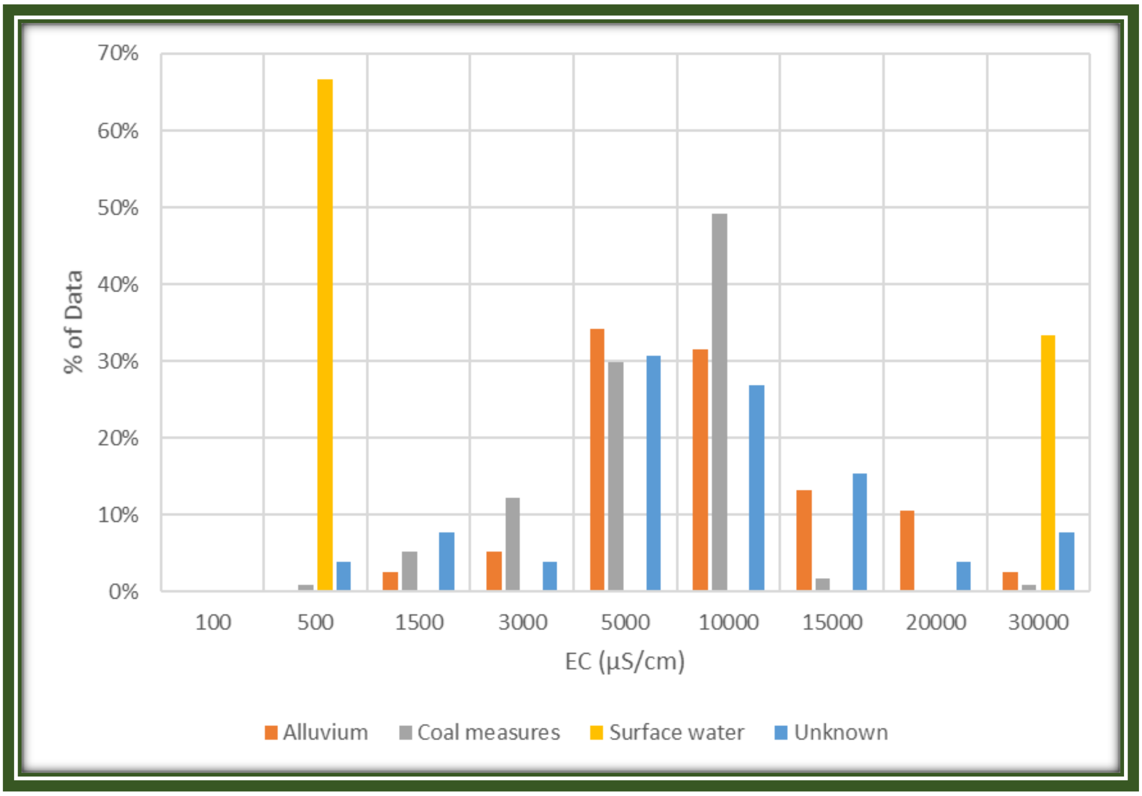

Figure 25 Regional EC - data

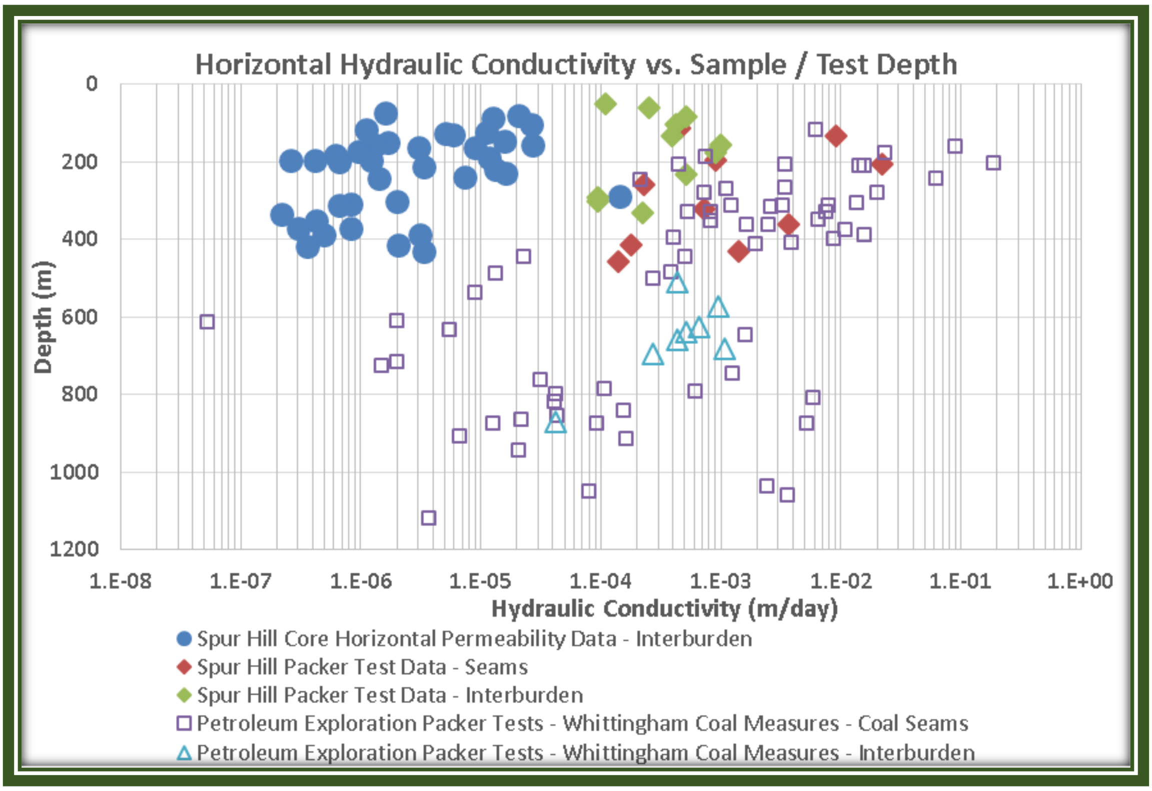

Figure 26 Horizontal K

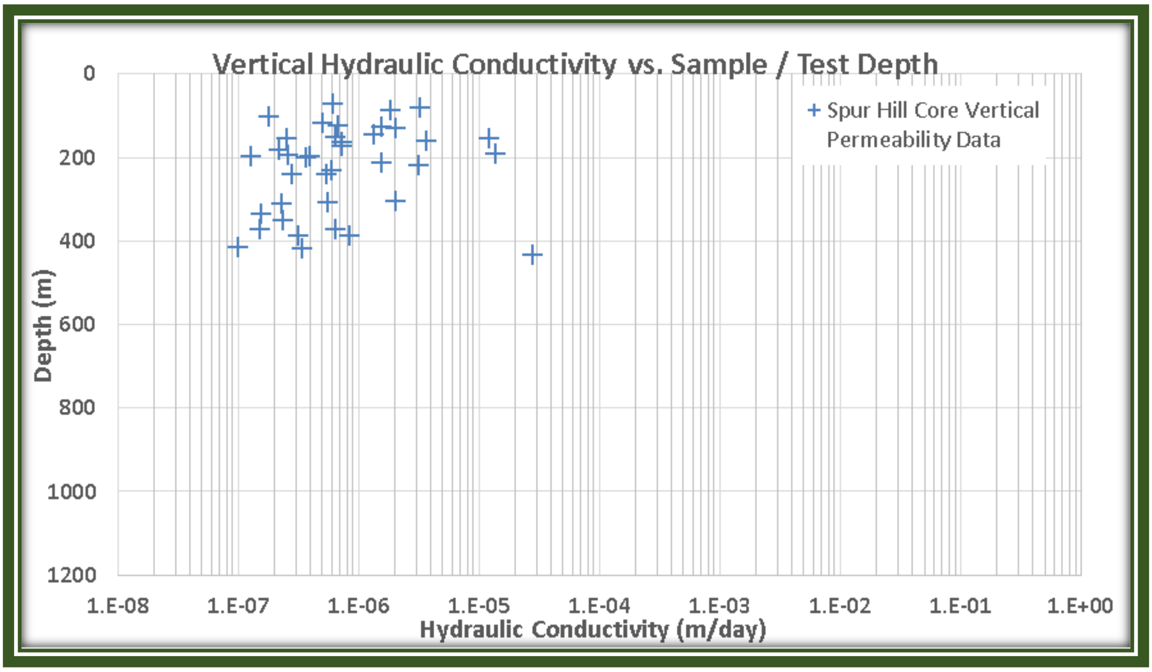

Figure 27 Vertical K

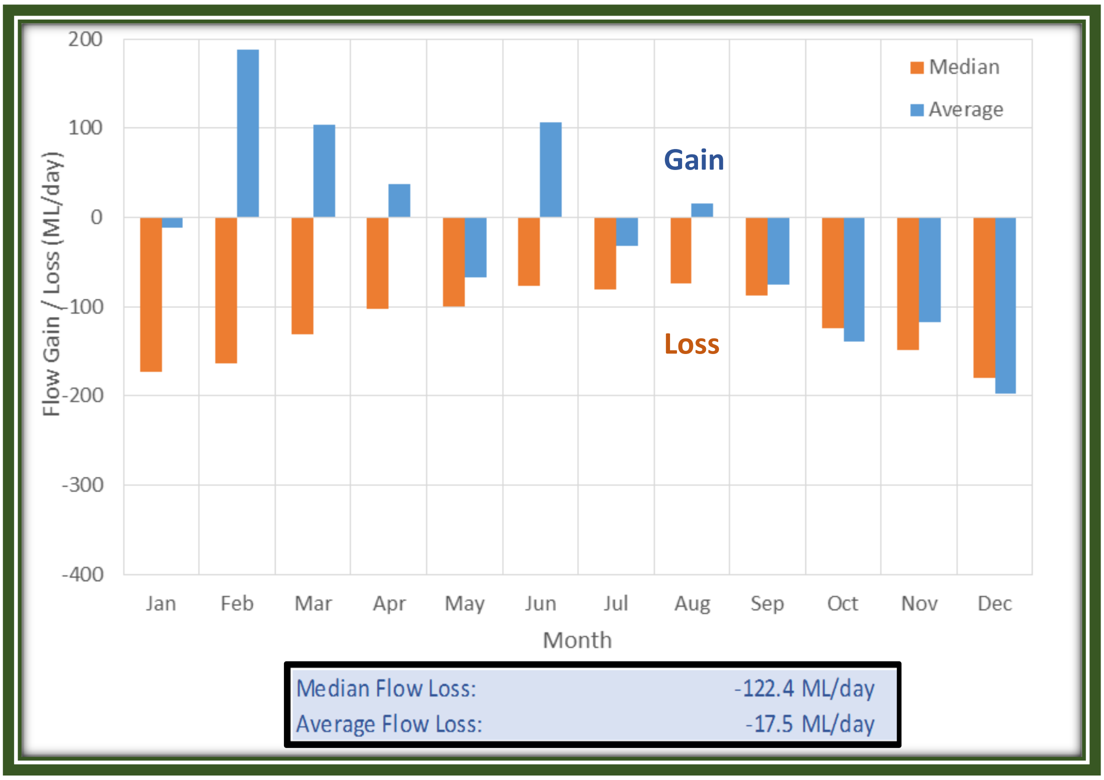

Figure 28 Monthly flow gain/loss on the Hunter River between Muswellbrook and Liddell (1913-2013)

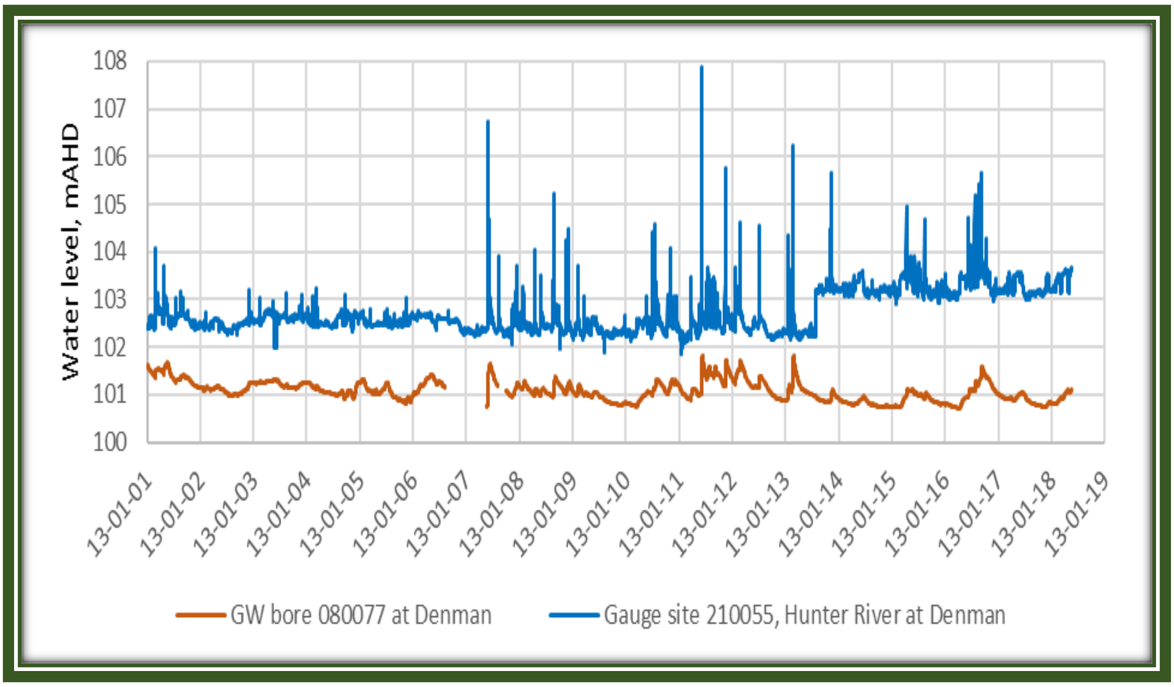

Figure 29 Hunter River surface water and alluvium water levels

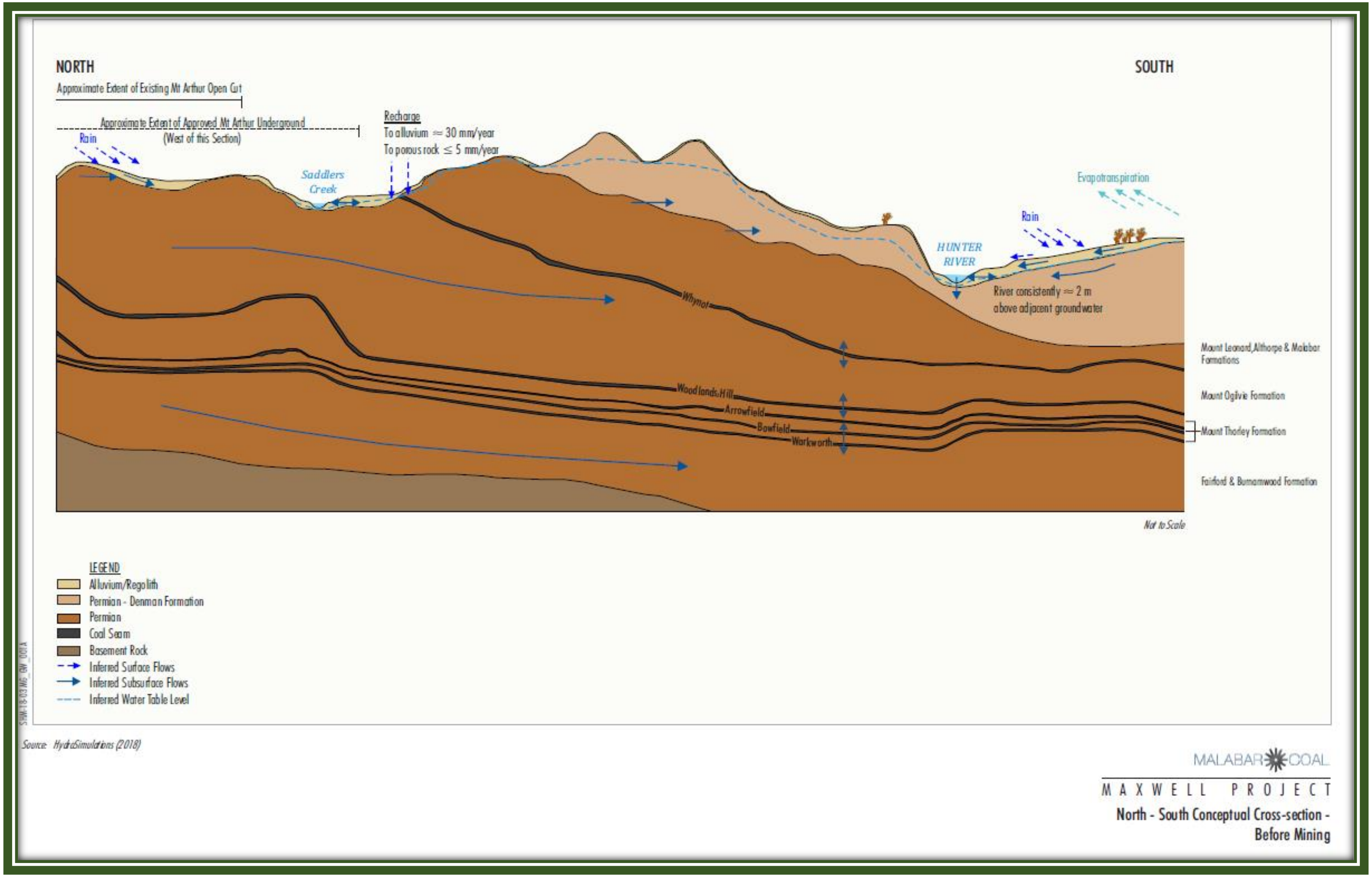

Figure 30 North – South conceptual cross section, EL 5460, before mining (not to scale)

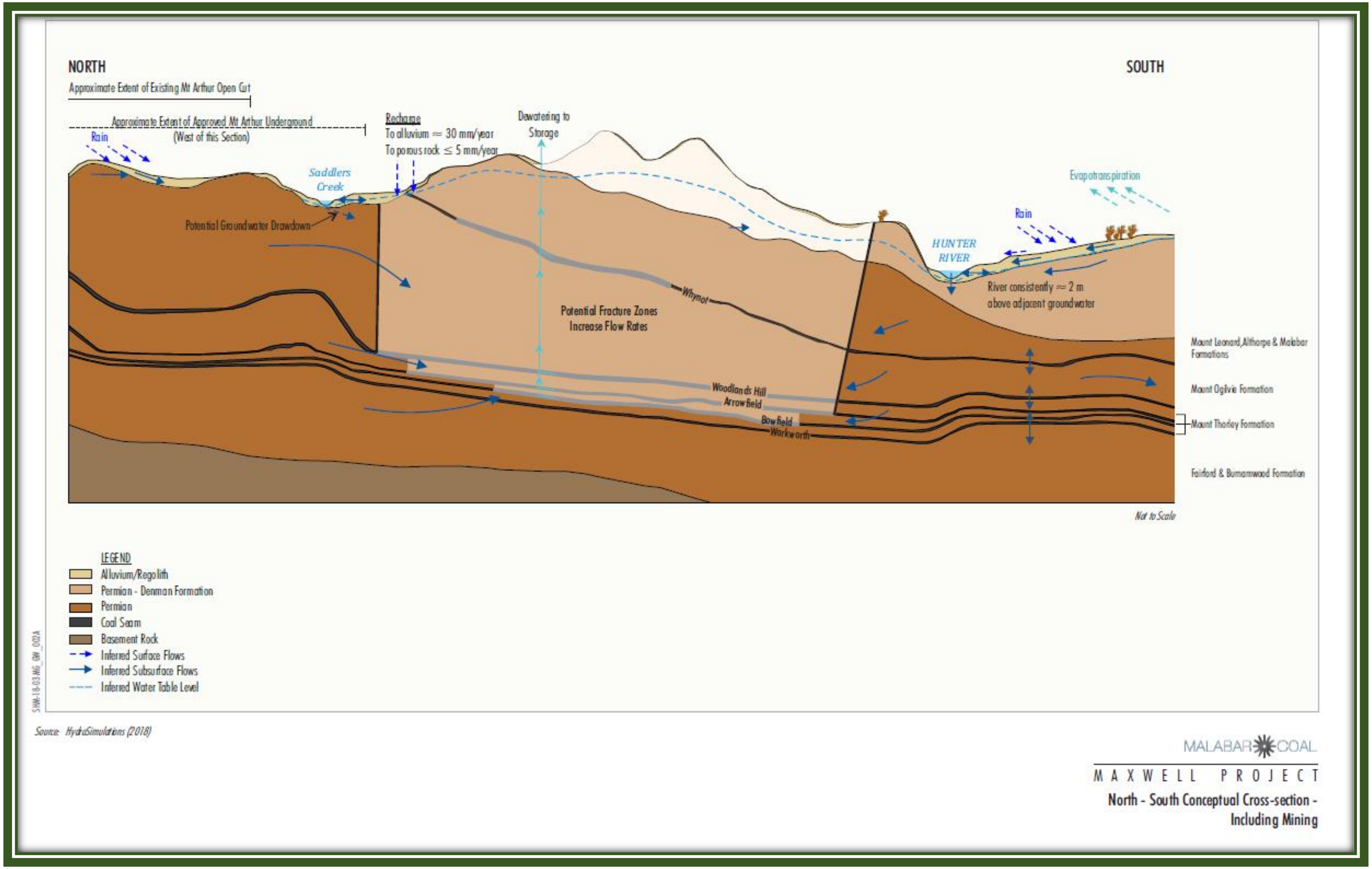

Figure 31 North – South conceptual cross section, EL 5460, including mining (not to scale)

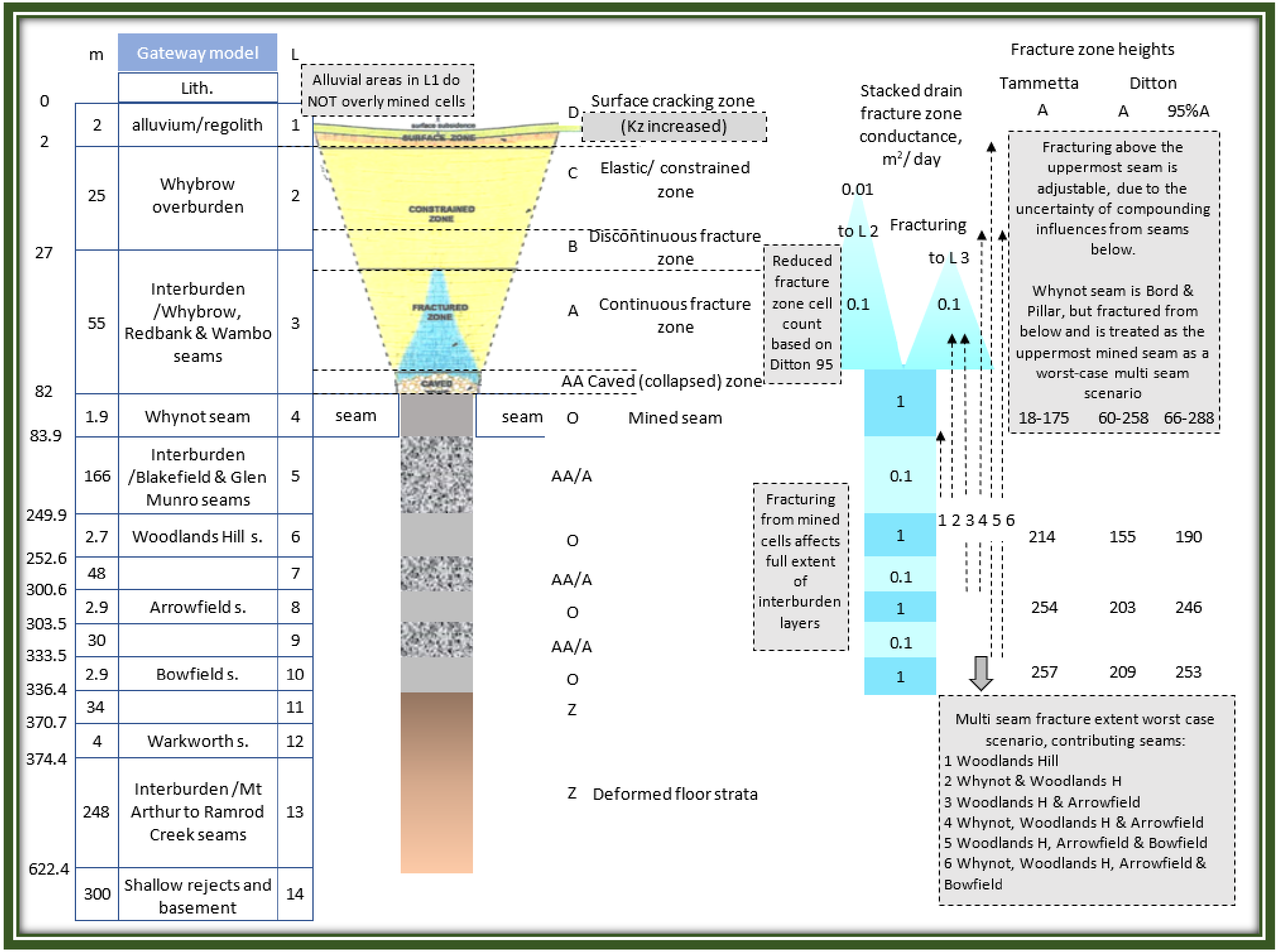

Figure 32 Mining deformation zones

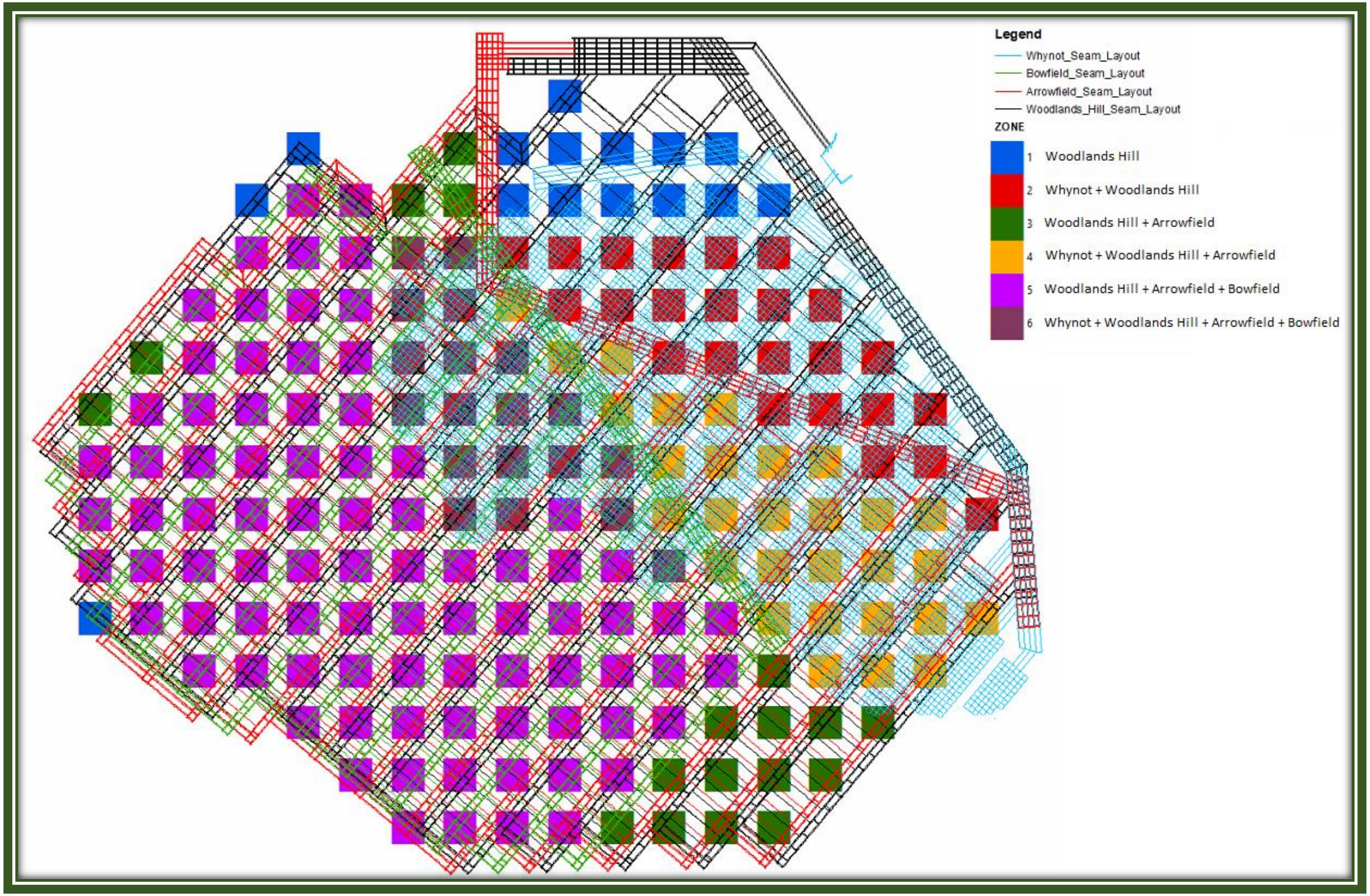

Figure 33 Stacked drain schematic

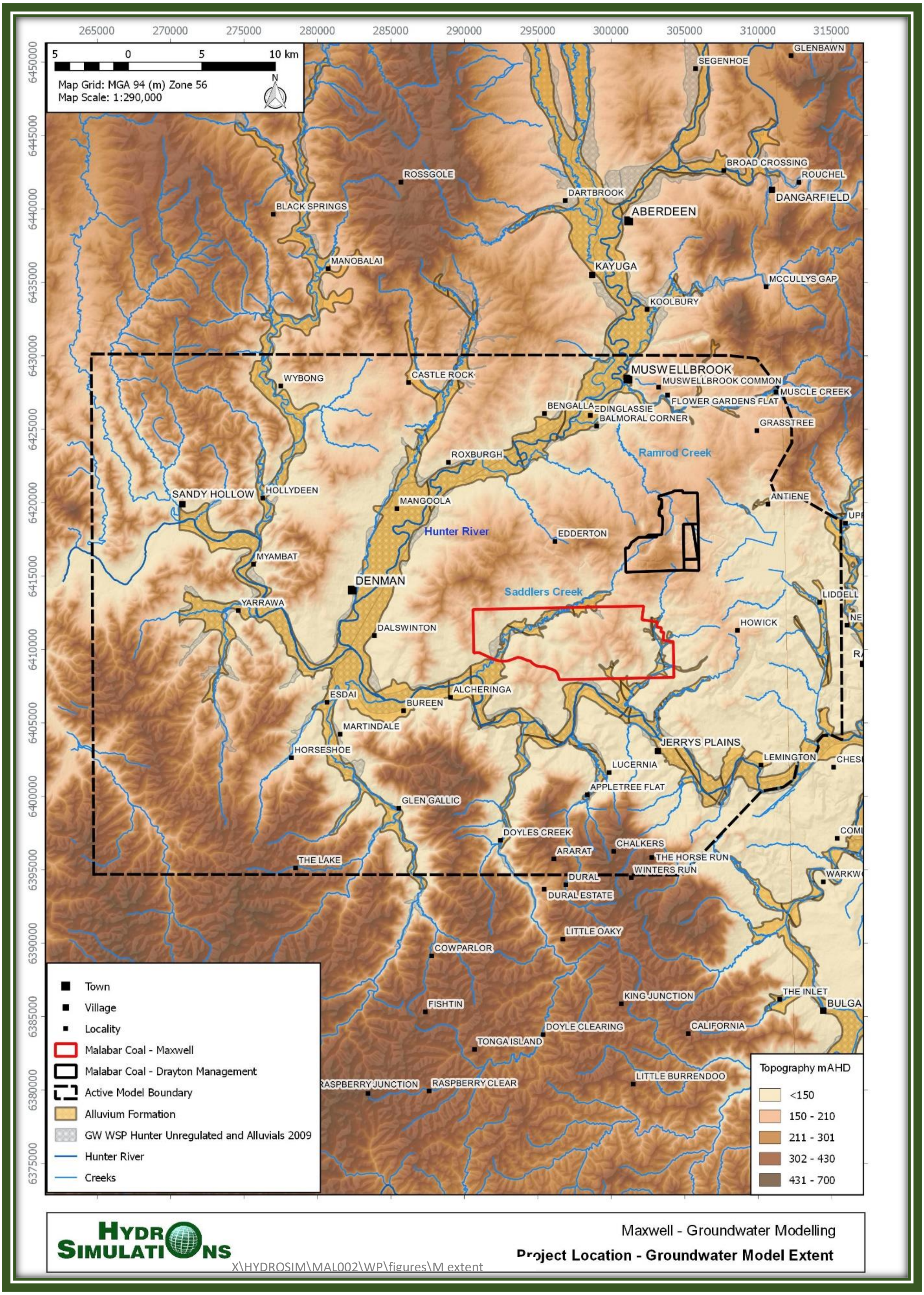

Figure 34 Groundwater model extent

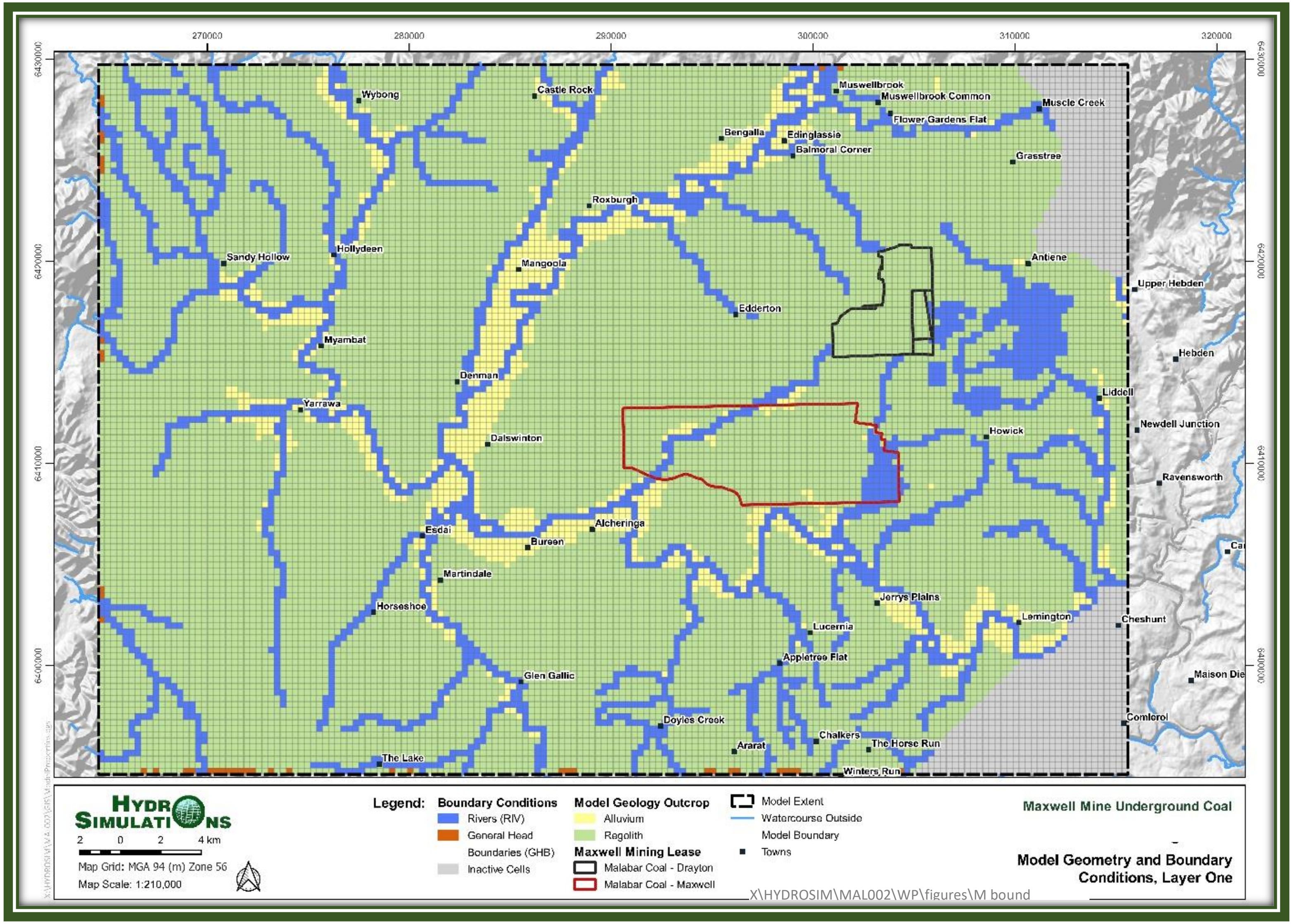

Figure 35 Model boundary conditions

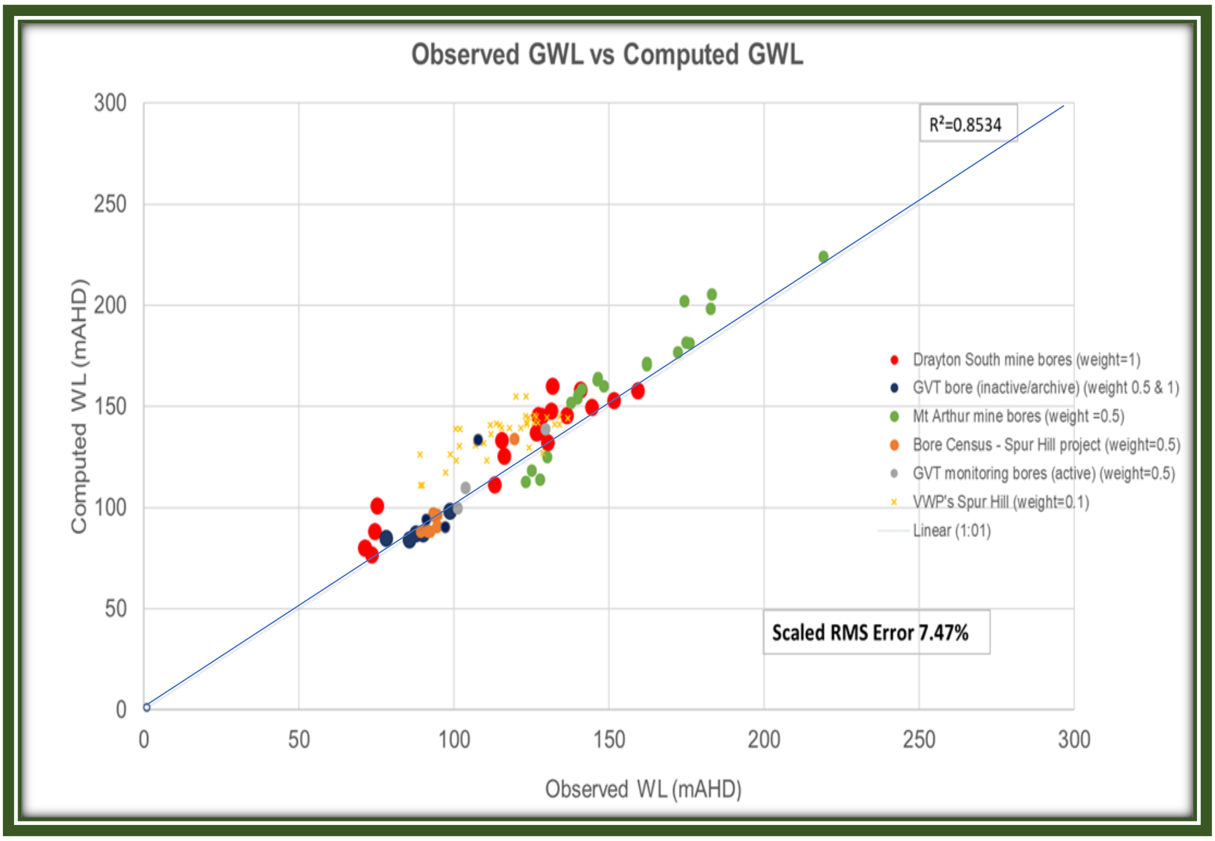

Figure 36 Calibration model observed and predicted calibration bore water levels

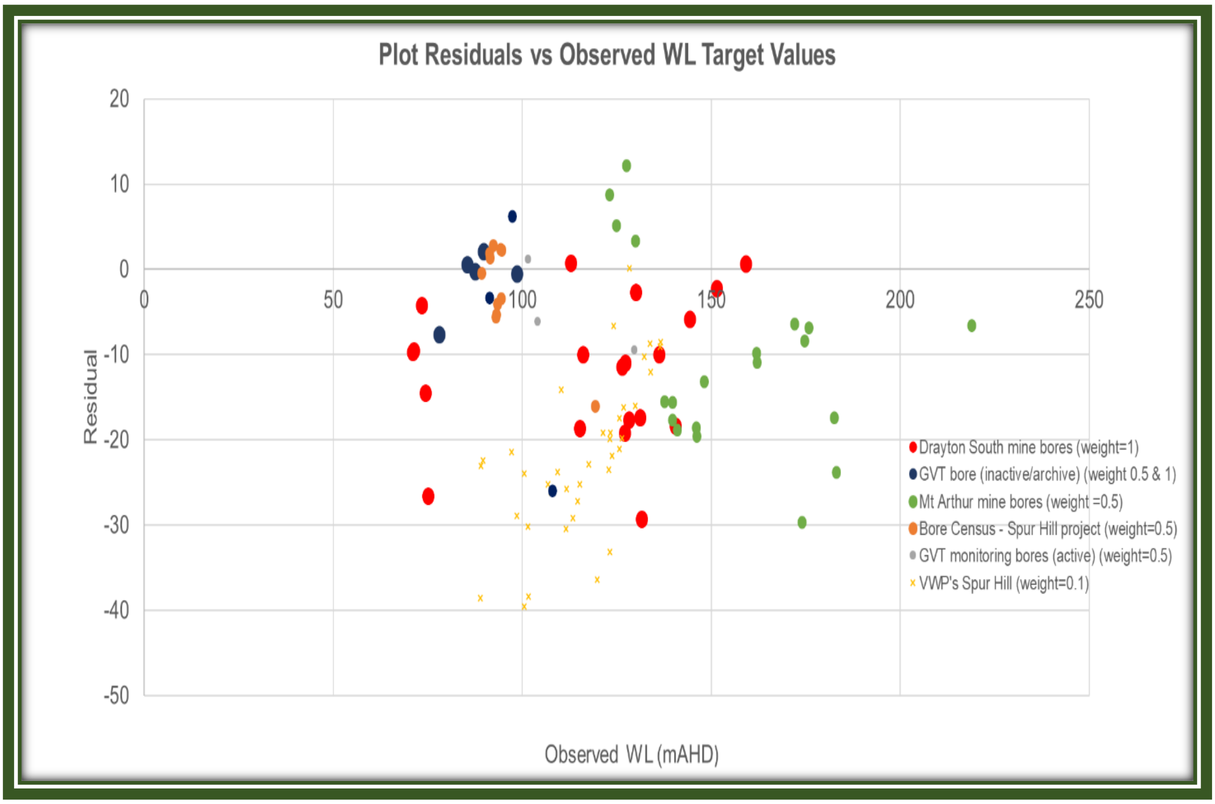

Figure 37 Calibration model observed and predicted value residuals

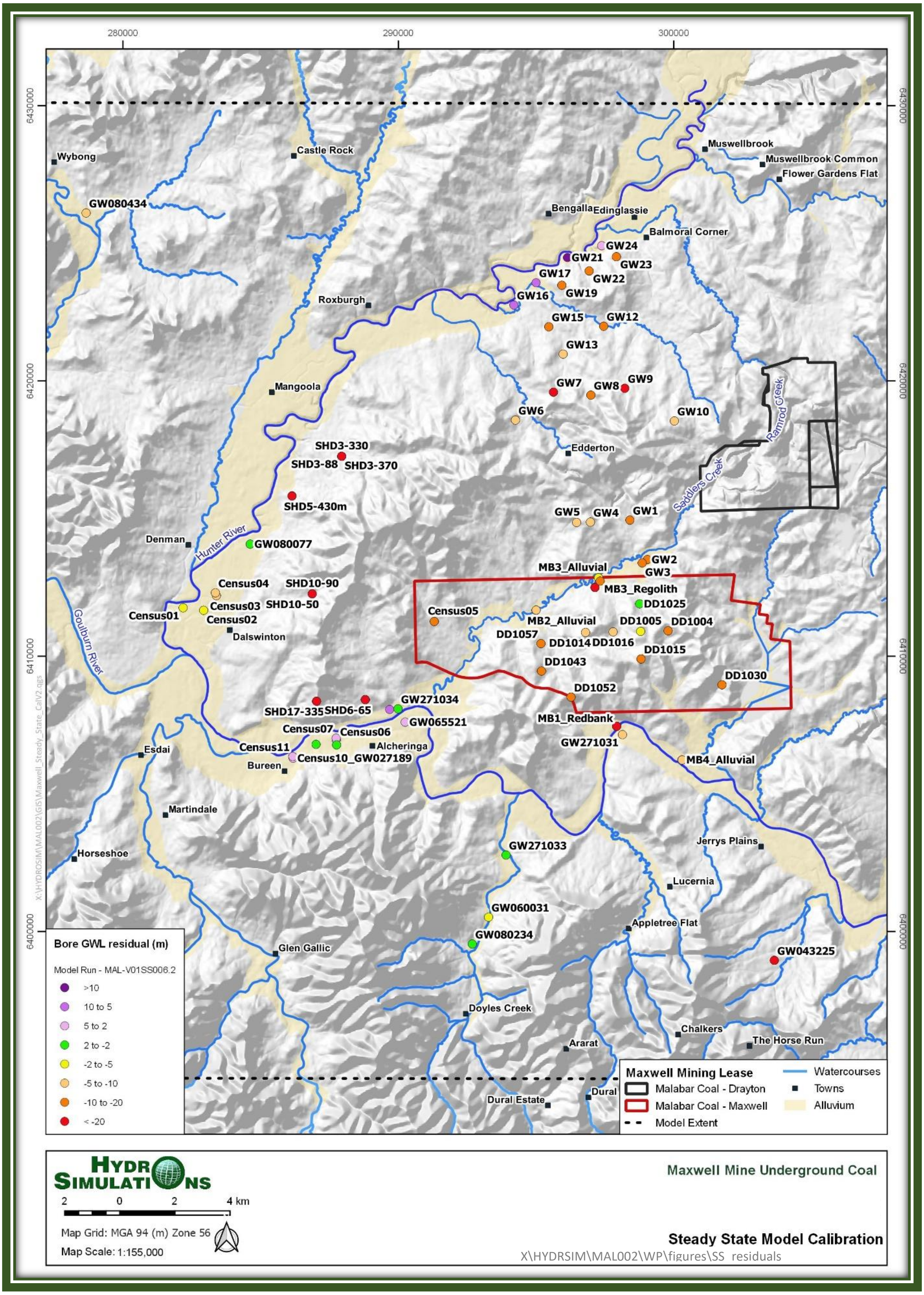

Figure 38 Steady state calibration residual map

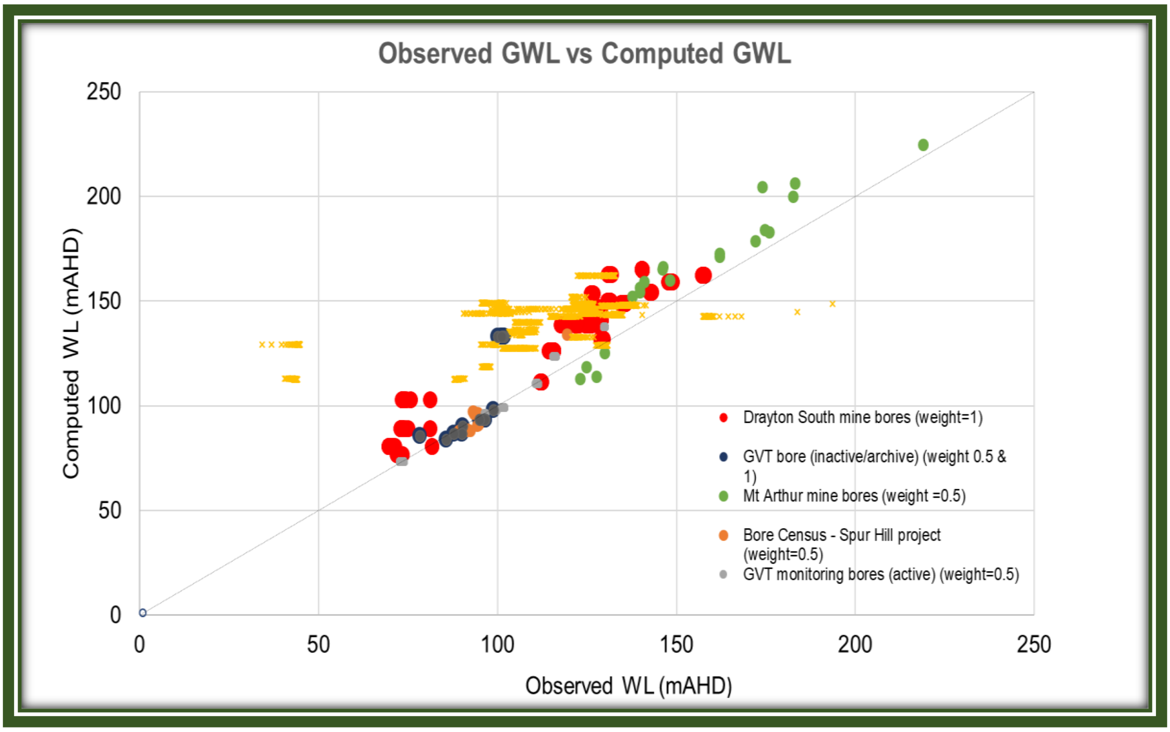

Figure 39 **Transient verification (stress period 1 to 216) model observed and predicted bore water levels**

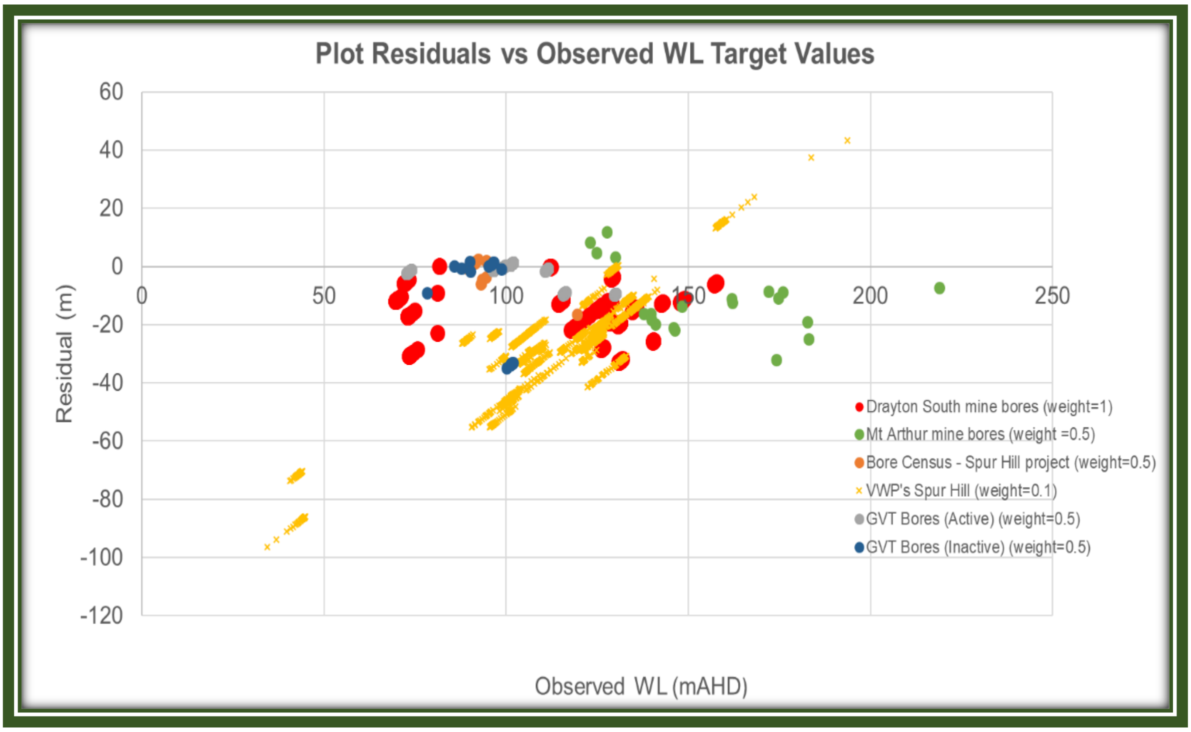

Figure 40 **Transient verification (stress period 1 to 216) model observed and predicted bore water level residuals**

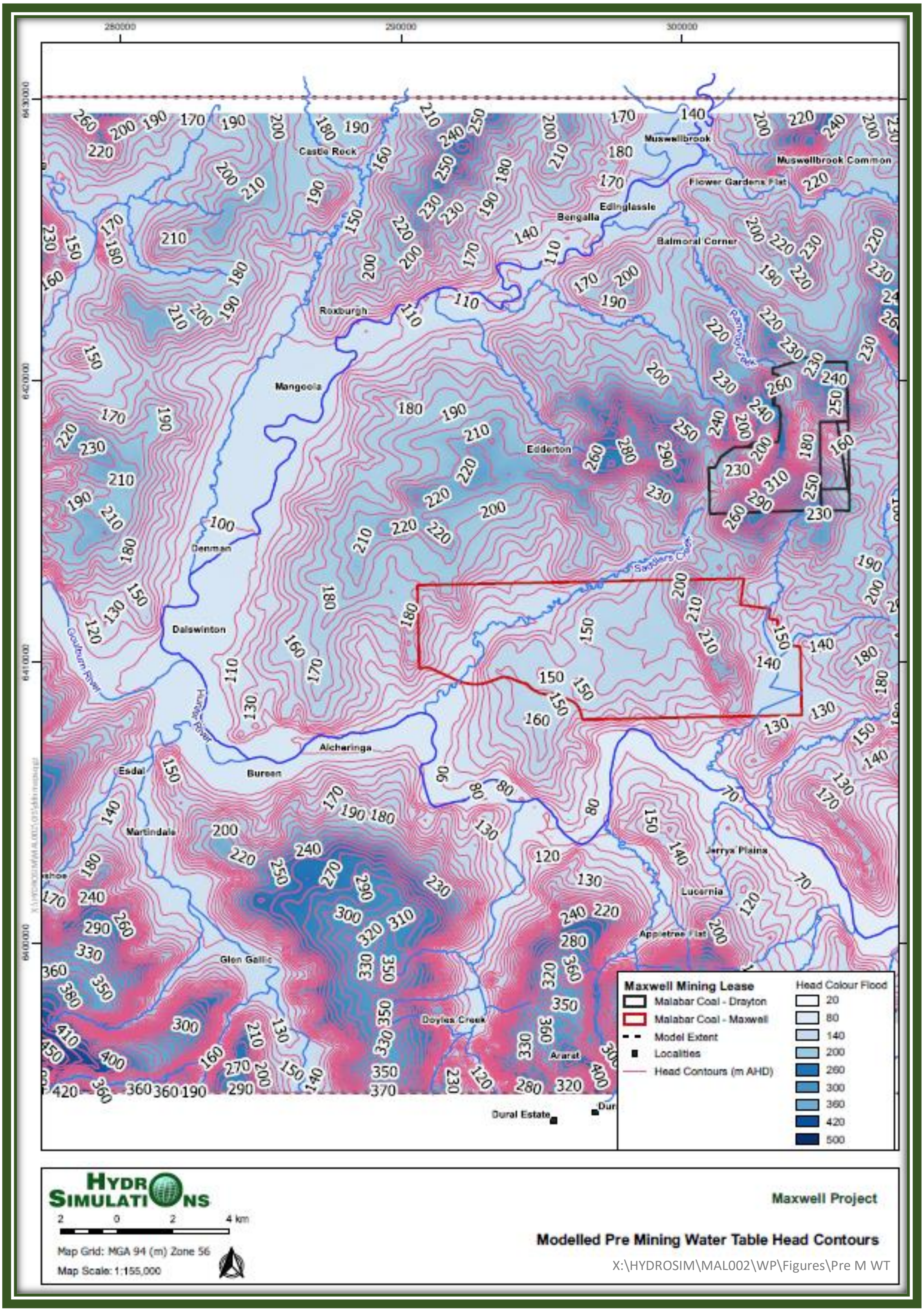

Figure 41 Predicted pre-mining water table contours

SP	Purpose	START	END	DAYS	Whynot L4	Woodlands Hill L6	Arrowfield L8	Bowfield L10	Production Year
					Coal Seam ("L"= model layer)				
1	INITIALISATION	Jan-2001	Jan-01	30					0
2-208	HISTORICAL	Jan-01	May-18	6301					0
209		May-18	Jun-18	30					0
210		Jun-18	Jul-18	30					0
211		Jul-18	Aug-18	30					0
212		Aug-18	Sep-18	30					0
213		Sep-18	Oct-18	30					0
214		Oct-18	Nov-18	30					0
215		Nov-18	Dec-18	30					0
216		Dec-18	Dec-18	30					0
217		Jan-19	Dec-19	364	HEADINGS				1
218		Jan-20	Dec-20	365					2
219		Jan-21	Jan-22	365					3
220		Jan-22	Jan-23	365					4
221		Jan-23	Jan-24	365					5
222		Jan-24	Jan-25	365					6
223		Jan-25	Jan-26	365					7
224		Jan-26	Jan-27	365	WHYNOT SEAM	WOODLANDS HILL SEAM			8
225		Jan-27	Jan-28	365					9
226	PREDICTIVE	Jan-28	Jan-29	365					10
227		Jan-29	Jan-30	365					11
228		Jan-30	Jan-31	365					12
229		Jan-31	Jan-32	365					13
230		Jan-32	Jan-33	365					14
231		Jan-33	Jan-34	365					15
232		Jan-34	Jan-35	365			ARROWFIELD SEAM		16
233		Jan-35	Jan-36	365					17
234		Jan-36	Jan-37	365					18
235		Jan-37	Jan-38	365					19
236		Jan-38	Jan-39	365					20
237		Jan-39	Jan-40	365					21
238		Jan-40	Jan-41	365					22
239		Jan-41	Jan-42	365				BOWFIELD SEAM	23
240		Jan-42	Jan-43	365					24
241		Jan-43	Jan-44	365					25
242		Jan-44	Jan-45	365					26
243		Jan-45	Dec-45	363		END OF MINING			27
244		Jan-2046	Dec-2095	18261					
245	RECOVERY	Jan-2096	Dec-2145	18261					
246		Jan-2146	Dec-2195	18261					
247		Jan-2196	Dec-2245	18261					

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Figure 42 **Model stress period layout**

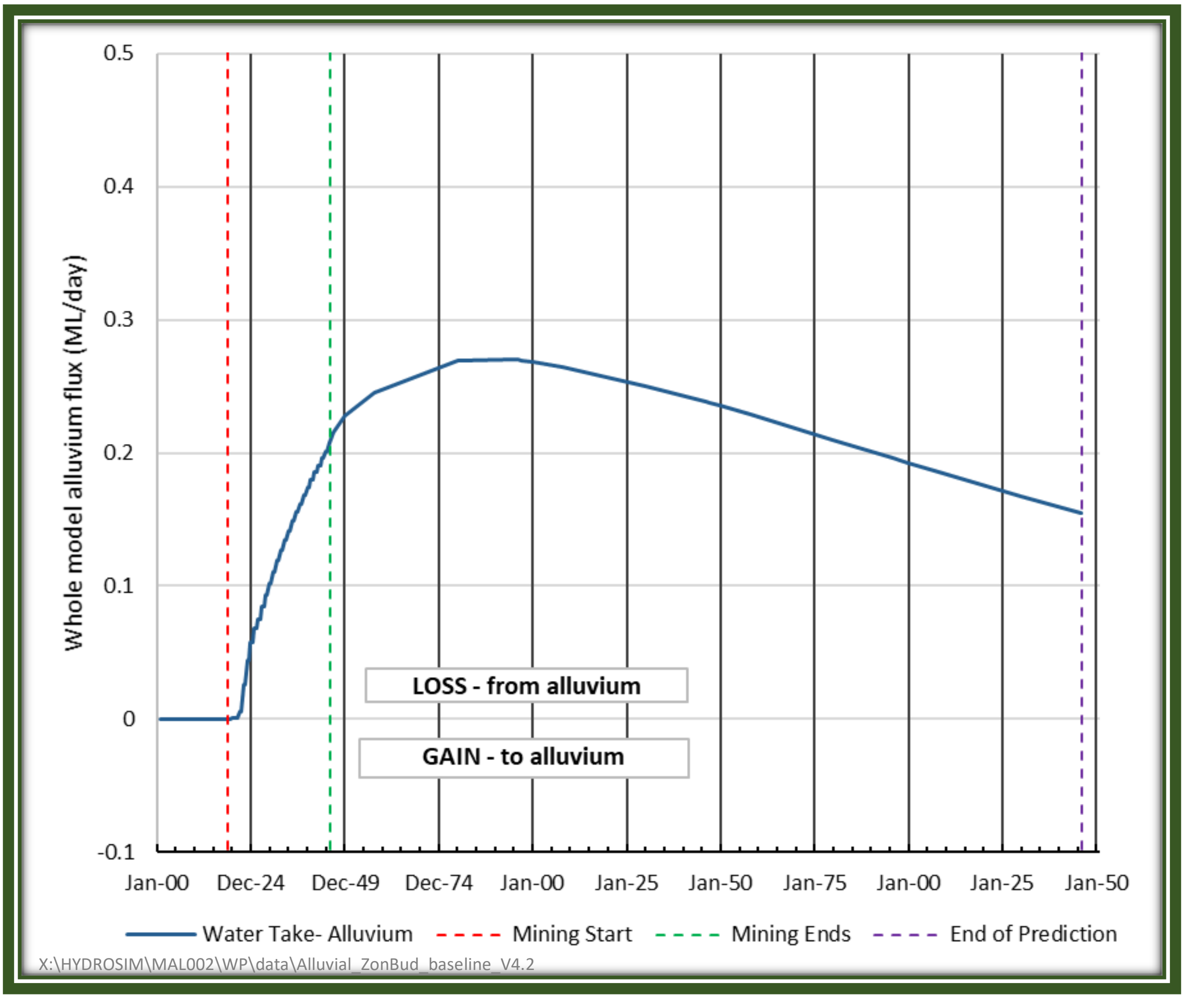

Figure 43 Predicted whole of model fluxes in alluvium

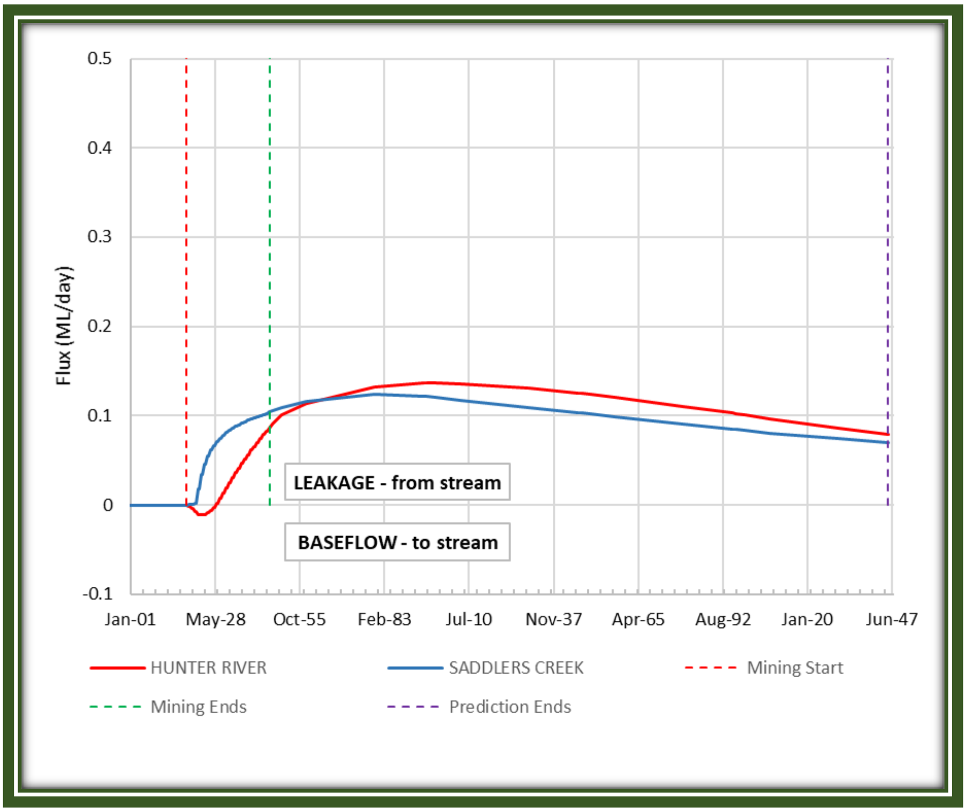

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Figure 44 Predicted whole of model fluxes in the Hunter River and Saddlers Creek

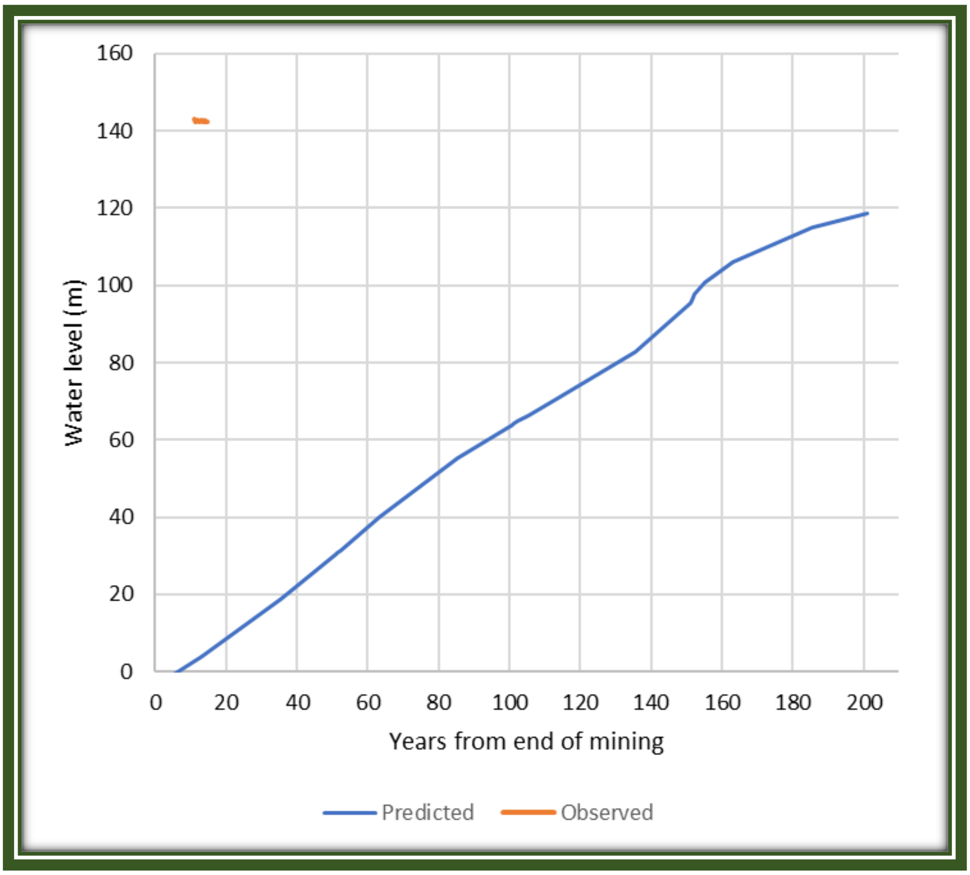

Figure 45 Predicted recovery water level, bore DD1016

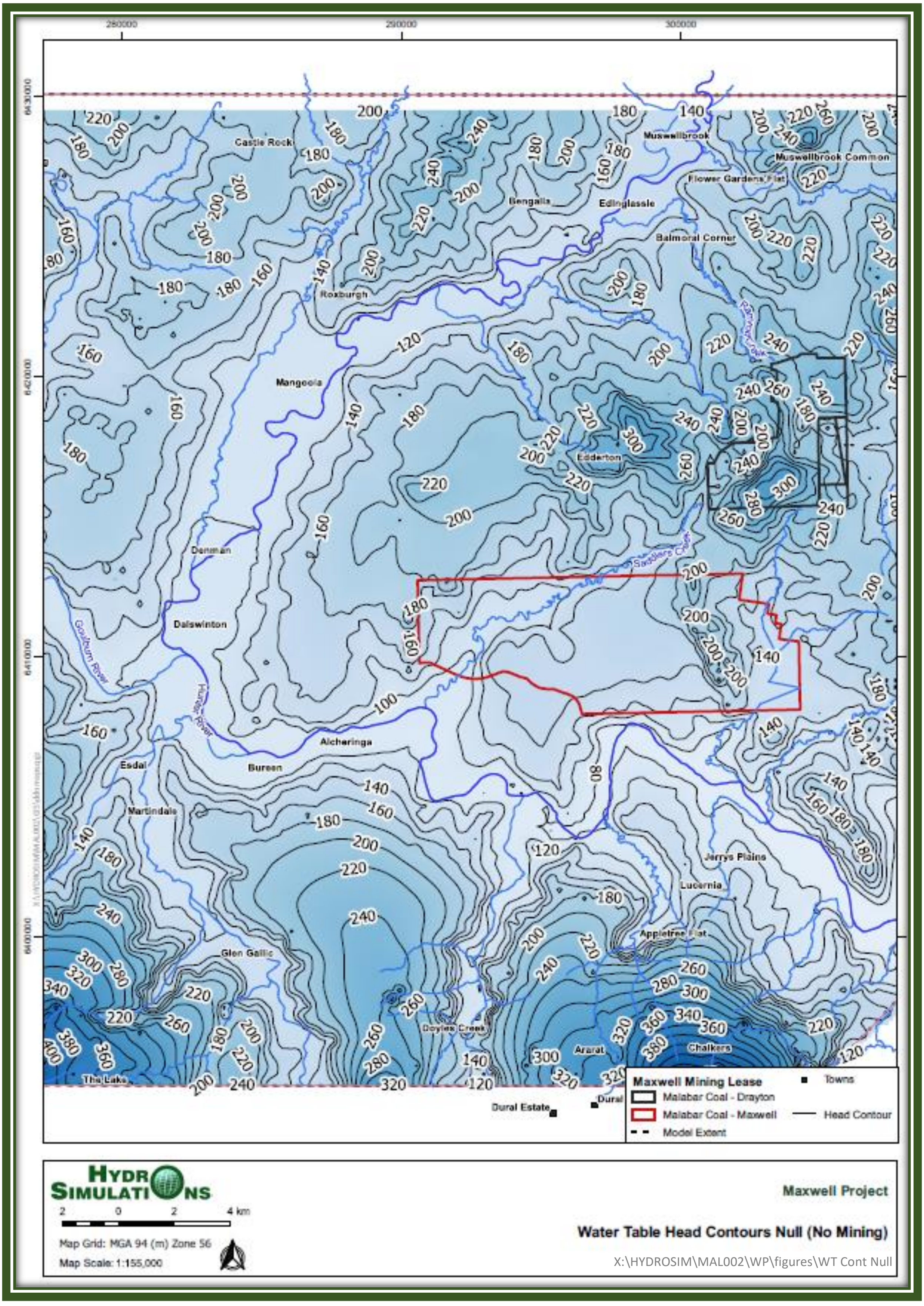

Figure 46 **Predicted water table contours at the end of 2045, without mining**

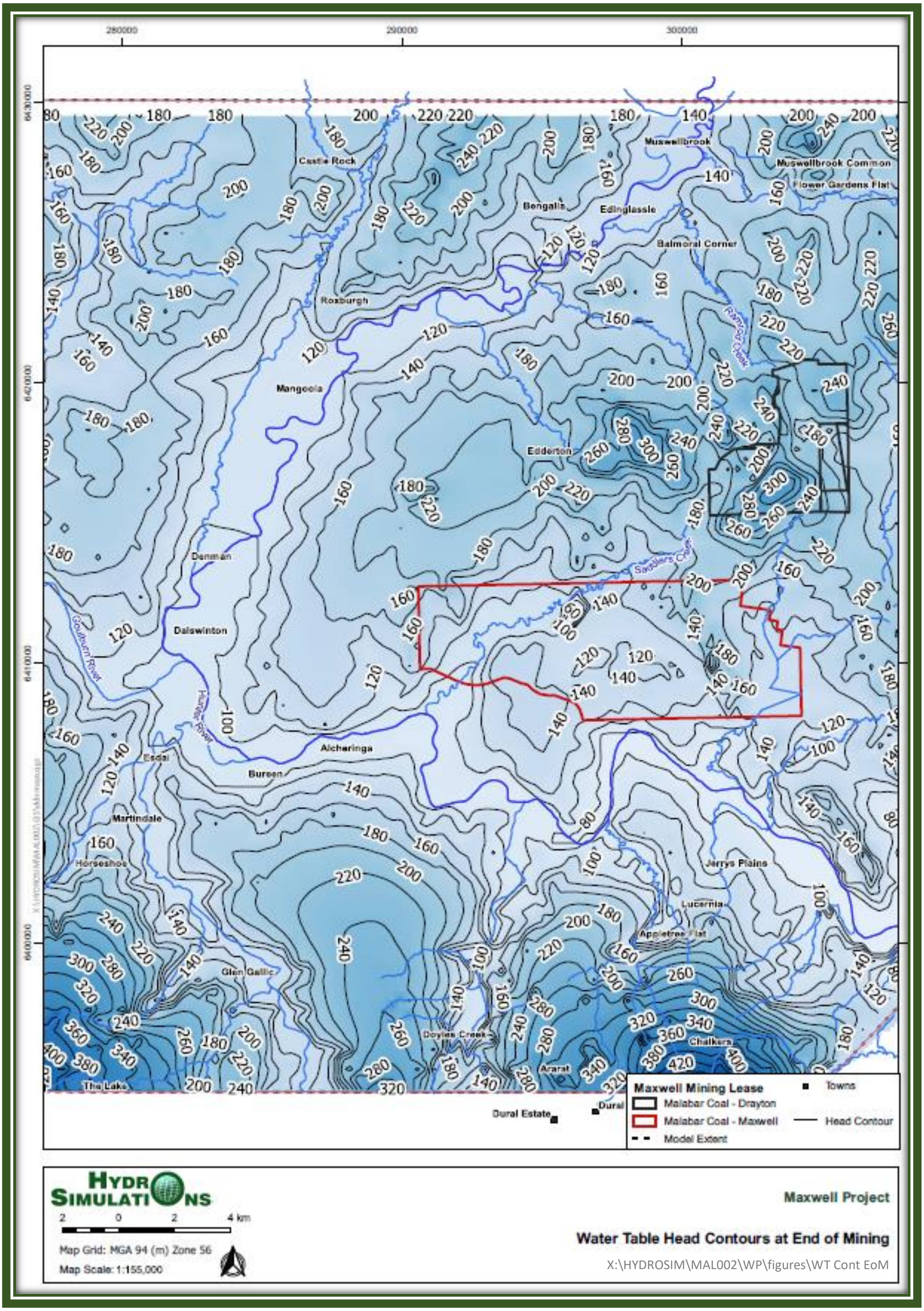

Figure 47 Predicted water table contours at the end of 2045, including mining