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Muswellbrook Coal Company
Continuation Project
Groundwater Assessment

Report Number 630.11575

28 April 2016

Muswellbrook Coal Company
Muscle Creek Road
Muswellbrook
NSW 2333

Version: Revision 1

Muswellbrook Coal Company

Continuation Project

Groundwater Assessment

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630.11575	Revision 1	28 April 2016	Brian Rask	Derwin Lyons	Ben Latimore
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TABLES

FIGURES

1 INTRODUCTION

1.1 Background

Muswellbrook coal mine (MCM) is an open cut coal mine operated by Muswellbrook Coal Company Limited (MCC). MCM is located on Muscle Creek Road, 3 kilometres (km) north-east of the township of Muswellbrook, in the Muswellbrook local government area (LGA) in New South Wales (NSW) as shown on **Figure 1**.

MCC has a long history of mining in the Muswellbrook area, with underground operations commencing at MCM in 1907. Underground operations ceased in the late 1990s however; open cut mining continues. MCC has approval from Muswellbrook Shire Council (MSC) to mine within the No. 1 Open Cut Extension Area (Open Cut 1) (DA 205/2002, as modified), with operations approved to be complete by 2020.

Additional coal resources have been identified to the north of Open Cut 1, between Open Cut 1 and Open Cut 2. While this area is within the development consent boundary, a modification to the existing development consent is required to modify the conceptual mine plan to allow mining of these additional resources, as well as extending the approved mine life and modifying the conceptual final landform (the modification) as shown on **Figure 2**.

The modification would maximise the recovery of coal resources within ML 1562, ML 1304 and CCL 713 and would enable the recovery of approximately 4.2 million tonnes (Mt) of additional coal resources.

In summary the modification involves:

- Extension of open cut mining operations in Open Cut 1;
- Extension of MCM life, with operations to cease by the end of 2025;
- Changes to the conceptual final landform within the modification area; and
- Overburden emplacement in both Open Cut 1 and Open Cut 2, so as to achieve the conceptual final landform.

As the modification involves mining within a previously disturbed area there would be no direct impact to previously undisturbed land.

No changes are proposed to the maximum production rate of 2 Mtpa, mining methods, coal processing, blasting methods, water management, waste management and handling, coal transport, access to site, employee numbers, or hazardous substances and dangerous goods management.

The modification is being assessed under Section 96(2) of the *Environmental Planning and Assessment Act* (EP&A Act). EMM Consulting was commissioned by MCC to prepare a Statement of Environmental Effects (SEE) to accompany a Development Application (DA) for the modification. SLR Consulting Australia Pty Ltd (SLR) was subsequently engaged to prepare a Groundwater Assessment (GWA) to support the DA.

1.2 Surrounding Land Use

Land uses surrounding MCM include agricultural activities, light industrial land uses and residential areas. Agricultural activities are located on properties surrounding MCM and primarily include grazing of beef cattle. Light industrial land uses include Muswellbrook Quarry to the north-west, St Heliers correctional centre to the north-west and Muswellbrook waste management facility to the south. Muswellbrook township is to the south-west, with other notable rural-residential areas along Sandy Creek Road to the north, Woodlands Ridge Estate to the south and along Muscle Creek Road to the south-east.

Other significant features surrounding MCM include the Main Northern Rail Line and the New England Highway, which run to the west through Muswellbrook township and to the south towards Singleton. Numerous other mining operations and power-generating facilities exist between Muswellbrook and Singleton.

1.3 Operations

Mining currently targets the Greta Coal Measures and is progressing to the north as an extension of Open Cut 1. Historical (decommissioned) operations include:

- No 1 Underground;
- St Heliers Colliery;
- No 2 Underground; and
- Common Open Cut.

Active extraction has ceased in all areas except for Open Cut 1. While the other areas are not actively mined, they remain important from a water management perspective.

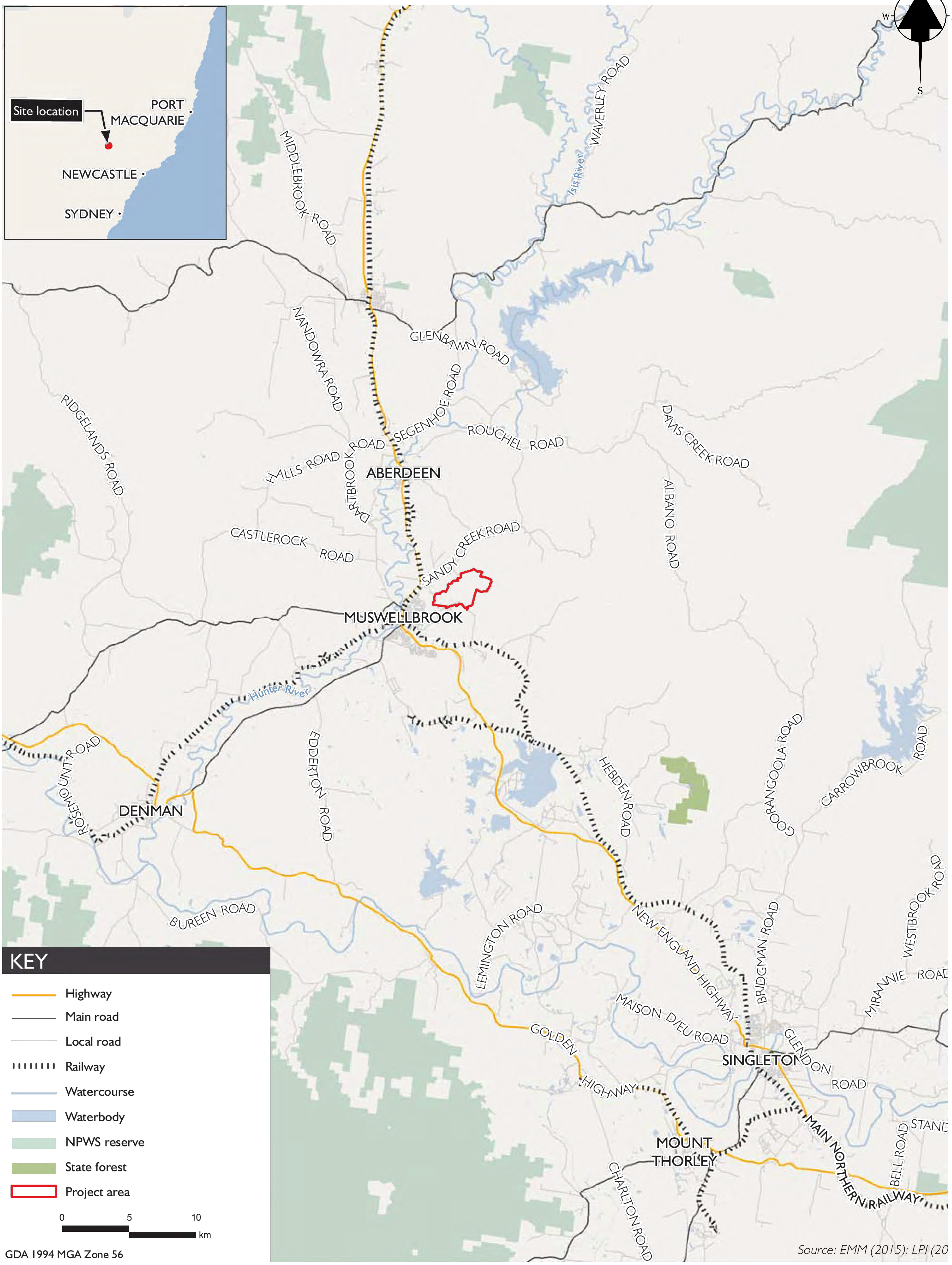
The current mining is undertaken on a truck and excavator basis with raw coal stockpiled adjacent the Coal Processing Plant (CPP) for processing and overburden backfilled into the Open Cut 1 behind active extraction. In this manner, the open cut pit is progressing to the north and emplacement activity is following behind the open cut pit. Raw coal is processed in the CPP before being trucked to the Ravensworth Rail Terminal for transport to the Port of Newcastle for export.

1.4 Overview of the Modification

Mining is currently targeting up to six coal seams in the Greta Coal Measures. The modification involves a continuation of the current mining in Open Cut 1 to the north through the western portion of an existing rehabilitated area. This area is expected to be up to 40m deep in places (through to a generally undisturbed rock strata). Subsequently, when progressing through this area, the existing overburden will be battered back to a lower grade than the underlying strata for stability purposes. This will redistribute the catchment area.

A number of options have been considered for managing overburden generated by the modification with the preferred option involving dumping of waste rock into both Open Cut 1 and Open Cut 2. This will require up to 14 million bank cubic metres (Mbcm) of bulk shaping to achieve maximum final landform slopes of 14 degrees in both final open cut pits (MCC, 2016).

The proposed mining and overburden emplacement activity will remain wholly within the current development consent boundary and from a groundwater management perspective there are no significant changes to the currently approved management of water resources.



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DRAWING NUMBER: FIGURE 1

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1.5 Groundwater Assessment Scope of Works

This GWA focussed on:

- Assessment of drawdown and inflows associated with the modification;
- Assessment of final void conditions; and
- Development of appropriate measures to mitigate potential impacts associated with the modification and ongoing operation of MCM.

The GWA scope of works included:

- Literature review of relevant legislation, policies and guidelines and relevant documentation;
- Identification of the key issues, relevant assessment criteria and constraints relating to groundwater;
- Details on the existing environment (surface hydrology, landowner bores, geology, hydrology; and water quality);
- An overview of the proposed groundwater monitoring and management system;
- Update of the analytical modelling used to assess potential impacts;
- An assessment of the impacts of the proposed modification on groundwater users within the local area and the surrounding areas; and
- Identification of proposed mitigation measures if required, to minimise or negate the impact the proposed modification may have on the existing environment, particularly with regards to the receiving environment.

2 RELEVANT LEGISLATION, POLICY, GUIDELINES AND LICENCES

2.1 Legislation

2.1.1 Protection of the Environment Operations Act 1997

The POEO Act is the key piece of environmental legislation administered and enforced by the NSW Environment Protection Authority (EPA). The POEO Act enables the Government to set out explicit protection of the environment policies and adopt more innovative approaches to reducing pollution.

MCC holds an Environment Protection Licence (EPL) under the POEO Act however; no discharge limits apply with respect to surface waters (refer to **Section 2.3**).

2.1.2 Water Management Act 2000 and Water Act 1912

The *Water Act 1912* (Water Act) and *Water Management Act 2000* (WMA) contain provisions for the licensing and management of water in NSW. Once a water sharing plan commences for a water source, the Water Act is repealed and the WMA then applies to licences within that water source. MCM is located within an area covered by the *Water Sharing Plan for the Hunter Regulated River Water Source 2003* (the Water Sharing Plan) (refer **Section 2.1.3**) for the management of surface water in the nearby Hunter River. Surface and groundwater within the alluvium of Sandy Creek and other tributaries, as well as bedrock aquifers, are managed under the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources*.

MCC holds four licences to extract groundwater under Part 5 of the Water Act. The access licence volumes are shown in **Table 1**.

Table 1 MCC Groundwater licenses under the Water Act.

<table>
<tr><th>Licence Number</th><th>Pertaining To:</th><th>Entitlement (ML/year)</th></tr>
<tr><td>20BL169014</td><td>Borehole RDH529</td><td>1000</td></tr>
<tr><td>20BL169037</td><td>Open Cut Pit No. 1</td><td rowspan="2">2000</td></tr>
<tr><td>20BL169038</td><td>Open Cut Pit No. 2</td></tr>
<tr><td>20BL170473</td><td>Borehole RDH607</td><td>3000</td></tr>
</table>

The Harvestable right provisions under the WMA provide for landholders in NSW to collect a portion of the rainfall runoff on their property and store it in dams (up to a certain size). This rainfall Harvestable Right is typically 10% of the total rainfall runoff for the property and is known as the Maximum Harvestable Right Dam Capacity (MHRDC). Where dams exceed this capacity or a certain size, they must be licensed.

Exclusions to this licensing requirement exist for dams used to control pollution or effluent. All dams at MCM are used for pollution control purposes (control of mine water and dirty water) and as such, are exempt from MHRDC licensing requirements at the current time. Following rehabilitation, consideration must be given to the applicability of the MHRDC for the property.

2.1.3 Water Sharing Plan for the Hunter Regulated River Water Source 2003

The Water Sharing Plan includes rules for protecting the environment, extractions, managing licence holders' water accounts, and water trading in the plan area.

As a means of achieving the objectives of the Water Sharing Plan, total daily extraction limits are in place to protect the water held under access licences for the purpose of providing water to the environment and protecting flow in local watercourses. Extraction limits and environmental flow protection rules provide equitable water sharing and protect, preserve, maintain and enhance the region's water.

Planned environmental water provisions are in place to achieve this and relate to water that is committed by management plans for fundamental ecosystem health or other specified environmental purposes, and that cannot to the extent committed, be taken or used for any other purpose. Adaptive environmental water conditions may be imposed on whole or part of an access licence as another way to ensure the environmental water supply is protected.

Surface water runoff from the wider mine site currently drains to either of the open cut pits or operational dams located around MCM. Surface water runoff is not discharged but rather, is pumped between dams for use within the operations. Operational water is extracted from the groundwater bores and from the various surface water dams around the mine.

2.1.4 Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources (AGE, 2010)

The Hunter Unregulated and Alluvial Water Sources Water Sharing Plan (HURAWSP) commenced on 1st August 2009 and applies for a period of 10 years to 31 July 2019. It is a legal document made under the WMA] Water Sharing Plans for unregulated rivers and groundwater systems (such as the HURAWSP) have been completed using a "macro" or broader scale river catchment or aquifer system approach. Unregulated rivers are those which rely only on natural flow and are not regulated by releases from upstream dams.

The HURAWSP includes the Hunter unregulated river and creeks, the highly connected alluvial groundwater above the tidal limit, and tidal pool areas. A licence holder's access to water is managed in the water sharing plan through the long-term average annual extraction limit which sets the total annual extraction rate through daily access rules.

The long term limit is a management tool against which total extraction will be monitored and managed over the 10-year life of the plan. The rules in the HURAWSP that determine when licence holders can and cannot pump on a daily basis are more specific. Basic landholder rights do not require a water access licence, however, water access licences are required for mining activities where these activities intercept an unregulated river or connected aquifer water.

With respect to groundwater, the HURAWSP includes rules that recognise that some alluvial aquifers are highly connected to their parent streams and in these circumstances, the goal of water sharing rules is to manage the surface water and highly connected groundwater as one resource.

The HURAWSP includes "cease to pump" rules that specify minimum water levels in surface water bodies and aquifers below which no extraction can be undertaken. For the groundwater users in highly connected systems the "cease to pump" rule will apply the same as for the river pumpers.

For the groundwater pumpers in less connected systems, within 40 metres of the river, the cease to pump rules applied from year six (1 August 2014) of the Water Sharing Plan and will be the same as for the river pumpers.

2.2 Policies and Guidelines

The following relevant policies and guidelines were considered as part of this GWA:

- National Water Quality Management Strategy (Australian Government Department of Environment, 1992);
- State Water Management Outcomes Plan;
- NSW Aquifer Interference Policy (NOW, 2012);

- NSW Groundwater Dependent Ecosystems Policy (NSW Department of Land and Water Conservation, 2001).

2.2.1 National Water Quality Management Strategy

The National Water Quality Management Strategy (NWQMS) provides a national approach to improving water quality in Australia's waterways. Development has progressed since 1992, with the Australian Government working in cooperation with state and territory governments to produce the Strategy. The Strategy incorporates a number of key guidelines concerning management and monitoring of water including the following:

- Australian Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000); and
- Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC/ARMCANZ, 2000).

Direction for the application of the guidelines is provided in the following document:

- Using the ANZECC Guideline and Water Quality Objectives in NSW (DEC, 2006).

These guidelines provide an agreed framework to assess water quality in terms of whether the water is suitable for a range of environmental values (including human uses).

2.2.2 State Water Management Outcomes Plan (WMA)

The WMA includes the State Water Management Outcomes Plan, a statutory document which sets the overarching policy, targets and strategic outcomes of the WMA. This document expired in 2007; however, the content of the document remains an important reference with regard to water management objectives for proposed developments.

2.2.3 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy was released in September 2012. It sets out the requirements for assessing the impacts of aquifer interference activities on water resources. It explains the role and requirements of the Minister in the water licensing and assessment processes for aquifer interference activities under the WMA and other relevant legislative frameworks.

There are three key parts to the Policy:

1. *All water taken must be properly accounted (and licensed) for.*
2. *The activity must address minimal impact considerations for impacts on water table, water pressure and water quality.*
3. *Planning for measures in the event that the actual impacts are greater than predicted, including making sure that there is sufficient monitoring in place (www.water.nsw.gov.au)*

2.2.4 NSW Groundwater Dependent Ecosystems Policy

The NSW Groundwater Dependent Ecosystem Policy was created in 2002. This policy explains the various types of groundwater dependent ecosystems (GDEs) found in NSW and promotes the management of these systems during planning processes. Five principles provide guidance on how to protect and manage these natural systems using a range of documented tools.

2.3 Environment Protection Licence

MCC holds an EPL (656) for coal works and mining for coal. No concentration or volumetric limits apply for EPL 656 in relation to discharge to surface waters. In the absence of any specific discharge criteria or limits, the overarching criteria of the POEO Act apply (as stated in EPL 656):

Except as may be expressly provided in any other condition of this licence, the licensee must comply with section 120 of the Protection of the Environment Operations Act 1997

3 EXISTING SOIL AND WATER ENVIRONMENT

3.1 Regional Hydrology

MCM is located in the Upper Hunter Valley region in the catchment of the Hunter River, which is located approximately 3km to the west of MCM. At its nearest point the river has an average flow rate of 200 ML/day. The Hunter River catchment is shown in **Figure 3** and covers an area of approximately 21,367km^2.

There are two important catchments within the vicinity of MCM including Sandy Creek and Muscle Creek which are both ephemeral tributaries of the Hunter River. Both watercourses flow in a westerly direction and join the Hunter River in the immediate vicinity of Muswellbrook township. No flow gauging data is available for these watercourses. Local watercourses of significance are shown in **Figure 4.**

3.2 Regional Climate

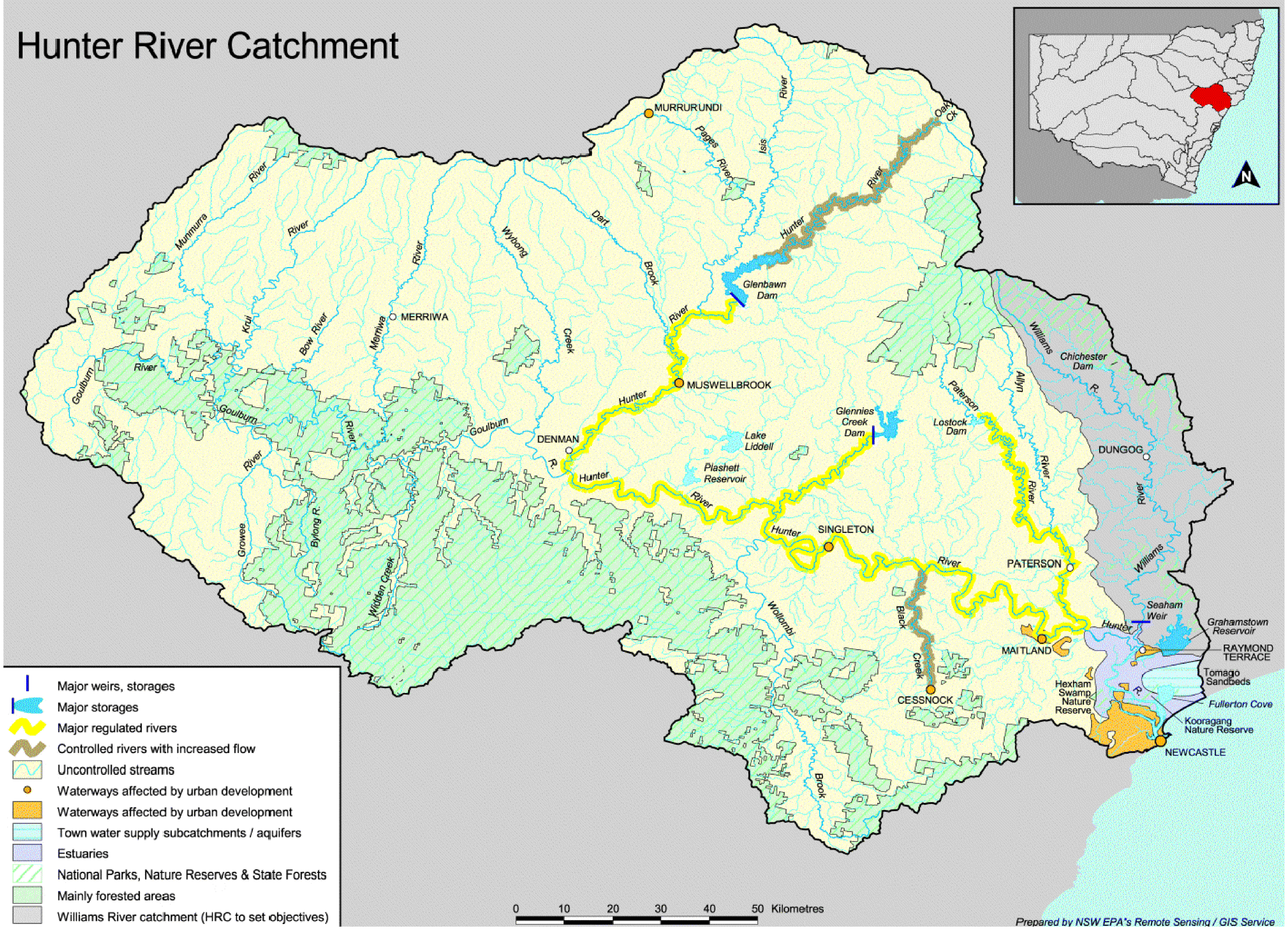
The regional climate is characterised by hot summers and mild winters, typical of temperate conditions. Rainfall is heaviest during the summer months with the majority of rainfall occurring as high intensity storms or cold fronts moving through from the southwest. The area is characterised by low average rates of runoff and infiltration, and high rates of evaporation. Long term average rainfall is reported at 620mm at the nearest Australian Bureau of Meteorology (BOM) monitoring station located at Lower Hill Street in Muswellbrook (Site No. 061053).

Long term temperature and rainfall data are summarised in **Table 2** as sourced from the combined Site Water Management Plan and Surface and Groundwater Monitoring Plan (MCC, 2015a), herein referred to as the Water Management Plan. Evaporation data was not available at this station. The nearest available evaporation data was sourced from the Soil Conservation Service Laboratory, located 27km away at Scone (MCC, 2015a).

Table 2 Climate Statistics

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Max (^{0}C)	28.5	28.6	27.6	24.9	19.8	17.8	17.4	19.1	20	25.3	25.9	29.1	**23.6**
Mean Min (^{0}C)	16.1	16.7	14.1	9.7	6.5	4.5	1.8	4.2	5.8	9.9	12.2	14.9	**9.6**
Mean Rainfall (mm)	69.3	66.5	52.6	3.4	41.1	50.9	44.1	39.2	40.9	48.7	55.0	67.3	**619.6**
Mean Daily Evap (mm)	7.1	6.2	4.9	3.5	2.2	1.6	1.8	2.7	3.9	5.1	6.1	7.1	**1606**

Source: MCC Site Water Management Plan, 2015.



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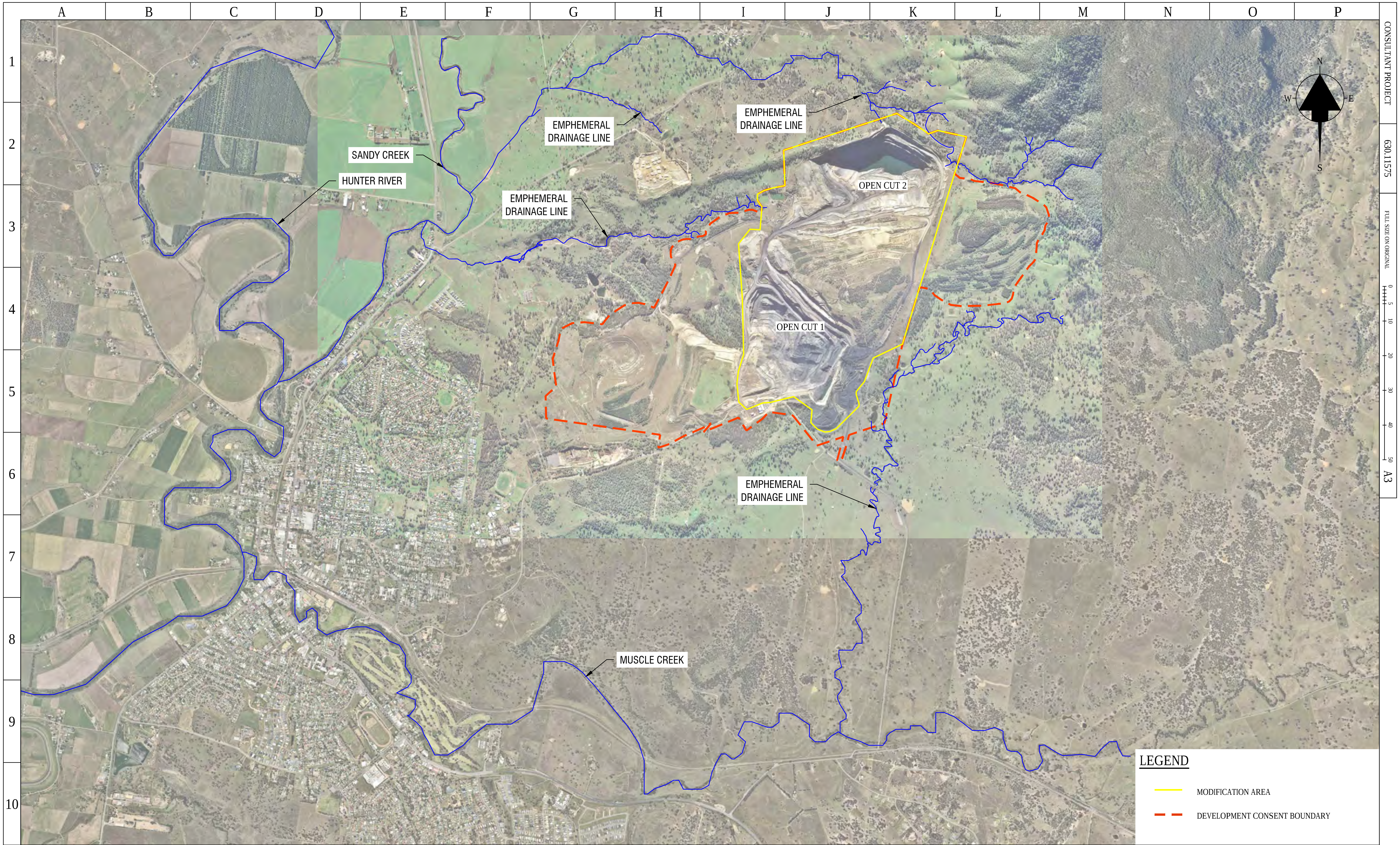

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3.3 Local Landform and Topography

The topography within the vicinity of MCM is dominated by the elevated terrain to the east including Bells Mountain with a maximum elevation of 690m AHD, and the Skellatar Ridge to the south (maximum elevation of 333m AHD) (MCC, 2015a).

Natural ground elevations at the mine range between 230 and 260m AHD, while the rehabilitated overburden emplacement areas extend up to 340m AHD. There is an overall fall in topography in a westerly direction toward the Hunter River, where the elevation on the flood plain adjacent to the river lies at around 150m AHD.

3.4 Local Hydrology

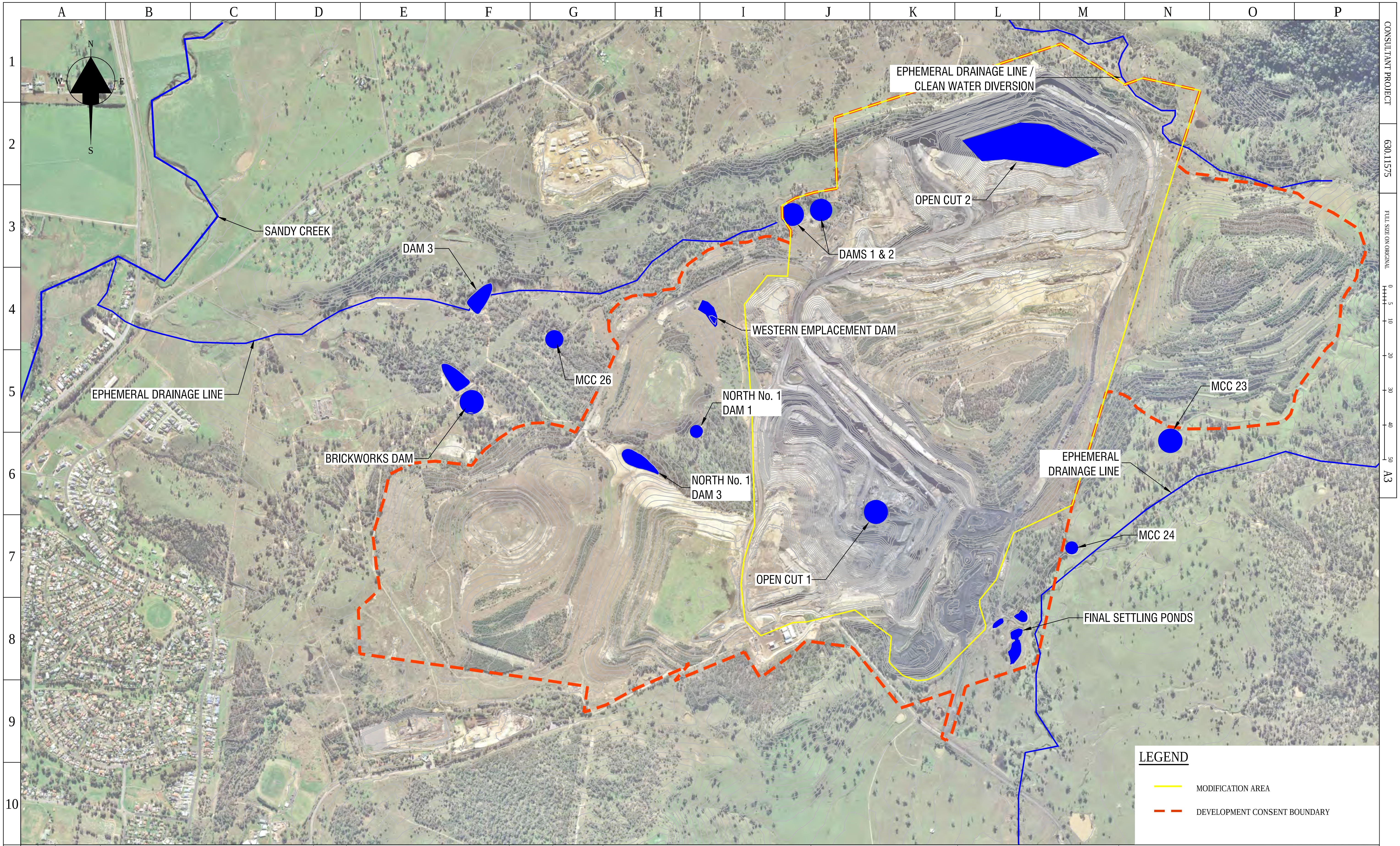
The Skellatar Ridge, situated immediately to the south of MCM forms the southwest to northeast trending boundary between the catchments of Sandy Creek and Muscle Creek. Runoff from the northern side of Skellatar Ridge flows in a northwest direction to Sandy Creek which flows westerly to the Hunter River. Incident rainfall on the south side of Skellatar Ridge flows to Muscle Creek in the south and subsequently to the Hunter River in Muswellbrook.

MCM is broadly characterised by two distinctly separate catchment types as follows:

- Rehabilitated areas – Historic overburden emplacement or disturbance areas which have undergone rehabilitation; and
- Operational areas – Areas currently utilised for operational activity or undergoing rehabilitation which. Runoff associated with these catchment types includes both mine water and dirty water depending upon the use of the area (refer to Section 4.1 of the SWA).
- Major surface water dams around MCM are shown in **Figure 5**.

3.4.1 Rehabilitation Areas

The rehabilitated land is generally characterised by a good surface cover (i.e. grasses and shrubs which minimises the potential for soil creep and assists in sediment capture across the rehabilitation areas.



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3.4.2 Operational Areas

The operational areas are generally highly disturbed comprising of haul roads, product stockpiles, overburden emplacement and general disturbance areas. Dirty water and mine water are broadly treated as a single water resource with this runoff draining directly into the open cut pits or the various dams around the Site.

The operational areas of MCM are delineated into the major catchment areas as detailed in **Table 3** and as show on **Figure 6**.

Table 3 Catchment Areas at the Mine

Catchment	Total Catchment Area (Ha)
Dam 1 & Dam 2 combined catchment;	101
Final Settling Ponds catchment;	49.5
Open Cut 1 catchment;	98.8
Open Cut 2 catchment;	91.3

Surface runoff from the operational areas collects in the base of Open Cut 1, Open Cut 2, Dams 1 and 2 or the Final Settling Ponds and is pumped around MCM to be used for operational activity.

There are a number of additional catchment areas associated with MCM however; these comprise of rehabilitation areas which drain to respective sediment dams and are not considered to have an impact on the modification. These dams are covered by the existing Erosion and Sediment Control Plan (ESCP) and Water Management Plan.

3.5 Hydrogeological Setting

3.5.1 Geology

The geological setting of the mine site is summarised in **Table 4** and shown on **Figure 7.**

Table 4 Summary of Geological Stratigraphy

Age	Group	Strata	Description
Recent		Alluvial Deposits	Clays, silts, sands and gravels
Middle Permian	Maitland	Branxton Formation	Sandstone, conglomerate, and siltstone
Early to Middle Permian	Greta Coal Measures		Sandstones, siltstones, mudstones and coal seams (Fleming – 2m thick, Hallet – 1m thick, Muswellbrook – 5m thick, St Heliers – 9.5m thick, Upper Lewis – 2m thick, Lower Lewis – 7m thick and Loder – 1.5m thick) occurring over a stratigraphic interval of approximately 60m at the base of the Greta Coal Measures). Include numerous igneous dykes and sills.
Early Permian	Dalwood	Gyarran Volcanics	Basic lavas, breccias, rhyolite, and ignimbrite

Further details on the stratigraphy and geological structure are included in **Appendix A.**

The closest alluvial deposits (approximately 2 km from site) are typically patchy, thin and localised to the lower reaches of Muscle and Sandy Creeks. More developed and thicker deposits are located further away in the Hunter River floodplain (>2 km from site). They are absent at the mine site.

In the immediate vicinity of the mine site the Greta Coal Measures are approximately 110m thick, and dip to the north-west at angles ranging between 4 and 11^{o}. Available information indicates a complex nature of geological structure, as follows:

- a regional north-south trending thrust fault (the Aberdeen Thrust Fault / St Helier Fault) extends below the eastern part of the site, extending through the No. 2 Open Cut void. It dips to the east and has a displacement of c. 400m vertical and c.30km horizontal;
- the axis of a north-south trending anticlinal structure (the Muswellbrook Anticline) also extends to the south-east of the mine site, exposing the older Gyarran Volcanics at the centre of the anticline;
- the Muswellbrook Anticline is truncated to the east by the Aberdeen Thrust Fault / St Helier Fault in the immediate vicinity of the Open Cut 2 void;
- a series of north-west to south-east trending normal faults cross the mine site (to the east of the Open Cut 1), and are reported to have throws of between 2m and 20m; and
- two bedding plane shear zones (glide planes) have been previously identified in the highwall of No.1 Open Cut, resulting from overthrusting to the east. The thrust planes are located within Greta Coal Measures (base of the Fleming Seam and c.1m below the top of the St Heliers Seam), with the overlying strata being displaced up to 100m in a westerly direction and rotated by c.10^{o} to 15^{o} in an anticlockwise direction.

Mine spoil generated from the coal mining activities at MCM and previous mining is present at the site. It is characterised by an anisotropic, heterogeneous mix of grain and boulder sized materials.

LEGEND

- DAMS 1 AND 2 CATCHMENT BOUNDARY
- FINAL SETTLING PONDS CATCHMENT BOUNDARY
- VOID 1 CATCHMENT BOUNDARY
- VOID 2 CATCHMENT BOUNDARY
- DEVELOPMENT CONSENT BOUNDARY

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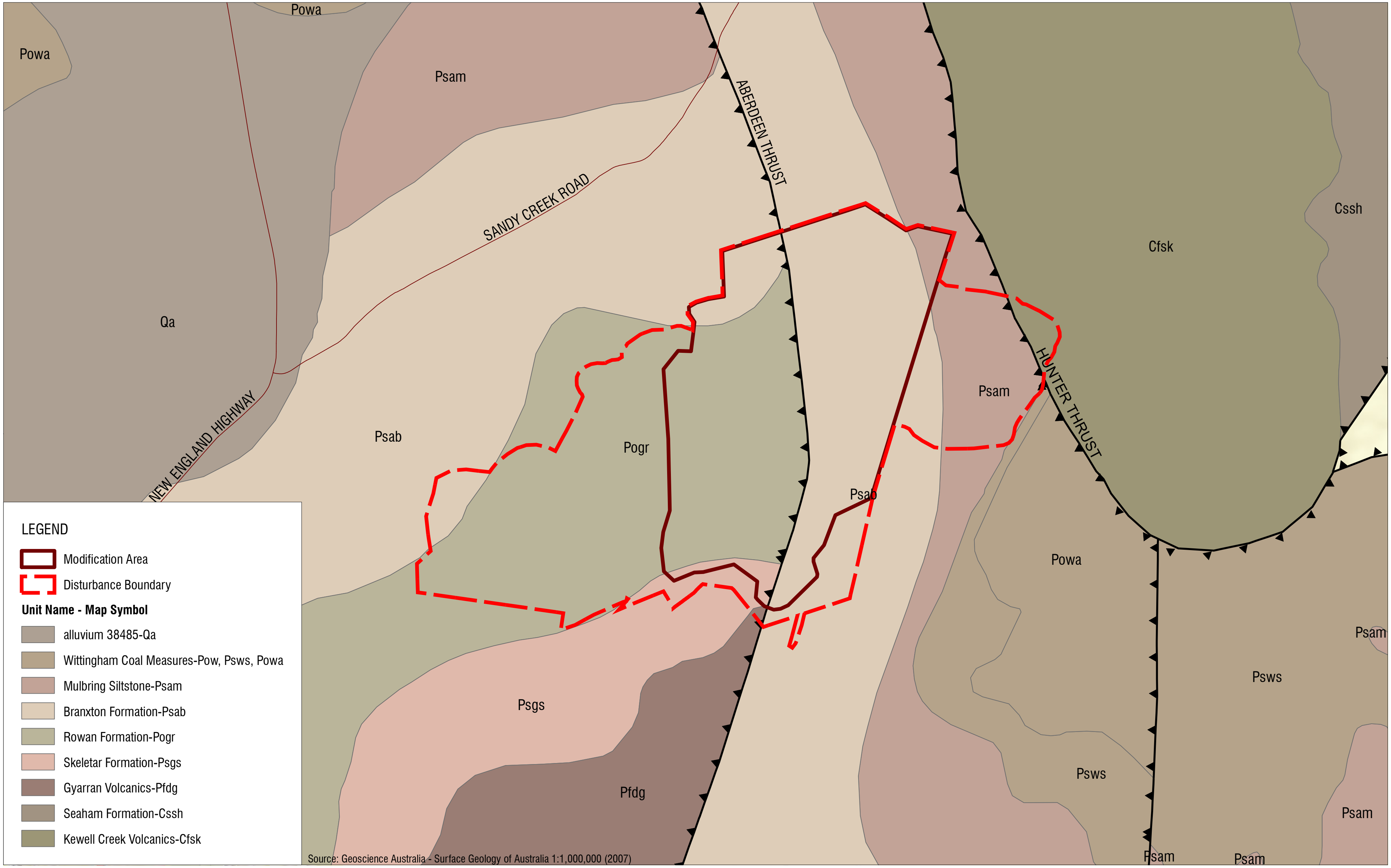
H:\Projects-SLR\630-SrvNTL\630-NTL\630.11575 MCC Continuation SW & GW Assessment\06 SLR Data\01 Drawings\630.11575 - LF - FIGURE 6.dwg



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Geology Map

FIGURE 7

3.5.2 Hydrogeology

3.5.2.1 Groundwater systems and characteristics

Two main groundwater systems are present at site and within the immediate vicinity of the mine site. **Table 5** outlines a summary of aquifer characteristics.

Table 5 Summary of Characteristics

Aquifer	Characteristics
Shallow bedrock (regolith)	• surficial sandy and silty-clayey soils and weathered bedrock • variable permeability and porosity (primary and secondary) • variable depth and thickness • temporary perched groundwater during sustained wet periods • provides a source of recharge to the underlying coal measures, although limited given the very low hydraulic conductivities of deeper strata
Permian Bedrock (Greta Coal Measures)	• negligible intergranular (primary) porosity and permeability • low to moderately permeable coal seams are the prime water bearing strata with typical permeability of c.2m/day at shallow depths to less than 0.01m/day at a depth of 130m • groundwater is associated with fracture (secondary) permeability and porosity from discontinuities (fractures, faults, joints and bedding planes) • intervening unproductive coal measures are "tight" with permeability c.2 orders of magnitude lower than that of the coal seams (i.e. 0.01m/day at shallow depths to 0.0001m/day at 100m depth) • specific storage coefficient (storativity) is estimated to be in the order of c.3 x 10-6

Groundwater will be present within any remaining (historic) flooded underground workings (bord and piller) of the No. 2 Underground and St Heliers Colliery following completion of Open Cut 1.

Water inflows have been noted at the contact between the Gyarran Volcanics and Greta Coal Measures, suggesting that this contact may form a groundwater pathway below the mine.

Permeability values assumed for the Coal Measures strata in the previous MODFLOW modelling work (Coffey, 2005), reported permeability values as follows:

- Undisturbed hardrock: varys with depth from 0.1m/day at 10m below ground to 0.001m/day at 150m below ground (local vertical averaging of coal, seams and interburden) - this correlates to the Permian Bedrock description in **Table 5**.
- Spoil: 1m/day uniform - this correlates to the shallow bedrock (regolith) description in **Table 5**.

Based upon the previously reported results of hydraulic testing at site (AGE, 2010), modelling results (Coffey, 2005), and the depth of coal for the modification area, the permeability value adopted for the Coal Measures to assess the impact of the open cut mining in the modification area was 0.001m/day.

Available information suggests that storativity of the Open Cut mine spoil generated at the site is likely to be c.15%.

3.5.2.2 Groundwater Levels and Flow

Review of the pre-mining baseline groundwater contours, as predicted within the HLA 2002 report (**Appendix B**), indicates that groundwater flows originally took place across the mine site and surrounding areas towards Sandy Creek (to the west and north-west) and Muscle Creek (to the south). Predicted groundwater elevations ranged between c.220m AHD to the immediate east of the mine site, and c.150m AHD to the west of the mine site, adjacent to the Sandy and Muscle Creeks at the eastern fringes of Muswellbrook.

With regard to current conditions (i.e. end of 2015), these have been assessed based on groundwater monitoring data which is routinely collected from an extensive network of locations within and surrounding the MCC mine site. The network comprises bores installed within the:

- Permian Bedrock at or in the immediate vicinity of the mine site; and
- Private bores within the alluvium on Sandy Creek and bedrock aquifers to the north-west and west of the mine.

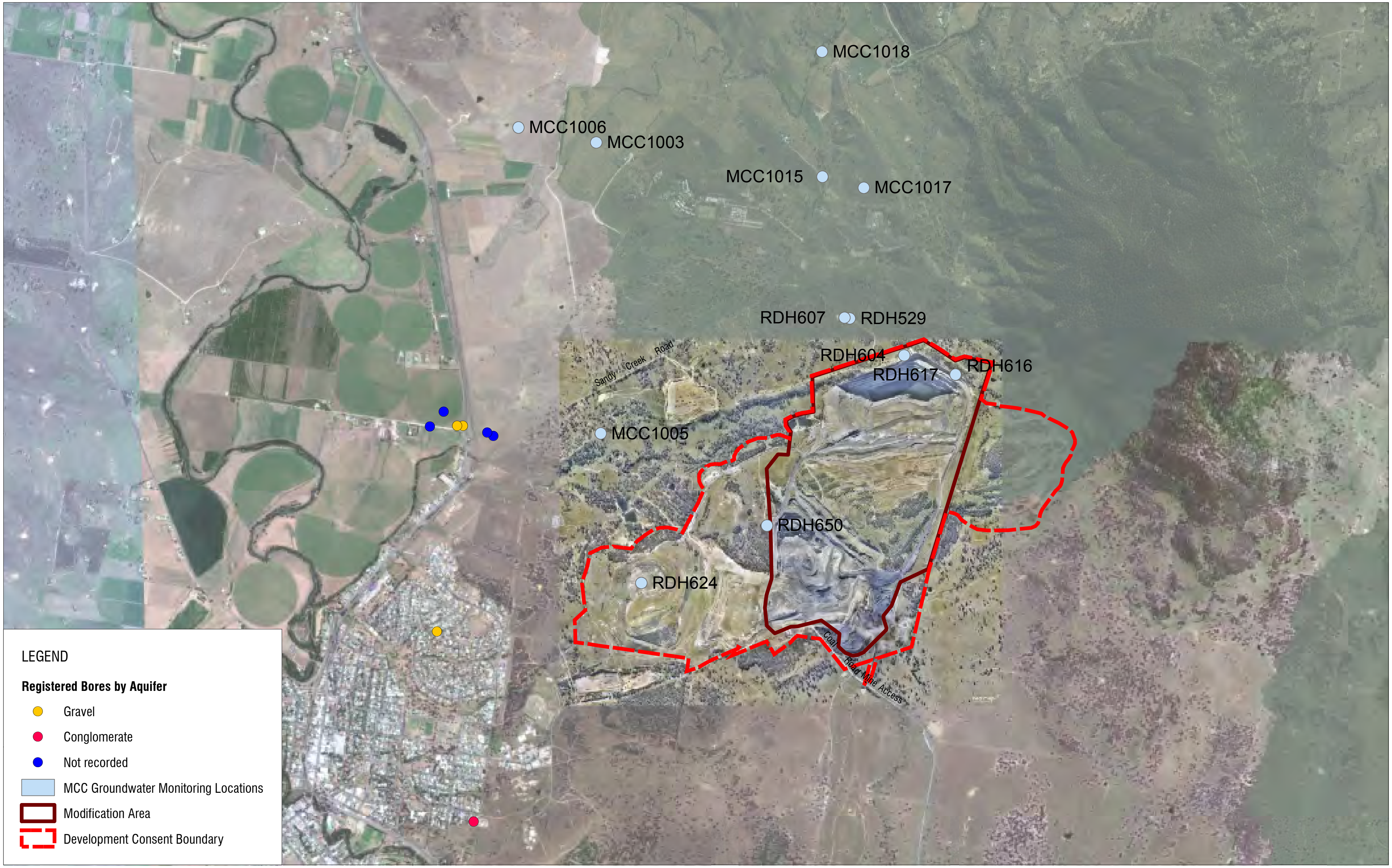
Sump water levels within the voids of Open Cut 1 and Open Cut 2 have also been included within this assessment, as they reflect groundwater elevations within the Permian bedrock aquifer.

Details for current monitoring bores are identified within **Table 6**, and their locations are shown on **Figure 8**.

Table 6 Groundwater Monitoring Locations

Site Ref.	Description	Details
Alluvial Aquifer – Sandy Creek		
MCC 1003	Groundwater Bore / Well	No information on depth or construction.
MCC 1005		
MCC 1006		
MCC 1015		
Permian Bedrock Aquifer - Greta Coal Measures		
RDH529	Groundwater Bore / Well	St Heliers Seam, 202 Panel No. 2 Underground Mine. Small BH Pump.
RDH522		St Heliers Seam in No. 2 Underground Mine. Located c.400m north of No. 2 Open Cut void.
DDH604		Cut 17 Highwall, immediately north of No.2 Open Cut void.
RDH607		St Heliers Seam in No. 2 Underground Mine. Large BH Pump.
RDH650		Lower Lewis Seam in No.2 Underground Mine, near Open Cut 1 void.
RDH615	Piezometer	Ground level down to Loder Seam. Monitoring ceased during 2011-12 reporting period due to mining operations moving through the area of the bore.
Permian Bedrock Aquifer - Greta Coal Measures / Branxton Formation?		
RDH624	Groundwater Bore / Well	No information on depth or construction. Located within Open Cut 1 void.
RDH616		No information on depth or construction. Located to the immediate north-east of Open Cut 2 void.
RDH617		
MCC 1017		No information on depth or construction. Located c.1.6km to north-west of Open Cut 2 void.
MCC 1018		

Groundwater hydrographs for RDH650, RDH529, RDH616, RDH617, RDH624 and RDH522, together with MCC – Sandy Creek series bores identified in **Table 6**, are included in **Figure 9** and **Figure 10**.



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Groundwater Monitoring Map

FIGURE 8

Figure 9 Groundwater Hydrographs for RDH Series Monitoring Locations

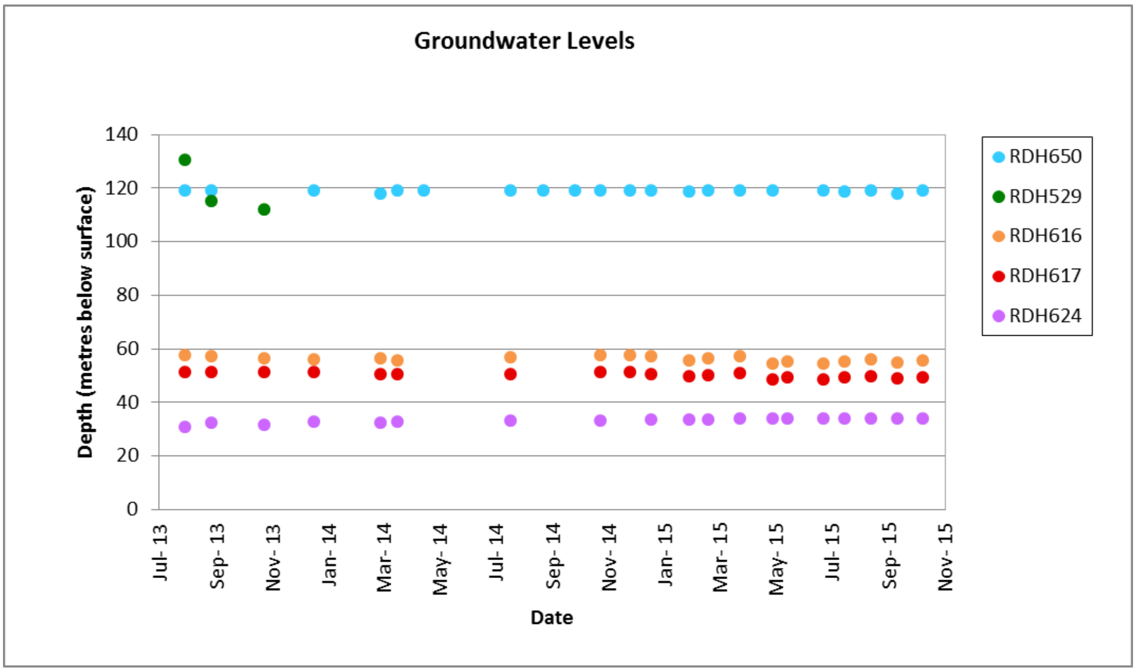
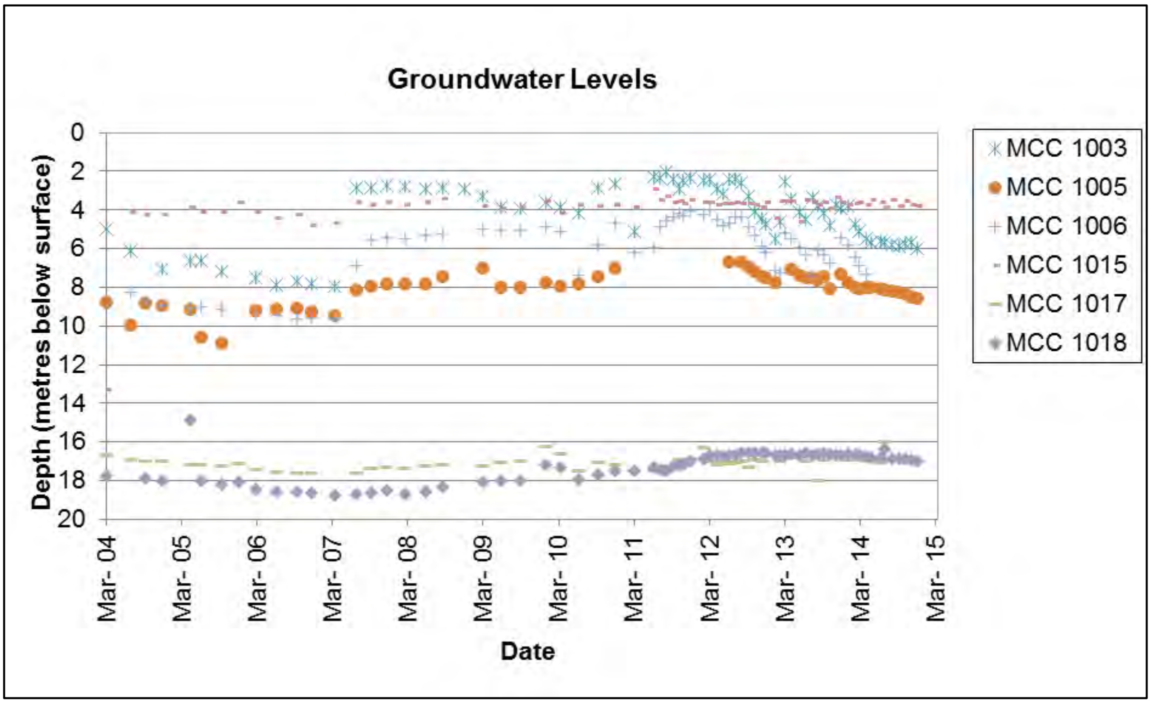


Figure 10 Groundwater Hydrographs for MCC – Sandy Creek Series Monitoring Locations



Review of these hydrographs, and comparison with the predicted pre-mining groundwater contours (**Appendix B**), indicates the following with regard to the Permian Bedrock Aquifer:

- Groundwater elevations within the hydraulically connected underground workings of the St Heliers Colliery and No.2 Underground mines (as represented by the groundwater elevations within RDH522, RDH529 and RDH650) indicate that water levels have fluctuated significantly, reflecting the depth (elevation) of active dewatering that has been required for mining to continue – that is in addition to the mines' water management strategy that uses these flooded mine workings for water storage. Hence, water is pumped into and out of the workings as required by mine operations.
- The lower groundwater elevations in these mine workings, as recorded within RDH522, may correspond to the period when the Open Cut 1 void extended down to an elevation of c. 43mAHD in 2010. The base of the Open Cut 1 void has also declined to similar low elevations, with a pit floor elevation of 13.4mAHD reported[1] for 2008 – 2009. However, groundwater fluctuations may also correspond to water abstraction via RDH529 (borehole pump No. 1) and nearby RDH607 (borehole pump No. 2).
- Currently groundwater elevations within the St Heliers Colliery and No.2 Underground mine workings are c.116mAHD, as recorded within RDH650 at the end of 2014, while the water elevation on the floor of the void of Open Cut 1 Extension is c.80mAHD. It is noted that the underground mine workings are directly connected to the Open Cut 1 Extension void, given that the extension is currently mining out these old underground workings.
- At the end of 2015, maximum groundwater level declines from pre-mining conditions were c.100m within Open Cut 1 Extension void, and c.120m within the No. 2 Open Cut void. A decline of c.100m is evident within the No.2 Underground and St Heliers Colliery mine workings at RDH650.
- Groundwater elevations within the Permian strata outside the old mine workings are significantly higher, as indicated by monitoring data for RDH616 and RDH617. Despite these two monitoring locations being located immediately adjacent to the No.2 Open Cut void, the groundwater elevations at these two locations are estimated at c.186 to c.193mAHD, which is:
  - c.110m higher than the water elevation within this void (c.80mAHD); and
  - c.75m higher than the groundwater elevations within the Heliers Colliery and No.2 Underground mine workings (c.116mAHD).
- The significant difference in groundwater elevations (noted in the last bullet point) is considered to reflect the low permeability of the undisturbed in situ bedrock around the mine site as well the monitoring points being located on the opposite side of a fault.
- The estimated drawdowns within RDH616 and RDH617 from pre-mining conditions is estimated to range between c.12 and c.18m at the end of 2015.
- Comparison of groundwater elevations for MCC1017 and MC1018, located c.1.5km and c.1.75km to the north of the Open Cut 2 void, with the pre-mining baseline groundwater contours suggests that there has been no significant impact on groundwater levels within these bores as a result of mining. It is also noted that the closest private bore, MC1018, is located c.1.1km to the north of northern extent of the No.2 Underground and St Heliers Colliery mine workings. This therefore supports the conclusions presented in previous assessments that the radius of influence on the potentiometric surface of the coal seam aquifers is no more than c.1km around the mine.

Based on the conditions described above, groundwater flow is taking place radially towards the current voids within Open Cut 1 and Open Cut 2. The flow pathways include drainage via the flooded underground mine workings associated with the No.2 Underground and St Heliers Colliery mine workings, diffuse flow via mine spoil that has been used to infill and rehabilitate/restore the voids, and fracture dominated flow within the in situ Permian bedrock surrounding the mine site.

3.5.2.3 MCC Groundwater Extraction

MCC holds four licences to extract groundwater, under Part 5 of the Water Act 1912. A summary of volumes extracted for the previous 5 years is provided in **Table 7**.

Table 7 Summary of MCC Groundwater Extraction

License No.	Extraction Entitlement (ML/Annum)	2010-2011 (ML)	2011-2012 (ML)	2012-2013 (ML)	2013-2014 (ML)	2014-2015 (ML)
20BL169014 (Borehole RDH529)	1000	300	498	448	31	4.5
20BL169037 (No.1 O/C Void)	2,000 (combined)	168	0	134	563	0
20BL169038 (No.2 O/C Void)		930	975	97	702	591.3
20BL170473 (Borehole RDH607)	3,000	780	837	923	987	2,036.5

Sources: Data gathered from MCC Annual Environmental Reports for corresponding years.

3.5.2.4 Groundwater Quality

Groundwater quality monitoring of the underground workings has been undertaken by MCC since 2012. The data indicates a poor quality, brackish to saline water with an Electrical Conductivity (EC) in the range 5,000 - 6200µS/cm. The pH of the coal seam groundwater is neutral to slightly alkaline, pH 7.1 – 7.6. A summary of water quality is provided in **Table 8**.

Table 8 Summary of Water Quality – Underground Workings

Year	Average pH	Average EC (µS/cm)
2012-2013	7.6	5,711
2013-2014	7.1	5,078
2014	7.3	5,525
2015	7.3	6,196

Source: 2015 Annual Environmental Report (MCC, 2015)

Additional groundwater monitoring has been undertaken in the Sandy Creek Area since 2010-2011. A summary of water quality is provided in **Table 9** and **Table 10**. The alluvial and hard rock aquifers in the Sandy Creek area are a significant lateral distance from the open cut footprint and no impacts and\or negative trends in water quality have been identified (MCC 2015).

Table 9 Summary of Water Quality - pH

Location	pH Annual Average					
	2010-2011	2011-2012	2012-2013	2013-2014	2014	2015
MCC1001	7.4	7.2	7.1	7.2	7.3	7.0
MCC1003	7.4	7.3	7.2	7.3	7.2	7.2
MCC1004	6.6	6.8	6.7	6.7	6.9	6.6
MCC1005	7.4	7.4	7.1	7.2	7.2	7.1
MCC1006	7.3	7.3	7.1	7.2	No result	No result
MCC1008A	7.5	7.3	7.4	7.4	7.5	7.3
MCC1009	7.7	7.6	7.7	7.7	7.9	7.6
MCC1010	7.6	7.6	7.6	7.6	7.9	7.7
MCC1012	7.4	7.6	7.4	7.5	7.5	7.3
MCC1015	7.3	7.1	7.1	7.1	7.1	7.2

Source: 2015 Annual Environmental Report (MCC, 2015)

Table 10 Summary of Water Quality - EC

Location	Electrical Conductivity Annual Average (µS/cm)					
	2010-2011	2011-2012	2012-2013	2013-2014	2014	2015
MCC1001	1,108	777	1,086	1,122	1,123	1,114
MCC1003	1,434	1,410	1,359	1,480	1,701	1,345
MCC1004	2,668	2,670	2,200	2,208	2,105	2,731
MCC1005	2,635	1,579	1,947	2,544	2,697	2,768
MCC1006	1,095	933	1,087	1,117	No result	No result
MCC1008A	934	1,059	1,174	1,012	1,323	1,076
MCC1009	1,233	1,126	1,332	1,409	1,472	1,264
MCC1010	6,298	5,725	5,805	5,980	6,520	5,860
MCC1012	1,574	1,272	1,355	1,495	1,908	1,990
MCC1015	2,417	2,531	2,169	2,452	2,402	2,659

Source: 2015 Annual Environmental Report (MCC, 2015)

3.6 Registered Groundwater Bores

For this assessment, a review of the NSW Office of Water website (http://allwaterdata.water.nsw.gov.au/water.stm) was conducted to assess if additional bores have been installed since the previous groundwater assessment by AGE (2010). No new bores have been installed since the 2010 assessment within a 2.5km radius of the site (**Figure 8**). Therefore the summary by AGE (2010) is still relevant and is summarised below:

- most of the registered bores are concentrated in the alluvial area at the confluence of Sandy Creek and the Hunter River alluvial plain;
- The majority of the registered bores are at least 2km from the mine; and
- The registered bores are primarily licensed for irrigation or industrial use with one or two for stock or domestic use.

Table 11 Registered Bores within 2.5km Radius of Modification (AGE, 2010)

Registered No.	Licence No.	Location (Easting)	Location (Northing)	Depth	Yield (L/s)	Salinity	Aquifer	Purpose
GW004900		6427819	302497	57.9	nr	nr	conglomerate	
GW027411	20BL019528	6431181	302667	nr	nr	nr	nr	Irrigation
GW027410	20BL145581	6431211	302614	12.20	nr	Good	nr	Irrigation
GW011360	20BL004515	6431268	302403	7.9	10.10	Good	Gravel	Industrial
GW011361	20BL004516	6431267	302351	7.9	10.10	Good	Gravel	Industrial
GW011667	20BL005300	6429477	302176	8.5	nr	nr	Gravel	Domestic
GW080181	20BL150465	6431392	302236	nr	nr	nr	nr	Irrigation
GW024727		6431263	302115	nr	nr	nr	nr	Stock

Note: nr = not recorded

3.7 Groundwater Dependant Ecosystems

SLR conducted a desktop review of the local area to explore the potential presence of any GDEs, and to assess the likelihood of any adverse impacts to such ecosystems by the modification.

GDEs are defined as "ecosystems which have their species composition and their ecological processes determined by groundwater" in the *NSW State Groundwater Dependent Ecosystem Policy* (Department of Land and Water Conservation, 2002). The Policy defines the following types of GDEs in NSW:

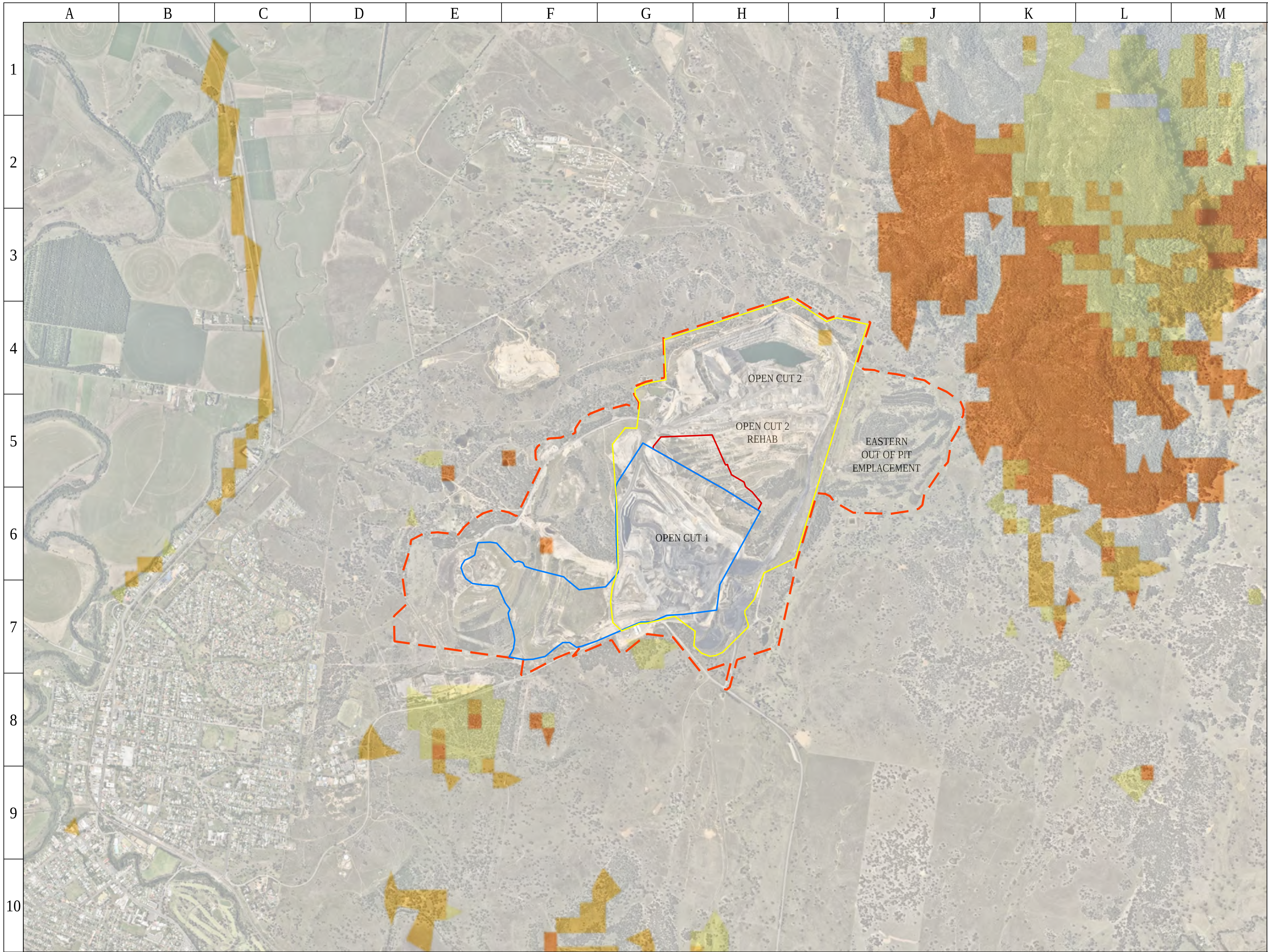
- Terrestrial Vegetation;
- Base flows in streams;
- Aquifer and cave ecosystems; and
- Wetlands (Inflow Dependant Ecosystems [IDEs]).

Of the above listed types of GDEs, it is expected that only Wetland or Terrestrial vegetation GDE types may occur in proximity to the MCM. A search of the BoM – *Atlas of Groundwater Dependant Ecosystems* (conducted on 6th March 2016) reveals there are no *known* GDEs occurring on or in close proximity to MCM which have been identified in any previous field or desktop studies. There are however, a number of areas surrounding MCM which show medium to high potential for containing the following ecosystem types:

- GDE - Vegetation reliant on subsurface groundwater; and
- IDE - rivers, springs and wetlands reliant on water in addition to rainfall.

The areas showing potential to contain GDEs are show in **Figure 11**. The areas showing potential to contain IDEs generally coincide with those areas showing potential for GDEs and for clarity are presented separately in **Figure 12**.

No potential GDEs or IDEs have been identified within or close to, the proposed modification area and as such, the modification is not anticipated to have any impact on IDEs or GDEs.



LEGEND

- MODIFICATION AREA
- DEVELOPMENT CONSENT BOUNDARY
- APPROVED EXTRACTION BOUNDARY
- ADDITIONAL EXTRACTION BOUNDARY

GDE, RELIANT ON SUBSURFACE GROUNDWATER (VEGETATION)

- HIGH POTENTIAL FOR GROUNDWATER INTERACTION
- MODERATE POTENTIAL FOR GROUNDWATER INTERACTION
- LOW POTENTIAL FOR GROUNDWATER INTERACTION

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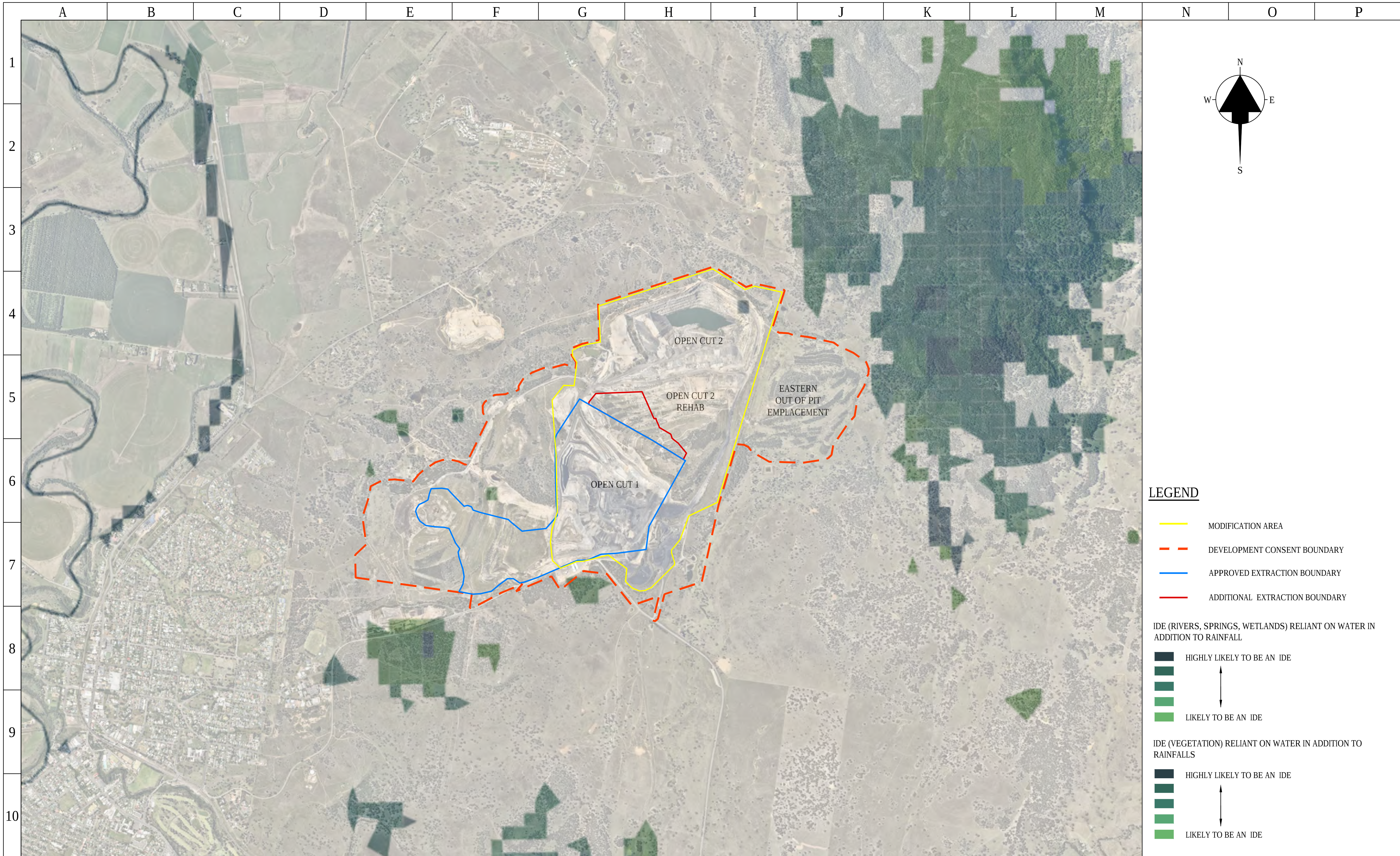
H:\Projects-SLR\630-SrvNTL\630-NTL\630.11575 MCC Continuation SW & GW Assessment\06 SLR Data\01 Drawings\OLD FILES\630.11575 - FIGURE 11.dwg



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4 REVIEW OF THE MOST RECENT GROUNDWATER MODELLING COMPLETED FOR MCM

4.1 HLA 2002

AGE 2010 provides the following summary of HLA 2002 modelling:

> *HLA (2002) developed a sophisticated 3D, numerical, groundwater flow model using the MODFLOW software to assess the impact of the then proposed No. 1 Open Cut Extension. The model consisted of 10 layers with layers 4 to 8 consisting of the coal seams to be mined and the interburden to the next mined seam.*
>
> *The model domain covered an 8km x 8km area with Sandy Creek, Muscle Creek and the Hunter River forming the northern, southern and western boundaries respectively and the groundwater divide beneath Bell Mountain, the eastern boundary. The model was calibrated to steady state conditions of the measured groundwater level in six open resource holes. Calibrated recharge was 3.1% of the mean annual rainfall at Muswellbrook High School.*
>
> *Predictive modelling consisted of transient simulation of the No. 1 Open Cut Extension mining activities from 2003 to 2011. The simulation indicated that inflow to the proposed No. 1 Open Cut extension increased from about 0.056ML/day (20.5ML/year) in 2003, to a maximum of around 0.22ML/day (80.3ML/year) in 2009-10. In addition the predictive simulations indicated a relatively stable inflow to the combined No. 2 Open Cut and No. 2 Underground Mines of 0.1ML/day (36.5ML/year) and about 0.14ML/day (51.0ML/year) to the No. 1 Open Cut Mine.*
>
> *HLA (2002) did not report the predicted radius of influence of mine dewatering on the potentiometric surface. They stated that changes in groundwater levels in the coal measures are largely dictated by the water storage strategy for the No. 2 Underground and that the proposed extension itself will have negligible impact on water levels and aquifers, except to lower the water levels to the base of the Loder Seam instead of the Lewis Seam (a drop in elevation of around 10m).*
>
> *HLA (2002) concluded that "the proposed extension mines through strata and groundwater regimes already disturbed by mining. Mining will lower the water levels in the Greta Coal Measures to the base of the Loder Seam over a small area. In the wider area, water levels will fall to the Lewis Seam when the Sandy Creek underground mine commences. The Loder Seam contains brackish water and is not considered a groundwater resource".*
>
> *The report reasoned that "the proposed mining should improve the groundwater regime in the area because a large portion of mined workings will have been removed and replaced with spoil, creating a better environment for groundwater recovery and improved groundwater quality".*
>
> *HLA also concluded that "the proposed extension itself will have negligible impact on water levels and aquifers, except to lower the water levels to the base of the Loder Seam instead of the Lewis Seam (a drop in elevation of around 10m)". They state that "no mitigation measures are required for effects on groundwater from the proposed extension".*

4.2 Coffey Geosciences Pty Ltd (2005)

This study was completed in order to assess the fully recovered water levels and rate of water level rise following cessation of all mining and rehabilitation activities at the MCM.

The MODFLOW model used for this study was based on an existing MODFLOW model which had been previously completed by Parsons Brinkerhoff (2004) to assess long-term fully-recovered water levels in the existing Open Cut 1 and 2 voids. According to the Coffey 2005 report (the Parsons Brinkerhoff report was not available for review); the Parsons Brinkerhoff model gave the following results:

- a fully recovered (steady-state) water level in the No.1 Open Cut void of approximately 181mAHD, with a final pond surface area of approximately 21ha (0.21km^2); and
- a fully recovered (steady-state) water level in the No.2 Open Cut void of approximately 158mAHD, with a final pond surface area of approximately 43ha (0.43km^2).

The Coffey model adopted all the modelling assumptions and parameters for the Parsons Brinkerhoff model, with the following exceptions:

- a revised position of the Open Cut 1 final void approximately 1km further east; and
- the long-term runoff coefficient of 20% for rehabilitated land was revised to 12% of Decile 5 (median) annual rainfall.

The Coffey model also assumed the following:

- The following areas would undergo filling following mine closure, as follows:
  - the Open Cut 1 final void: Filling would occur from a pond water level (assumed base of void) elevation of approximately 120mAHD;
  - the Open Cut 2 final void: Filling would commence prior to completion of mining of Open Cut 1, from a pond water level (assumed base of void) elevation of approximately 50mAHD; and
  - the Main Underground (St Heliers and No. 2 Underground combined): Filling would occur from some water level not greater than 130mAHD, the approximate lowest point of old workings intersected by open cut operations.
- The No.1 and No.2 Open Cut voids would receive surface water runoff, while the flooding voids would experience direct rainfall inputs and evaporation losses, in addition to groundwater inflows.
- The Main Underground would receive lateral groundwater inflow and vertical infiltration from rainfall.
- Any water stored in the spoil of Open Cut 2 would provide seepage to the Open Cut 2 void for a limited time, until either the storage was depleted or the water level in the spoil has subsequently equilibrated with the water level within the Open Cut 2 flooded void.
- Equilibrium would be reached when the inflows and outflows for each of the three storages had balanced.

The parameters used in the updated Coffey model are indicated in **Table 12**.

Table 12 Modelling parameters – Coffey model

Parameter	Assumed/Adopted Values
Catchment areas (pond areas included)	No.1 OC final void: 1km^2. No.2 OC final void: 1.5km^2
Runoff coefficient	12% of Decile 5 rainfall for unsubmerged parts of each catchment (assumes fully rehabilitated land)
Rainfall recharge	Calibrated spatially uniform rainfall recharge of 6 x 10^{-5} m/day (22mm/year, or 4.3% of Decile 5 annual rainfall).
Hydraulic conductivity	Undisturbed hardrock: varying with depth from 0.1m/day at 10m depth to 0.001m/day at 150m depth (local vertical averaging of coal, seams and interburden Spoil: 1m/day uniform
Rainfall	Decile 5 annual rainfall of 591mm
Evaporation	Decile 5 annual pan evaporation (1556mm) x 80%

Source: Table 2 of Coffey (2005)

The modelling predicted that the long-term (steady-state) water levels in the final voids for average climatic conditions would be approximately 161mAHD for the Open Cut 1 void and 151mAHD for the Open Cut 2 void.

Other conclusions reached by this study are listed below:

> *"The rate of filling is dependent on many factors and cannot be accurately assessed at the present time. The assessed long-term hydraulic head distribution in the surrounding hardrock aquifer suggests the voids will act as groundwater sinks.*
>
> *Given the prevailing climate, available data, and results of numerical simulation, it is assessed that the following conditions will occur following mine closure:*
>
> *Permanently lowered water levels in the surrounding aquifers.*
>
> *Possible progressive salinity increase in each void lake.*
>
> *If no post-mining use of the pit lakes is to be made, it is assessed that progressive salinity increase in the final voids is unlikely to impact surrounding aquifers, given the generally low permeability of the surrounding rock strata at depth and the assessed future behaviour of the voids as groundwater sinks.*
>
> *Spoil from the Greta Coal Measures is known to produce acid mine drainage at other mines in the Hunter Valley, however this has not been observed at Muswellbrook Mine. Ponded water in the mine voids has exhibited a neutral pH for over 25 years, indicating a greater buffering capacity of natural waters than observed elsewhere. There is no data to suggest that progressive acidity increase (resulting from oxidation of sulphidic material) may occur.*
>
> *Based on the results of numerical simulation and available data, the final voids at Muswellbrook Mine are assessed as forming groundwater sinks in the future, and will thus not release stored water to the local or regional groundwater system. Although the void lakes may become more saline over time, they will not have a significant impact on surrounding groundwater resources in the foreseeable future."*

4.3 Australasian Groundwater & Environmental Consultants Pty Ltd (June 2010)

This assessment was completed to support the extension of mining operations within a 28.4ha area adjoining the Open Cut 1 Extension Area, of which 8.2ha was outside (to the immediate north) of the Open Cut 1 Extension Area (the 2010 Modification Area).

The report states that an additional 3D numerical model was not developed for this assessment of the 2010 Modification Area, given the following:

- detailed predictive modelling was previously developed to assess the impact of the Open Cut Extension 1 includes the extent of the 2010 Modification Area, which is quite small and adjoins the the Open Cut 1 Extension; and
- previous model predictions have been shown, via monitoring, to be reasonably accurate.

However a spreadsheet model was developed [based on an equation developed by Marinelli and Niccoli (2002)] "in order to provide a broad assessment of the radius of influence of mining the Modification Area on the piezometric surface of the coal measures aquifer system, and inflow to the Modification Area pit from the coal measures."

The key assumptions of the spreadsheet model were as follows:

- the pit walls are approximated as a right circular cylinder;
- the static groundwater level in the Loder Seam, the deepest seam to be mined, is approximately horizontal;
- uniform distributed recharge to the coal seam sub-crop as a result of surface infiltration of rainfall, assumed as 6.5mm/year (1.0% of the annual average rainfall);
- groundwater flow toward the pit is horizontal and axially symmetric;
- horizontal hydraulic conductivity of the Coal Measure is 10^{-3}m/day;
- the pre-mining water table (potentiometric level) of the Loder Seam is at 210mAHD and the maximum depth of the Open Cut 1 pit in the 2010 Modification Area is 77mAHD, resulting in a saturated thickness of the Coal Measures of 133m;
- the height of the seepage face in the pit wall is 1m; and
- the effective radius of the 2010 Modification Area mine pit is 300m.

The main conclusions of this assessment are summarised below:

- the maximum radius of drawdown influence of the piezometric surface (groundwater levels) due to dewatering activities at the MCC mine (including the Modification Area) would be 1,050m;
- consequently, the cone of depression does not extend under or impact the alluvial aquifers of the Hunter River, Sandy Creek and Muscle Creek or groundwater dependent ecosystems;
- the long term additional steady-state groundwater inflow to the 2010 Modification Area was predicted at 64m^3/day (24ML/year), which is a similar order of magnitude to that obtained by previous predictive modelling; and
- the groundwater quality of the coal seam aquifers is brackish to saline.

4.4 SLR Groundwater Management Study (July 2015)

In July 2015, SLR conducted a groundwater management study. The study included the following tasks:

- Development of a water balance model to confirm previously assumed parameters, by comparison of:
    - 2005-2015 pumped volumes;
    - analytical modelling of groundwater inflows;
    - groundwater throughflows from rainfall recharge area to the east, using model-calibrated infiltration;
    - surface water inflows estimated from pit catchment areas and model-calibrated runoff rates; and
    - evaporation rates from open water.
- Assessment of the long term steady state water levels in the surface mine voids, taking into consideration the water balance model.

The development of a water balance model was undertaken in order to confirm that the assumed parameters adopted within the previous models, together with the resulting model predictions, remain applicable to the completed development of the MCC mine site, with particular focus on the long term steady state water levels in the surface mine voids post closure.

The water balance model was developed (where possible) by comparison of:

- pumped volumes;
- analytical modelling of groundwater inflows;
- estimated groundwater throughflows from the rainfall recharge area to the east of the MCC mine site;
- surface water inflows estimated from pit catchment areas and model calibrated runoff rates; and
- evaporation rates from open water.

By comparing the results of the simple runoff calculations to that reported in the Annual Environmental Management Report for 2013 – 2014 for mine inputs, the water balance modelling confirmed that the following assumptions remained relevant for the analytical modelling of surface water contributions to final void levels:

- average annual rainfall of 630.1mm;
- a long-term runoff coefficient for rehabilitated areas of 0.12, as indicated by the Coffey modelling assumptions; and
- a runoff coefficient of 0.74, based on the recently completed Surface Water Management Study (SLR, 2015a).

The results of the final void modelling process indicated that the estimated final water surface elevation would be c.155mAHD for Open Cut 1 and c.95mAHD for Open Cut 2. It should be noted that there are some changes to the catchment areas and final void depths associated with the final landform proposed as part of the modification, compared with what was assessed for the 2015 study.

5 MODEL UPDATE

5.1 Approach

The analytical modelling conducted to support the groundwater assessment is based upon that conducted previously by AGE 2010 and SLR 2015b. Numerical modelling was not conducted because:

- Monitoring to date has shown that the previous modelling is reasonably accurate;
- The modification is relatively small and adjacent to currently approved mining associated with Open Cut 1;
- The modelling approach has previously been accepted as part of the AGE, 2010 assessment of impacts to groundwater supporting a Development Consent Modification; and
- Water balance modelling by SLR has further confirmed that analytical modelling can provide similar results to that measured at site for water make.

5.1.1 Analytical Modelling of Groundwater Inflows

Analytical modelling of groundwater inflows into the Open Cut 1 and 2 voids, following the cessation of mine dewatering and completion of rehabilitation of the surface water catchments, has been completed using spreadsheet models based on equations developed by Marinelli and Niccoli (2000), and Niccoli et al (1998). For the modelling exercise, each void was treated independently (i.e. modelled separately).

The Marinelli and Niccoli (2000) analytical model is illustrated in **Figure 13**.

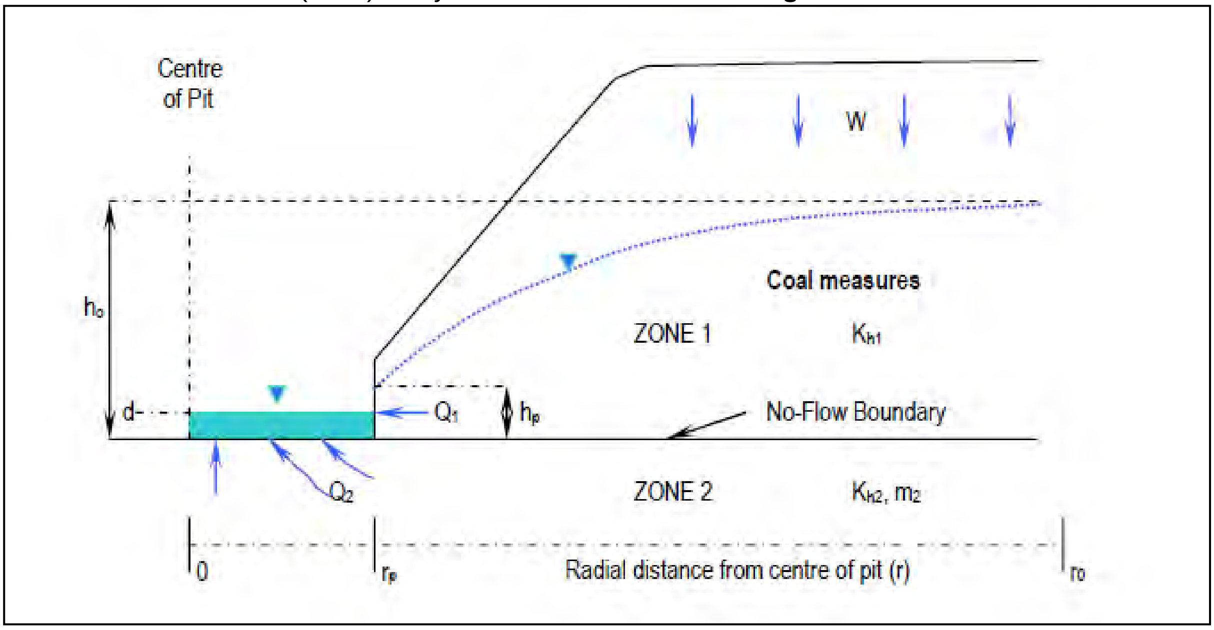

Figure 13 Pit Inflow Analytical Model (Marinelli and Niccoli, 2000)

The following key assumptions are made by this model:

- flow within Zone 1 is steady state, unconfined, horizontal, axially symmetric radial flow, with uniformly distributed rainfall recharge at the water table;
- groundwater inflows can also take place through the base of the pit.

Although it is recognised that the conditions are not fully met, these assumptions are considered to be reasonable, given that the base of the void will be sitting on mine spoil infill within the Permian bedrock aquifer surrounding and underlying the final voids; and the hydrogeological setting of the site.

The modelling approach recognises that there will be significant water losses as a result of the high (pan) evaporation losses from the water surface of the flooded void compared to the available rainfall. This is likely to cause localised drawdown of each void water level, and the groundwater level within the surrounding bedrock aquifer which is in direct hydraulic connection with the flooded void, unless additional surface water inputs from the surrounding post landform catchment can make up the deficit.

These spreadsheet models, together with their parameterisation are included within **Appendix C**. The models use input parameters derived from previous modelling.

5.1.2 Surface Water Inflows for Final Landform

Surface water inflows to the Open Cut 1 and Open Cut 2 voids have been calculated for the final landforms of both catchments, as detailed within the spreadsheet model included within **Appendix C**.

Catchment areas have been calculated based on topography and the revised final landform, and the revised long-term runoff coefficient of 0.12 from the previous Coffey MODFLOW model has been adopted.

Average annual rainfall used for these calculations is based on the combined average long term annual rainfall totals for rainfall stations at Aberdeen, Scone SCS and Muswellbrook (St Heliers).

5.1.3 Evaporation Rates for Open Water

The evaporation rate (1.606m/year) that has been utilised to estimate long-term average water losses from the No. 1 and No. 2 Open Cut voids following cessation of mining and completion of rehabilitation of the final landform catchments at MCM, is based on the potential (pan) evaporation data for the Scone SCS meteorological station.

5.1.4 Modelling Process

The elevation of each final void water surface has been estimated as follows:

(1) The surface area of each flooded void was calculated, based on the measured surface area of standing water within the flooded void when water levels have recovered to a range of theoretical elevations at 1m intervals.

(2) For each given theoretical void water surface elevation from (1), the groundwater and surface water inflows were calculated as outlined above (**Sections 5.1.1 and 5.1.2**), along with the evaporation losses as outlined above (**Section 5.1.3**).

(3) Using the inflow and loss calculations from (2), revised water surface areas for each flooded void were calculated using a water balance approach.

(4) The void water surface area calculated in (1) was compared to the revised surface area calculated in (3), with the process repeated until the two calculations of surface area matched, i.e. the models converged.

5.2 Model Results

The results of the modelling process show that the estimated final water surface elevation is c.192mAHD for Open Cut 1 void, and c.165mAHD for Open Cut 2 void.

The full results from the spreadsheet models outlined above are provided in **Table 13** for Open Cut 1 void and **Table 14** for Open Cut 2 void. Model spreadsheets and assumptions are included within **Appendix C.**

Table 13 Spreadsheet Model Results for Open Cut 1 Void

Ref No.	Parameter	Proposed Scenario	Derivation	SLR 2015
A	Long term water elevation in flooded void (mAHD):	192		155
B	Drawdown below predicted pre-development groundwater level (210mAHD):	18	= 210 - A	55
C	Area of flooded void (m^2):	245,970	Measured from MCC Drawing No. J16011 Final Landform	80,545
D	Effective Radius of void (m):	280	Calculated using $A = pr^2$	160
E	Calculated radius of influence (m):	409	Niccoli et al (1998) (see Appendix C)	505
F	Calculated groundwater inflow rate (ML/year):	10.7	Marinelli and Niccoli (2000) (see Appendix C)	16.3
G	Calculated surface water runoff inputs from final landform catchment (ML/year):	391	SLR spreadsheet (see Appendix C)	110.2
H	Total calculated inflows to void (ML/year):	401.7	H = F + G	126.5

Table 14 Spreadsheet Model Results for Open Cut 2 Void

Ref No.	Parameter	Primary Scenario	Derivation	SLR 2015
A	Long term water elevation in flooded void (mAHD):	165		95
B	Drawdown below predicted pre-development groundwater level (210mAHD):	45	= 210 - A	115
C	Area of flooded void (m^2):	238,116	Measured from MCC Drawing No. J16011 Final Landform	118,807
D	Effective Radius of void (m):	275.3	Calculated using $A = pr^2$	194
E	Calculated radius of influence (m):	578.6	Niccoli et al (1998) (see Appendix C)	871
F	Calculated groundwater inflow rate (ML/year):	25.8	Marinelli and Niccoli (2000) (see Appendix C)	44.3
G	Calculated surface water runoff inputs from final landform catchment (ML/year):	362.5	SLR spreadsheet (see Appendix C)	137.5
H	Total calculated inflows to void (ML/year):	388.3	H = F + G	181.8

It is noted that the potential interactions between Open Cuts 1 and 2 voids and the historic underground mine workings have not been assessed using this modelling approach.

However, it is considered that the relatively low permeability of the Permian bedrock aquifer and the negligible effective aquifer recharge will limit groundwater inflows to the voids. Also, the water balance calculations (included within **Appendix C**) completed in order to assess size of the catchment areas that are likely to provide groundwater recharge appear to be reasonable, given the site's topographic and hydrogeological setting.

6 GROUNDWATER IMPACT ASSESSMENT

6.1 Assessment Focus

It is noted that the activities under the modification will be wholly contained within the existing catchment areas of Open Cut 1, Open Cut 2 and Dams 1 and 2. There will be no disturbance or mining activity beyond the development consent boundary.

The key aspects of the modification which have potential to impact upon groundwater resources are detailed in the sections below.

6.2 Changes to Groundwater Levels

6.2.1 Operational Phases

The extent of the proposed modification to Open Cut 1 is minor enough that the analytical modelling methods used previously (AGE, 2010) and for the Groundwater Management Study (SLR 2015b) are insensitive to the minor change. This comes about because of the need to simplify the mining footprint as an effective radius. In addition, pit floor elevation is not expected to change significantly in depth from that previously assessed.

Therefore, previous assessments for radius of impacts remain valid with this proposed modification, which were a maximum radius of drawdown of approximately 1km. These estimates are consistent with the monitoring data to date.

6.2.2 Final Landform

The modelled standing water levels in each open cut final void are 192mAHD for Open Cut 1 and 165mAHD in Open Cut 2 which represents a standing water level of 26m and 33m respectively. These levels are below the background standing water level of 210mAHD. Therefore the final voids are expected to remain a groundwater evaporative sink and will not contribute water to the groundwater system(s).

The Open Cut 1 void is estimated to reach 90% equilibrium (190mAHD) within approximately 25 years and reach equilibrium (192mAHD) in approximately 60 years. The Open Cut 2 void is estimated to reach 90% equilibrium (162mAHD) within approximately 30 years and reach equilibrium (165mAHD) in approximately 90 years.

The updated final void water levels are similar to those estimated in the Coffey 2005 report, which was used in support of the 2010 Final Void Management Plan. The Coffey 2005 report estimated water levels of 181 mAHD for Open Cut No. 1 and 158 mAHD for Open Cut No. 2. The revised estimates are predicted to be higher than those estimated for the recent update to the Groundwater Management Study (SLR, 2015b) conducted to support the updated MOP (2015). In SLR 2015b, final void water levels were estimated to be c.155mAHD for Open Cut 1 void, and c.95mAHD for No.2 Open Cut void. The difference between the current estimate and the SLR 2015b report is due to the change in final land surface, in particular the raising of the base elevation of the voids. What is common amongst all estimates to date is that the voids will act as groundwater evaporative sinks and will not contribute water to the groundwater system(s).

Based on the final landform, the spill levels for each open cut pit are approximately 210m AHD for Open Cut 1 and 200m AHD for Open Cut 2. This provides approximately 18m freeboard in Open Cut 1 and 34m freeboard in Open Cut 2. This equates to an overall freeboard capacity of approximately 5,800 ML in Final Void 1 and 11,000 ML in Final Void 2, which is more than sufficient to hold rainfall from the calculated catchments for the Probable Maximum Precipitation rainfall event.

6.3 Impact on other users

The estimated radius of impacts, along with current monitoring, indicates that alluvial aquifers and registered bore users have not been impacted by current operations and will not be impacted as a result of the proposed modification.

6.4 Potential Groundwater Dependant Ecosystems

As the activities under the modification remain within the catchments of Open Cut Pit 1, Open Cut Pit 2 and Dams 1 and 2, there is not anticipated to be any significant change to groundwater levels beyond that which is currently approved. No GDEs have been identified within the area surrounding the Mine and as such, there are no foreseeable impacts to GDEs, as per Principle 5 of the *NSW State Groundwater Dependent Ecosystem Policy* (Department of Land and Water Conservation (2002).

6.5 Groundwater Inflows to mine

The HLA (2002) numerical model estimated a combined inflow of approximately 116.5ML/yr for Open Cut 1 and 2. Recent water balance estimates (SLR 2015b) confirm a groundwater inflow of approximately 100ML/yr for 2014. The total inflow during operations including the proposed modification is estimated to be within the range of those previously estimated by the HLA (2002) modelling and the water balance estimates.

Cumulative groundwater inflow to the recovered final voids is estimated to be approximately 36.5 ML/yr (**Table 13** and **Table 14**) from bedrock aquifers.

All predicted inflows are within the current licences held by MCC.

6.6 Groundwater Quality

A review of available groundwater quality information has been completed in order to assess the potential changes in water quality within the Open Cut 1 and 2 voids as water levels within the voids are allowed to reach equilibrium levels following completion of mine dewatering and rehabilitation of the MCC site.

The mechanisms for long term change in groundwater quality within the rehabilitated voids are as follows:

- potential acid mine drainage impacts due to groundwater moving through the mine spoil and previously dewatered Coal Measures bedrock where oxidised sulphide minerals (e.g. pyrite) may be present. The flushing of the resulting sulphate by groundwater as water levels recover can potentially generate a weak sulphuric acid, with corresponding reduction in pH levels and mobilisation of metallic elements within the groundwater;
- buildup of salts due to long term evaporation from the flooded voids, given that there will be a net loss of water from the flooded voids which will be driven by significantly higher annual potential (pan) evaporation rates compared to annual precipitation rates. Consequently, the flooded voids will act as groundwater sinks, drawing groundwater to them in the long term from the surrounding catchment;
- input of salts from runoff from the surrounding surface water catchments, as a direct result of the high levels of potential evaporation and evapotranspiration that are experienced in the general area of MCM.

The groundwater in the coal seams are the only water bearing zones assessed to be impacted during and after mining operations. As the groundwater quality of the coal seams is poor (brackish to saline), and final voids are expected to remain as evaporative sinks, no adverse offsite impacts to the groundwater quality are expected during and after mining operations.

7 MONITORING AND REPORTING

The groundwater assessment does not indicate a need for changes to the current monitoring and reporting as a result of the modification. Therefore, no changes to the groundwater monitoring program nominated in the SGWMP are proposed and as such, water quality and flow level monitoring will continue to be undertaken in accordance with the currently approved SGWMP. Monitoring will be carried out to confirm that the water management system is effective, and that the impacts of mining are consistent with the predictions made in this GWA.

Results of water quality monitoring and water flow monitoring will continue to be reported in the AEMR on an annual basis in accordance with the currently approved WMP and SWGMP.

8 MANAGEMENT AND MITIGATION MEASURES

The SGWMP provides measures for the monitoring of potential impacts as well as management and mitigation measures to minimise and mitigate impacts that may occur. The incremental impacts on groundwater resources as a result of the modification are predicted to be negligible. As such, no changes are recommended at this time for the SWMP or the SGWMP to account for the proposed modification.

9 CONCLUSIONS

The modification involves a continuation of existing mining activity to the north, into an area previously disturbed by historic mining activity. No additional disturbance is proposed beyond the current approved development consent boundary and all other activities will continue to be undertaken in accordance with the existing approvals. The key parts of the Modification which have the potential to impact upon the surrounding environment remain consistent with those potential impacts relating to the existing approved mining activity including:

- A maximum radius of drawdown of approximately 1km is estimated, which is consistent with the monitoring data to date;

- The modelled standing water levels in each open cut final void are 192mAHD for Open Cut 1 and 165mAHD in Open Cut 2 which represents a standing water level of 26m and 33m respectively. These levels are below the background standing water level of 210mAHD. Therefore the final voids are expected to remain a groundwater evaporative sink and will not contribute water to the groundwater system(s).

- The Open Cut 1 void is estimated to reach 90% equilibrium (190mAHD) within approximately 25 years and reach equilibrium (192mAHD) in approximately 60 years. The Open Cut 2 void is estimated to reach 90% equilibrium (162mAHD) within approximately 30 years and reach equilibrium (165mAHD) in approximately 90 years.

- Cumulative groundwater inflow to the recovered final voids is estimated to be approximately 36.5 ML/yr from bedrock aquifers.

- Based on the final landform, the spill levels for each open cut pit are approximately 210m AHD for Open Cut 1 and 200m AHD for Open Cut 2. This provides approximately 18m freeboard in Open Cut 1 and 34m freeboard in Open Cut 2. This equates to an overall freeboard capacity of approximately 5,800 ML in Final Void 1 and 11,000 ML in Final Void 2, which is more than sufficient to hold rainfall from the calculated catchments for the Probable Maximum Precipitation rainfall event.

- The total inflow during operations including the proposed modification is estimated to be within the range of those previously estimated by the HLA (2002) modelling, and the water balance estimates. Inflow rates are not estimated to exceed current MCC licenses for groundwater extraction;

- The groundwater in the coal seams are the only water bearing zones assessed to be impacted during and after mining operations. As the groundwater quality of the coal seams is poor (brackish to saline), and final voids are expected to remain as evaporative sinks, no adverse offsite impacts to the groundwater quality are expected during and after mining operations..

All currently approved management plans will continue to be utilised and maintained throughout the continuation of mining with the existing groundwater monitoring points remaining in use. The environmental management, mitigation and monitoring programs identified in the Site Water Management Plan will continue to be implemented. No impacts to local groundwater resources are expected to occur as part of the modification.

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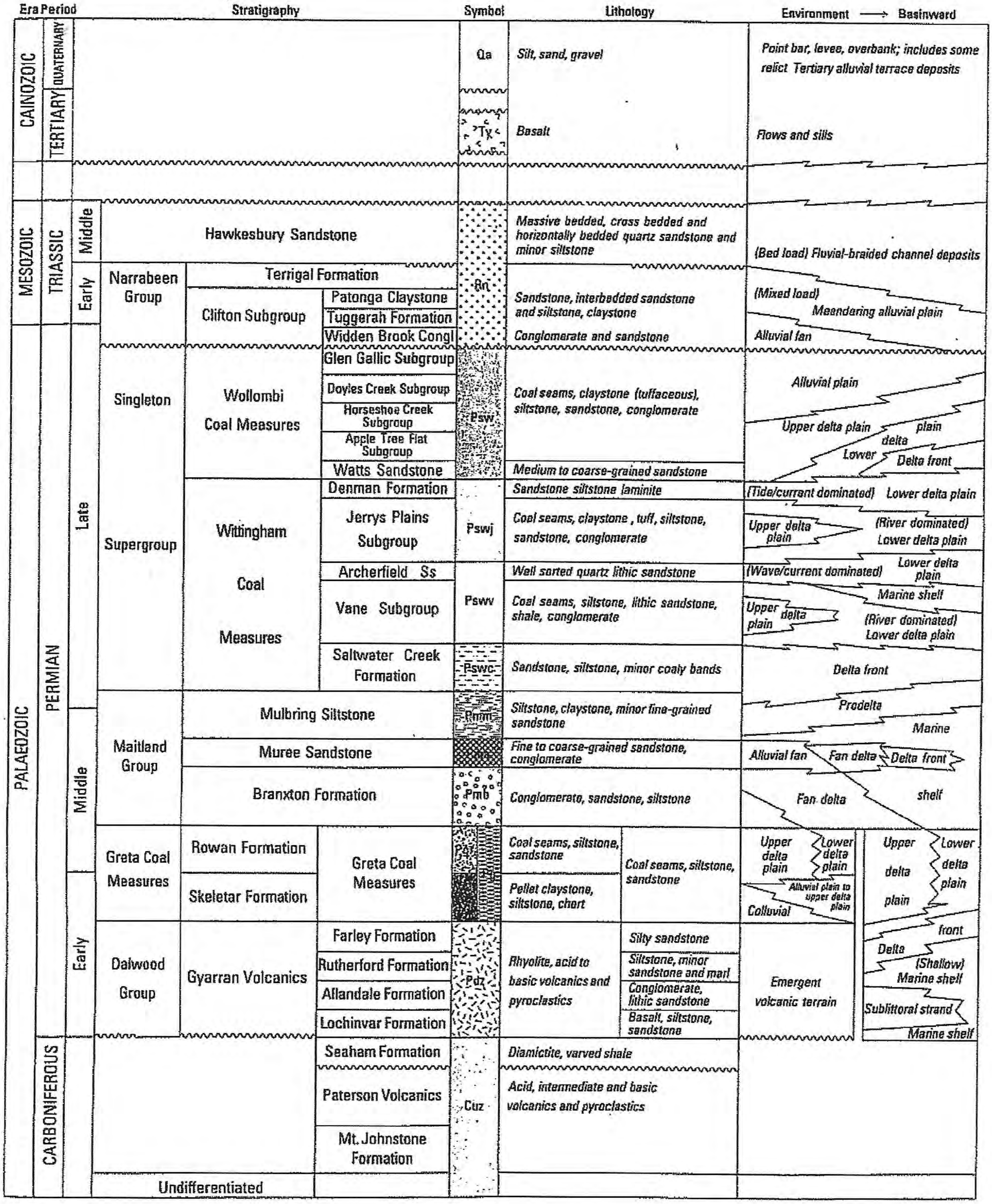
APPENDIX A Geological Details



Reference: Hunter Coalfield 1:100000 Geology Map, DMR, 1987.

HLA

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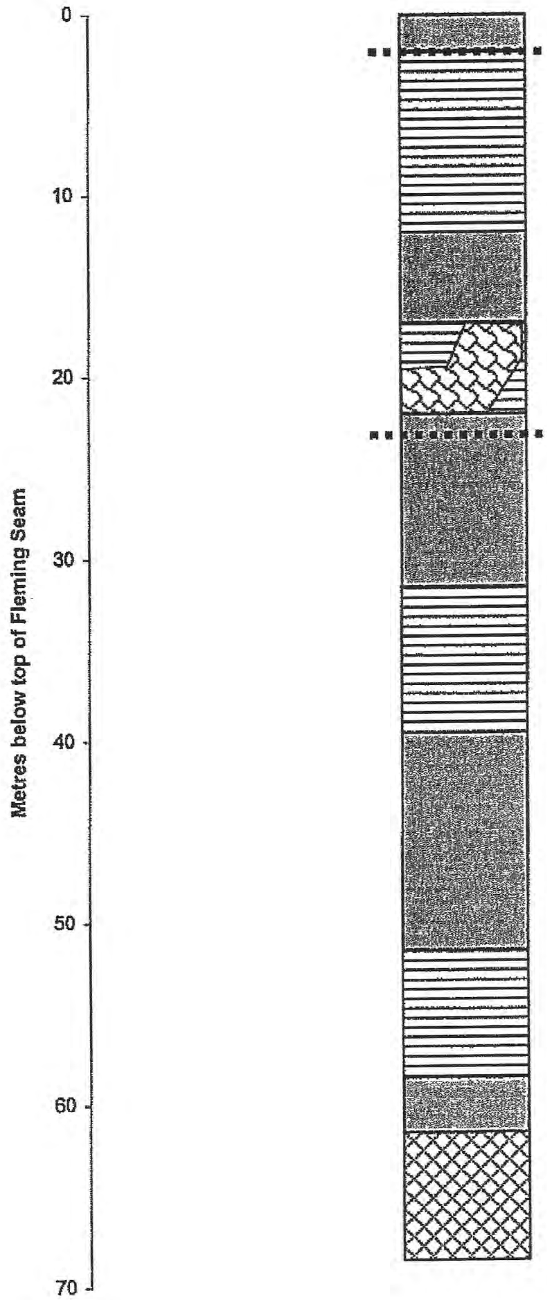
STRATIGRAPHY OF THE UPPER HUNTER VALLEY
Muswellbrook Coal Company Ltd
Water Management Study
No.1 Open Cut Extension, Muswellbrook NSW

FIGURE
6

DRAWN	PROJECT-TASK NUMBER	APPROVED	DATE	REVISED DATE
	U888-7	[signature]	March 2002	



STRATUM	THICKNESS
Upper Greta Coal Measures	41.5m
Fleming Seam (Glide plane at base)	2m
Interbedded sandstone and siltstone (includes the Hallet Coal Seam)	10m
Muswellbrook Seam	5m
Siltstone (some diorite sills)	5m
St Helliers Seam (Glide plane 1m below top)	9.5m
Interbedded sandstone and siltstone	8m
Lewis Seam (upper and Lower splits)	12m
Claystone	7m
Loder Seam	3m
Skeletar Formation	7m
Gyarran Volcanics	Unknown

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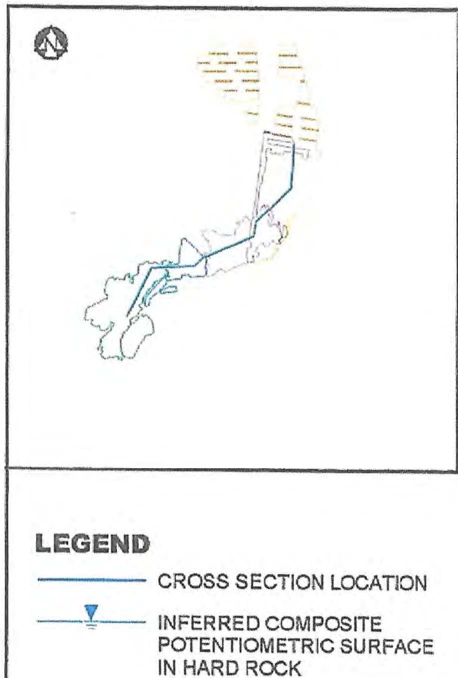
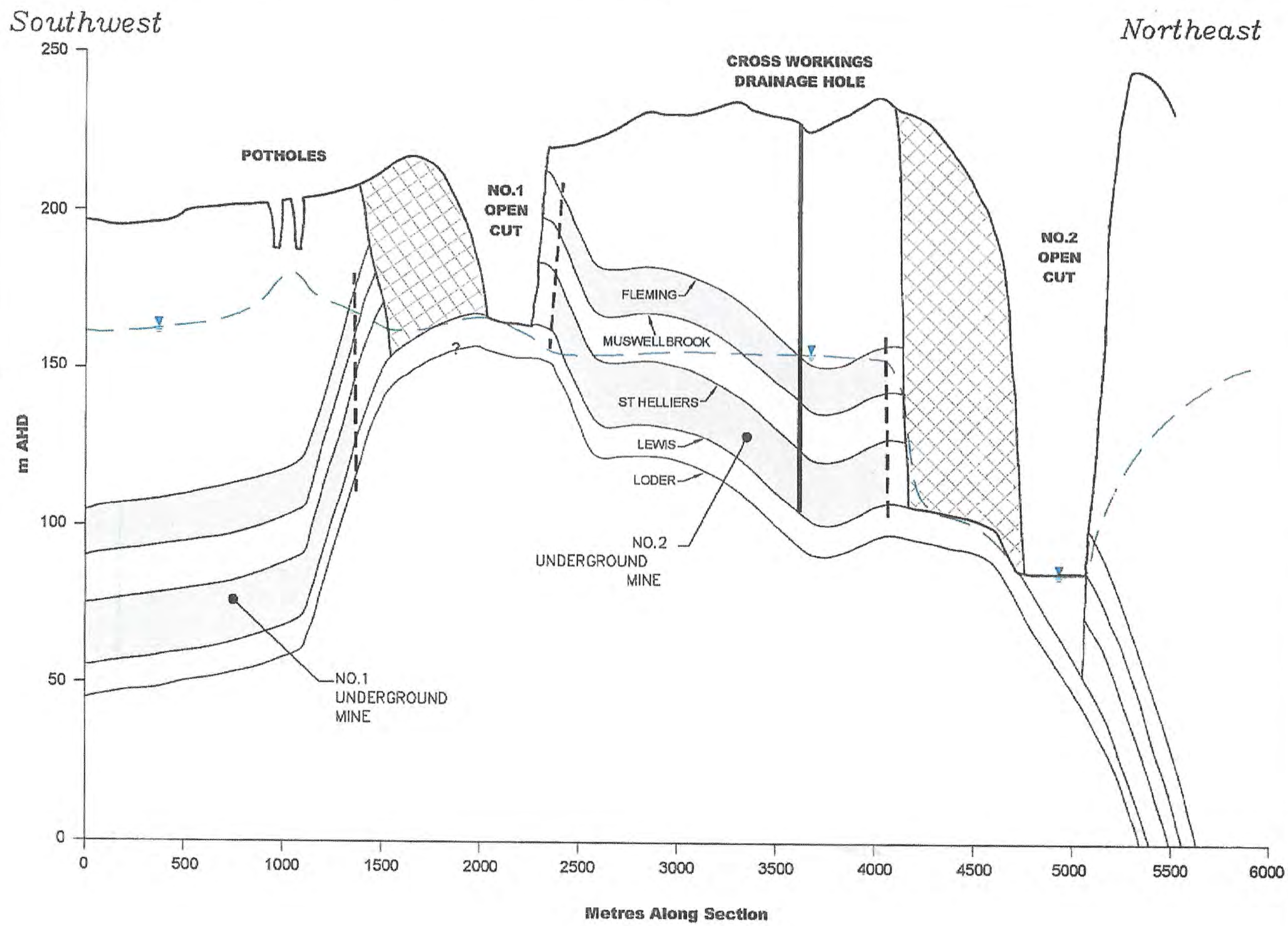
(02) 9988 4422

REPRESENTATIVE STRATIGRAPHY OF THE WORKS AREA
Muswellbrook Coal Company Ltd
Water Management Study
No.1 Open Cut Extension, Muswellbrook NSW

FIGURE **7**

DRAWN	PROJECT-TASK NUMBER	APPROVED	DATE	REVISED DATE
	U888-7		March 2002	





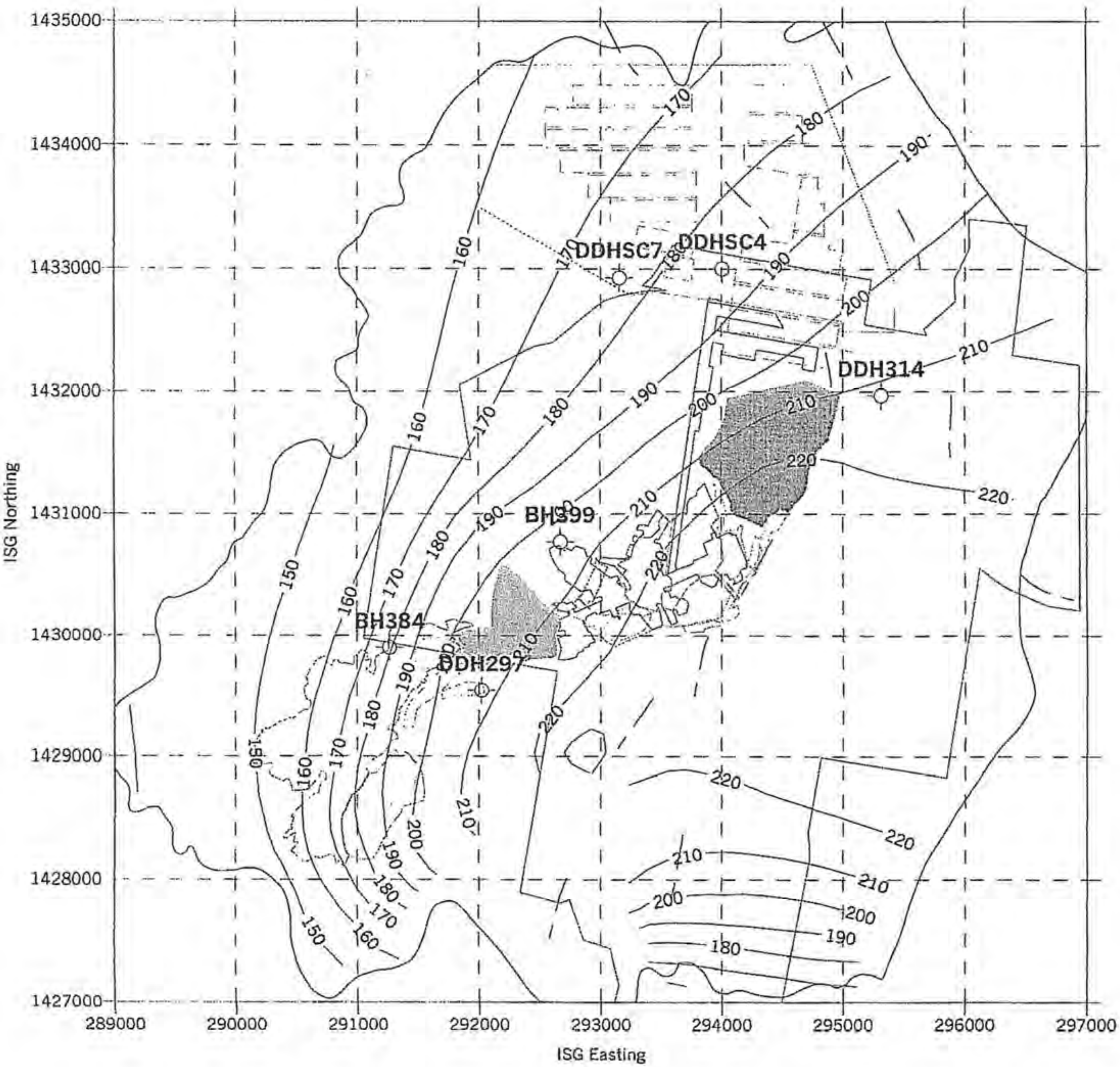
HLA-Envirosciences Pty Limited
55-65 Grandview Street
Pymble, NSW
61 2 9988 4422

HYDROGEOLOGICAL CROSS SECTION
Muswellbrook Coal Company Ltd
Water Management Study
No.1 Open Cut Extension, Muswellbrook NSW

FIGURE **11**

DRAWN	PROJECT-FILE NAME	APPROVED	DATE	REVISED DATE
LJE	U888-011		March 2002	

APPENDIX B Pre-Mining Groundwater Contours



Calibrated model heads in Layer 10 for the case of no mining (virgin conditions)

Notes:

Contours are piezometric head, in mAHD.

Calibration bore.

FIGURE D2

APPENDIX C Analytical Modelling of Final Voids

20) Flow to a pit (Marinelli and Niccoli, 1998)

$$Q_1 = P\pi\left(R_0^{\ 2} - r_w^{\ 2}\right)$$

$$Q_2 = 4\left(\frac{K_{h2}}{m_2}\right) r_w (H-d)$$

$$m_2 = \sqrt{\frac{K_{h2}}{K_{v2}}}$$

Essential input
Optional input
Calculated

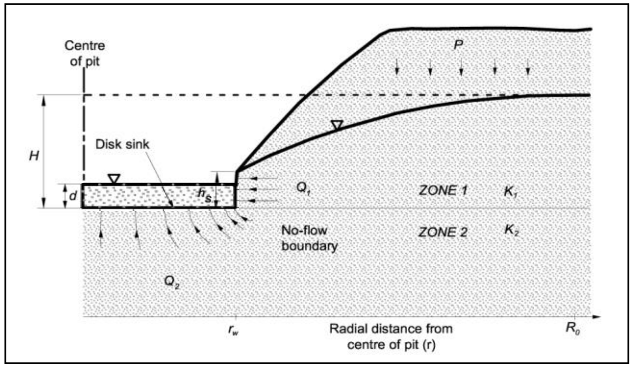
Flow into a pit using separate solutions for the sides and the base.

(Follow on from ROI spreadsheet 19. To find Radius of influence for this procedure)

Head		expected		min	max	
Height of wt at radius of influence	H	18.0	m			m
Depth of Ponded Area	d	0.0	m			m
Layer 2						
Horizontal Conductivity	K_{h2}	1.10E-08	m/s			m/s
		9.5E-04	m/d			
Vertical Conductivity	K_{v2}	1.10E-08	m/s			m/s
Anistropy	m_2	1.0		1.0	1.0	
Distributed recharge	P	1.90E-10	m/s			m/s
		1.6E-05	m^3/d			
Radius of quarry	r_w	280.0	m			
Radius of influence	R_o	409.4	m			m

Can be taken from ROI worksheet or other sources

Inflow						
Inflow through Seepage Face	Q_1	5.32E-05	m^3/s	5.32E-05	5.32E-05	m^3/s
		(4.6	m^3/d	4.599	4.599	m^3/d
Inflow through Mine base	Q_2	2.22E-04	m^3/s	2.22E-04	2.22E-04	m^3/s
		(19.2	m^3/d	19.2	19.2	m^3/d
Total Inflow	**Qt**	**0.000**	**m^3/s**	0.000	0.000	m^3/s
		(23.8	m^3/d	23.8	23.8	m^3/d



The following assumptions apply to this equation

- There is no groundwater flow between zones 1 and 2

Zone 1

- steady-state, unconfined, horizontal radial flow
- uniformly distributed recharge at the water table
- pit walls are approximated as a right circular cylinder
- initial static water table and groundwater flow are both horizontal
- groundwater flow to the pit is axially symmetric

Zone 2

- steady state flow to one side of a circular disk sink of constant and uniform drawdown
- hydraulic head is initially uniform throughout Zone 2.
- initial head is equal to the elevation of the initial water table in Zone 1
- disk sink has a constant hydraulic head equal to the elevation of the pit lake water surface
- flow to the disk sink is three-dimensional and axially symmetric
- materials are anisotropic, prinicipal directions for K are horizontal and vertical

(Marinelli & Niccoli, 1998)

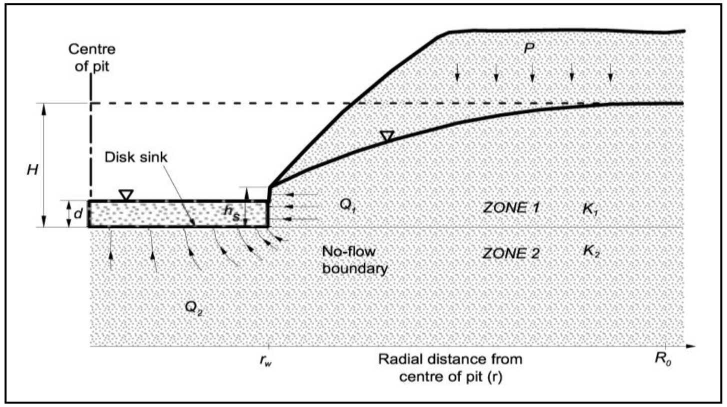
Data sources (to complete an audit trail)		
Height of wt at radius of influence	H	Pre-development WL: 210mAHD; Void WL: 192mAHD
Depth of Ponded Area	d	Based on AGE model as a worst case
Layer 2 Horizontal Conductivity	K_{h2}	Based on AGE and Coffey models
Layer 2 Vertical Conductivity	K_{v2}	Assumed same as Kh2, given bedrock beneath backfilled mine waste.
Distributed recharge	P	Based on AGE (1% of average rainfall)
Radius of quarry	r_w	Based on Flooded Area at c.192mAHD
Radius of influence	R_o	Calculated using Niccoli et al (1998) - see spreadsheet

19) Radius of influence (Niccoli et al, 1998) - Method to estimate radius of influence if other parameters can be estimated with reasonable accuracy

$$H = \sqrt{h_s^2 + \frac{P}{K_{h1}}\left[R_0^2 \ln\left(\frac{R_0}{r_w}\right) - \frac{R_0^2 - r_w^2}{2}\right]}$$

Essential input
Optional input
Calculated

Height of water table at radius of influence	H	18	m			m
Saturated thickness to seepage face	h_s	0	m			m
Drawdown = ($H-h_p$)	s	18	m	18	18	m
Layer 1 horizontal hydraulic conductivity	K_{h1}	0.001	m/d			m/d
Recharge	P	1.7e-05	m/d			m/d
Radius of quarry	r_w	280	m			
Effective radius	R_0	409.36		409.36	409.36	



The following assumptions apply to this equation

- steady-state, unconfined, horizontal radial flow
- uniformly distributed recharge at the water table
- pit walls are approximated as a right circular cylinder
- the static water table is horizontal
- groundwater flow is horizontal
- groundwater flow to the pit is axially symmetric

(Niccoli et al, 1998)

Data sources (to complete an audit trail)

Height of water table at radius of influence	H	Pre-development WL: 210mAHD; Void WL: 192mAHD
Saturated thickness to seepage face	h_s	Based on AGEmodel as a worst case
Layer 1 horizontal hydraulic conductivity	K_{h1}	Based on AGE and Coffey models
Recharge	P	Based on AGE (1% of average rainfall)
Radius of quarry	r_w	Based on Flooded Area at c.192mAHD

20) Flow to a pit (Marinelli and Niccoli, 1998)

$$Q_1 = P\pi\left(R_0^{\ 2} - r_w^{\ 2}\right)$$

$$Q_2 = 4\left(\frac{K_{h2}}{m_2}\right) r_w (H - d)$$

$$m_2 = \sqrt{\frac{K_{h2}}{K_{v2}}}$$

Essential input
Optional input
Calculated

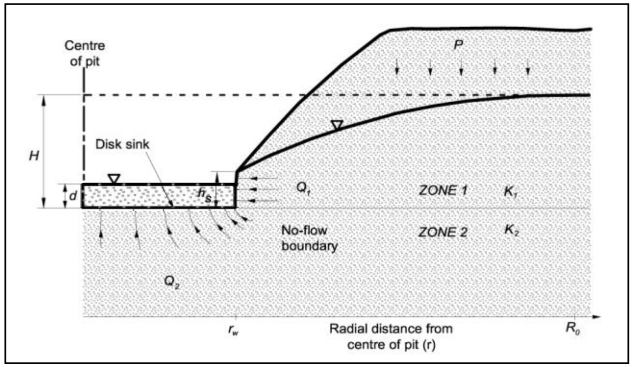
Flow into a pit using separate solutions for the sides and the base.

(Follow on from ROI spreadsheet 19. To find Radius of influence for this procedure)

Head		expected		min	max	
Height of wt at radius of influence	H	45.0	m			m
Depth of Ponded Area	d	0.0	m			m
Layer 2						
Horizontal Conductivity	K_{h2}	1.10E-08	m/s			m/s
		9.5E-04	m/d			
Vertical Conductivity	K_{v2}	1.10E-08	m/s			m/s
Anistropy	m_2	1.0		1.0	1.0	
Distributed recharge	P	1.90E-10	m/s			m/s
		1.6E-05	m^3/d			
Radius of quarry	r_w	275.3	m			
Radius of influence	R_o	578.5	m			m

Can be taken from ROI worksheet or other sources

Inflow						
Inflow through Seepage Face	Q_1	1.55E-04	m^3/s	1.55E-04	1.55E-04	m^3/s
		(13.4	m^3/d	13.354	13.354	m^3/d
Inflow through Mine base	Q_2	5.45E-04	m^3/s	5.45E-04	5.45E-04	m^3/s
		(47.1	m^3/d	47.1	47.1	m^3/d
Total Inflow	**Qt**	**0.001**	**m^3/s**	0.001	0.001	m^3/s
		(60.4	m^3/d	60.4	60.4	m^3/d



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- hydraulic head is initially uniform throughout Zone 2.
- initial head is equal to the elevation of the initial water table in Zone 1
- disk sink has a constant hydraulic head equal to the elevation of the pit lake water surface
- flow to the disk sink is three-dimensional and axially symmetric
- materials are anisotropic, pirincipal directions for K are horizontal and vertical

(Marinelli & Niccoli, 1998)

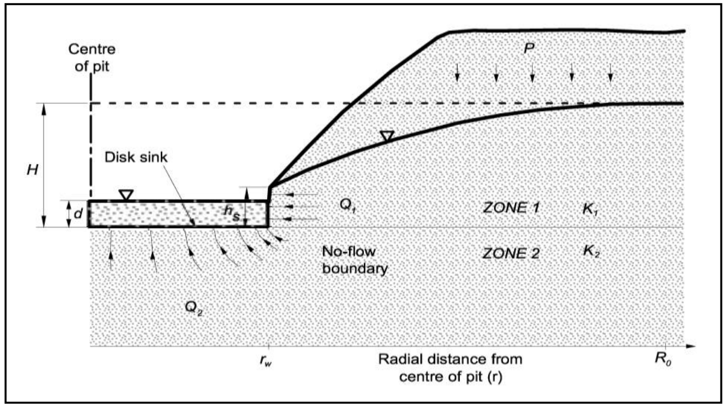
Data sources (to complete an audit trail)		
Height of wt at radius of influence	H	Pre-development WL: 210mAHD; Void WL: 165mAHD
Depth of Ponded Area	d	Based on AGE model as a worst case
Layer 2 Horizontal Conductivity	K_{h2}	Based on AGE and Coffey models
Layer 2 Vertical Conductivity	K_{v2}	Assumed same as Kh2, given bedrock beneath backfilled mine waste.
Distributed recharge	P	Based on AGE (1% of average rainfall)
Radius of quarry	r_w	Based on Flooded Area at c.165mAHD
Radius of influence	R_o	Calculated using Niccoli et al (1998) - see spreadsheet

19) Radius of influence (Niccoli et al, 1998) - Method to estimate radius of influence if other parameters can be estimated with reasonable accuracy

$$H = \sqrt{h_s^2 + \frac{P}{K_{h1}}\left[R_0^2 \ln\left(\frac{R_0}{r_w}\right) - \frac{R_0^2 - r_w^2}{2}\right]}$$

Key
Essential input
Optional input
Calculated

Height of water table at radius of influence	H	45	m			m
Saturated thickness to seepage face	h_s	0	m			m
Drawdown = ($H-h_p$)	s	45	m	45	45	m
Layer 1 horizontal hydraulic conductivity	K_{h1}	0.001	m/d			m/d
Recharge	P	1.7e-05	m/d			m/d
Radius of quarry	r_w	275.3	m			
Effective radius	R_0	578.55		578.55	578.55	



The following assumptions apply to this equation

- steady-state, unconfined, horizontal radial flow
- uniformly distributed recharge at the water table
- pit walls are approximated as a right circular cylinder
- the static water table is horizontal
- groundwater flow is horizontal
- groundwater flow to the pit is axially symmetric

(Niccoli et al, 1998)

Data sources (to complete an audit trail)

Height of water table at radius of influence	H	Pre-development WL: 210mAHD; Void WL: 165mAHD
Saturated thickness to seepage face	h_s	Based on AGEmodel as a worst case
Layer 1 horizontal hydraulic conductivity	K_{h1}	Based on AGE and Coffey models
Recharge	P	Based on AGE (1% of average rainfall)
Radius of quarry	r_w	Based on Flooded Area at c.165mAHD

Runoff Co's	
Vegetated Area	0.4
Hardstand Area	0.9
VOID 1	
Final Landform Catchment	
Vegetatated catch (ha)	97.3
Hardstand catch (VOID FOOTPRINT) (ha)	25.7
Avg Annual Surface Water Inflow (ML)	**391.0**
VOID 2	
Final Landform Catchment	
Vegetatated catch (ha)	88.3
Hardstand catch (VOID FOOTPRINT) (ha)	24.7
Avg Annual Surface Water Inflow (ML)	**362.5**