APPENDIX 15

Blast Assessment

Appendix 15a

Blasting Impact Assessment

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UMWELT (AUSTRALIA) PTY LIMITED
on behalf of
GLENDELL TENEMENTS PTY LIMITED

BLASTING IMPACT ASSESSMENT FOR THE GLENDELL CONTINUED OPERATIONS PROJECT

FINAL

REPORT NO. UM-1845-261119

Thomas Lewandowski
26th November 2019

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1.0 INTRODUCTION

Enviro Strata Consulting Pty Limited (ESC) was engaged by Umwelt (Australia) Pty Limited (Umwelt) to undertake a Blasting Impact Assessment (BIA) for the Glendell Continued Operations Project (the Project) on behalf of Glendell Tenements Pty Limited (the Proponent). The Project (see **Figure 1**) will involve expansion of the current open cut mine (Glendell Pit) in a northerly direction, referred to as the Glendell Pit Extension.

Glendell Mine together with the proposed Project is a part of the Mount Owen Complex. The Mount Owen Complex is located within the Hunter Coalfields in the Upper Hunter Valley of New South Wales (NSW), approximately 20 km north-west of Singleton, 24 km south-east of Muswellbrook and to the north-west of Camberwell. Mt Owen Pty Limited (Mount Owen), a subsidiary of Glencore Coal Pty Limited (Glencore), currently owns three existing open cut operations in the Mount Owen Complex; Glendell (Glendell Pit), Mount Owen (North Pit) and associated infrastructure and Ravensworth East (Bayswater North Pit).

Glendell Mine operates under Development Consent (DA 80/952) (Glendell Consent) within the Mount Owen Complex.

This BIA has been prepared by ESC on behalf of Umwelt as part of the Environmental Impact Statement (EIS) for the Project. The BIA has been undertaken in accordance with the Secretary of the Department of Planning and Environment's Environmental Assessment Requirements (SEARs) for the Project. The BIA has been undertaken in accordance with the guidelines contained in Australian and New Zealand Environment Council 'Technical Basis for guidelines to minimise annoyance due to blasting overpressure and ground vibration' (ANZECC, 1990) guidelines.

The BIA will assess the impact of the Project on the following:

- local community; including private residential receivers,
- historical / heritage points of interest,
- existing, approved and proposed infrastructure,
- adjacent mines, and
- the neighbouring Bowmans Creek area and Yorks Creek Realignment.

The BIA has not assessed potential blast impacts on Glencore owned mining and associated assets other than the Integra Underground Mine and associated infrastructure.

The BIA includes ground vibration and airblast overpressure modelling, utilising parameters representative of the Glendell Mine conditions. The impacts of fumes / odour from the Project on the surrounding environment are addressed in the Air Quality Impact Assessment (Jacobs 2019). Visual impacts associated with blasting are assessed in the main text of the EIS.

The blasting methods are proposed to remain the same as for the current Glendell Mine operations (i.e. through-seam blasting), subject to future changes in blasting technology over the life of the Project. Occasionally, geology permitting, conventional blasting methods may also be used. The results of this assessment are presented in the context of the relevant vibration and overpressure limits for the points of interest as outlined in the current Glendell Consent and, where relevant, the Mount Owen Continued Operations Project Development Consent (SSD-5850) (Mount Owen Consent) which forms a part of the Mount Owen Complex.

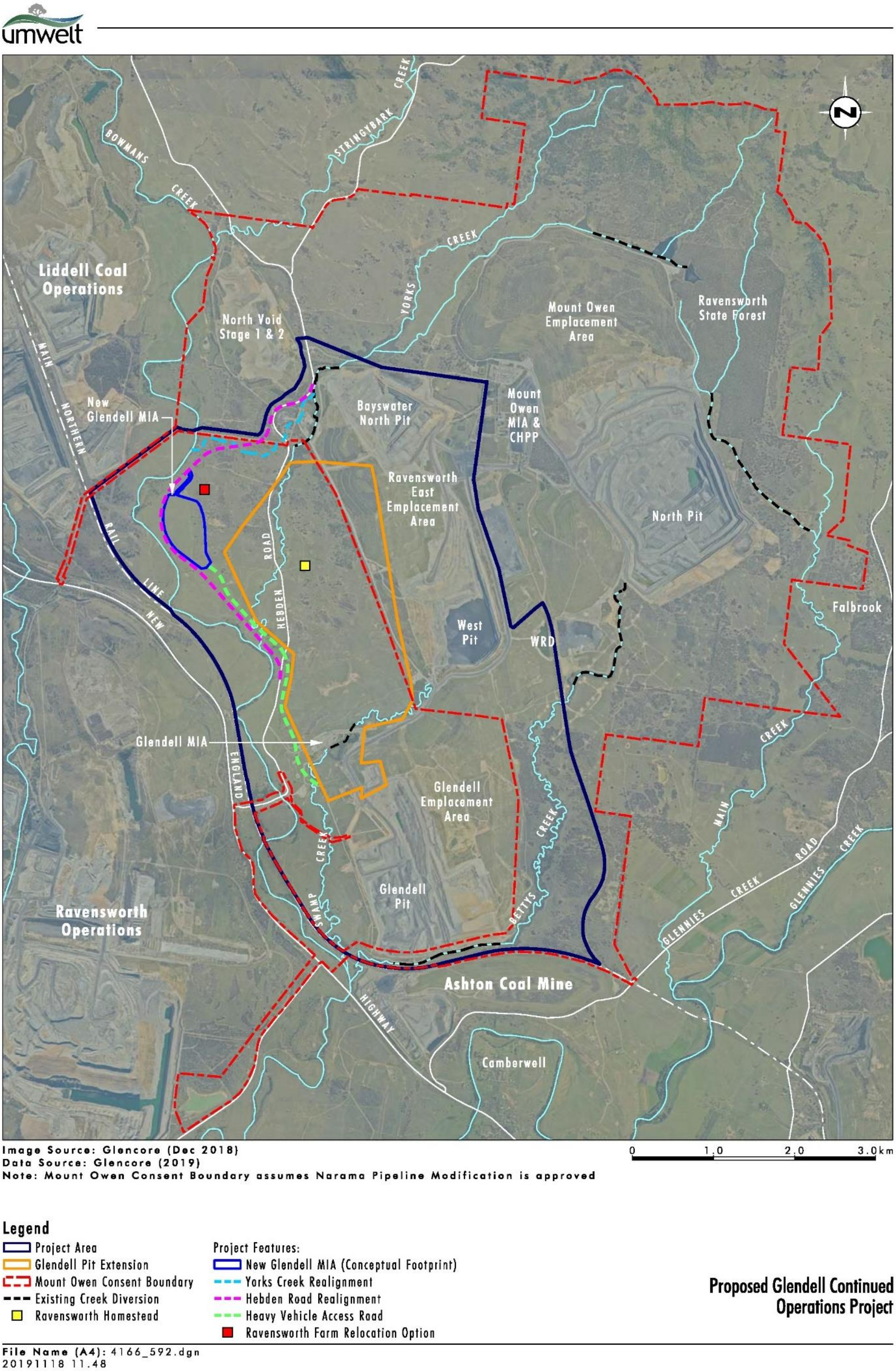

Figure 1 – Proposed Glendell Continued Operations Project

2.0 PROJECT DETAILS

The Glendell Mine forms part of the Mount Owen Complex in the Hunter Region of New South Wales (NSW) and is owned and operated by subsidiaries of Glencore Coal Pty Limited (Glencore). The site is part of the Hunter Valley Coalfields and is located approximately 20 km northwest of Singleton in the Singleton Local Government Area (LGA). The Mount Owen Complex is currently operated by Mt Owen Pty Ltd, and the complex also includes Mount Owen Mine, Ravensworth East Mine, a coal handling and preparation plant (CHPP) and coal transport infrastructure.

The Glendell Continued Operations Project (the Project) is an extension of open cut mining operations immediately to the north of the existing Glendell Mine (refer to **Figure 1**). The Project would extend the life of the Glendell Mine to approximately 2044 and allow for the recovery of approximately 135 million tonnes of ROM coal and provide ongoing employment opportunities for existing Mount Owen Complex workforce.

The key features of the Project include:

- extension of open cut mining to the north of the existing Glendell Mine until 2044,
- extraction of approximately 135 million tonnes of run-of-mine (ROM) coal,
- continued integration of the mine with the wider Mount Owen Complex, including the use of the Mount Owen CHPP, rail loop and associated infrastructure for ROM coal processing and product coal transport,
- demolition of the existing Glendell Mine Infrastructure Area (MIA) and the construction of a new MIA,
- realignment of a section of Hebden Road,
- realignment of part of Yorks Creek,
- relocation of Ravensworth Homestead,
- other ancillary infrastructure works such as the construction of a Heavy Vehicle Access Road,
- progressive rehabilitation of the site.

3.0 GEOLOGY, CONCEPTUAL BLAST DESIGN AND MINING STAGES

3.1 GEOLOGY OF THE AREA AND BLASTING IMPLICATIONS

The Project will aim to extract up to eight main coal seams (see **Figure 2**), down to and including the Hebden seam. Listed in order of increasing depth, the key target seams for mining within the Glendell Pit Extension include the following seams:

- Lemington A-C (3 seams),
- Pikes Gully,
- Arties,
- Liddell,
- Barrett,
- Hebden.

From a geological perspective, the Project Area is subdivided by the Camberwell anticline (centrally located and trending north-south), which separates the Project into western and eastern sections, see **Figure 3.** The sections are structurally different, although similar stratigraphically. Notably, there is some variation in the number of coal seams between the western and eastern sections i.e. only one Lemington seam is present in the western section, while three Lemington seams are present in the eastern section.

Other prominent geological features include a reverse fault (cutback fault) present in the western section of the Project (marked in red on **Figure 3**). There is also a wide block fault zone located in the northern section of the Project, which consists of a number of fault lines (generally less than 12 m throw) and a number of dyke intrusions (generally less than 4 m in width).

In other areas of the Project (outside of the block fault zone), occasional geological disturbances may occur, these being small-scale faulting (less than 2 m throw), small-scale dyke/cinder zones (less than 4 m thick), bedding plane shear and/or coal seam mylonite.

Based on the Pre-feasibility report (Glencore 2018) which identifies the extent of the fault zone affectation, there is an indication that the Project would potentially generate some elevated vibration levels along the wide block fault zone, which traverses the northern section of the Project Area and extends beyond the Project boundaries. The blasting through this zone may induce potential magnification in vibration levels along the fault zone area, as described by Lewandowski et al (2009).

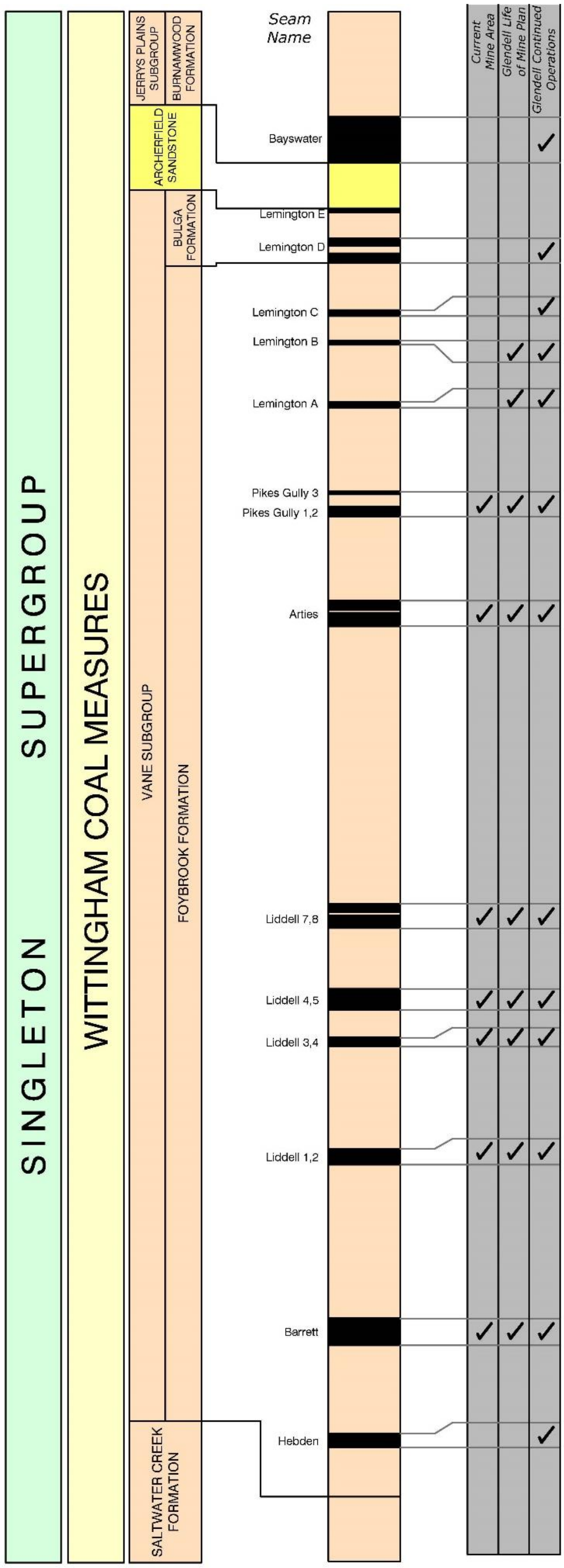

Figure 2 – Typical stratigraphy at Glendell Mine

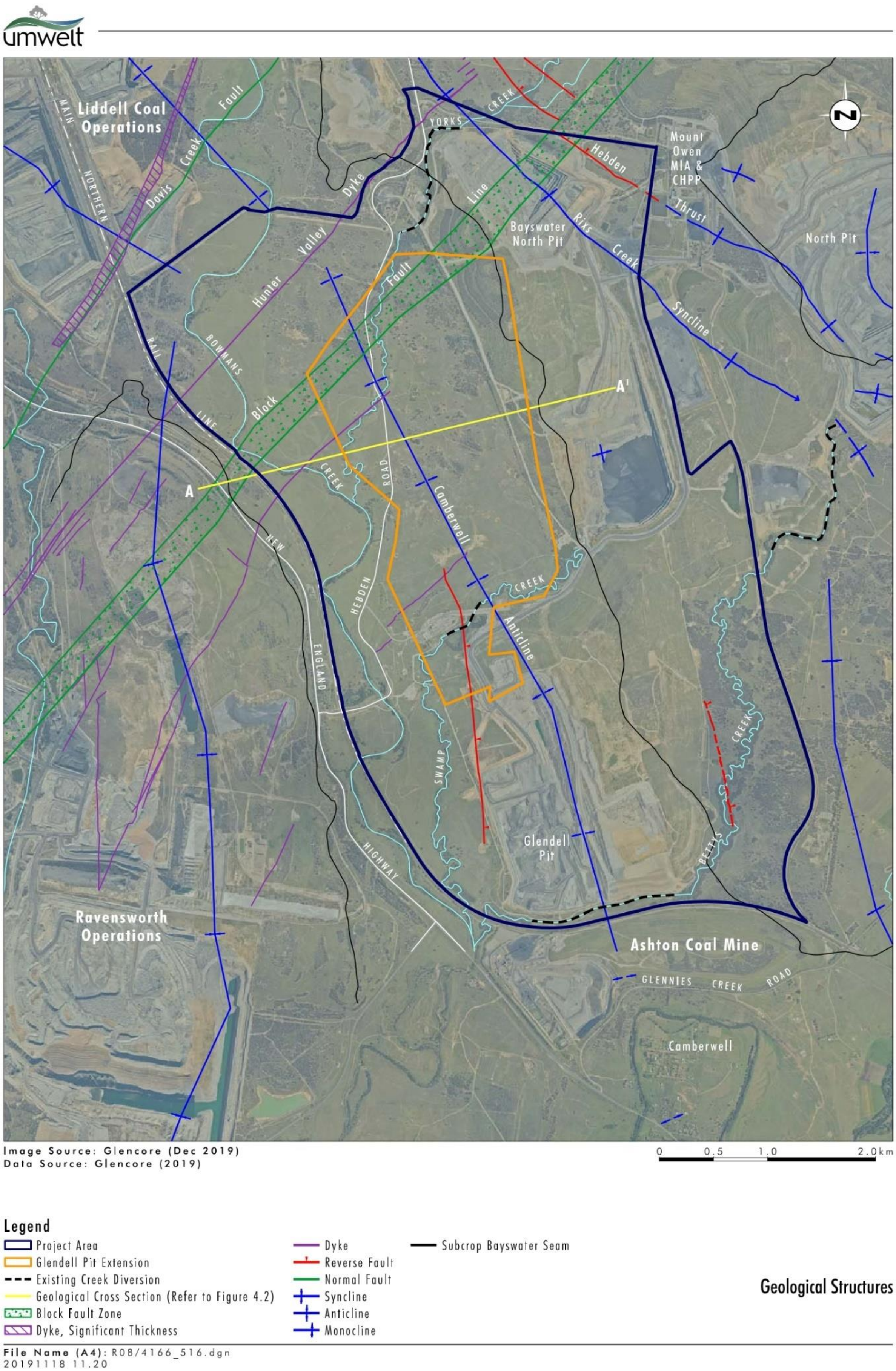

Figure 3 – Glendell Pit Extension and Identified Geological Features

Based on the geological model developed for the Project Area, the maximum extraction depth for the Glendell Pit Extension varies from 120 to 280 m below natural ground level. The east-west cross-section of the Glendell Pit Extension is presented in **Figure 4.** The proposed Glendell Pit Extension is located along the Camberwell anticline which runs in a general north-south alignment through the proposed Glendell Pit Extension. The Camberwell anticline dips to the north and exhibits steep dips on its eastern flank and western flank.

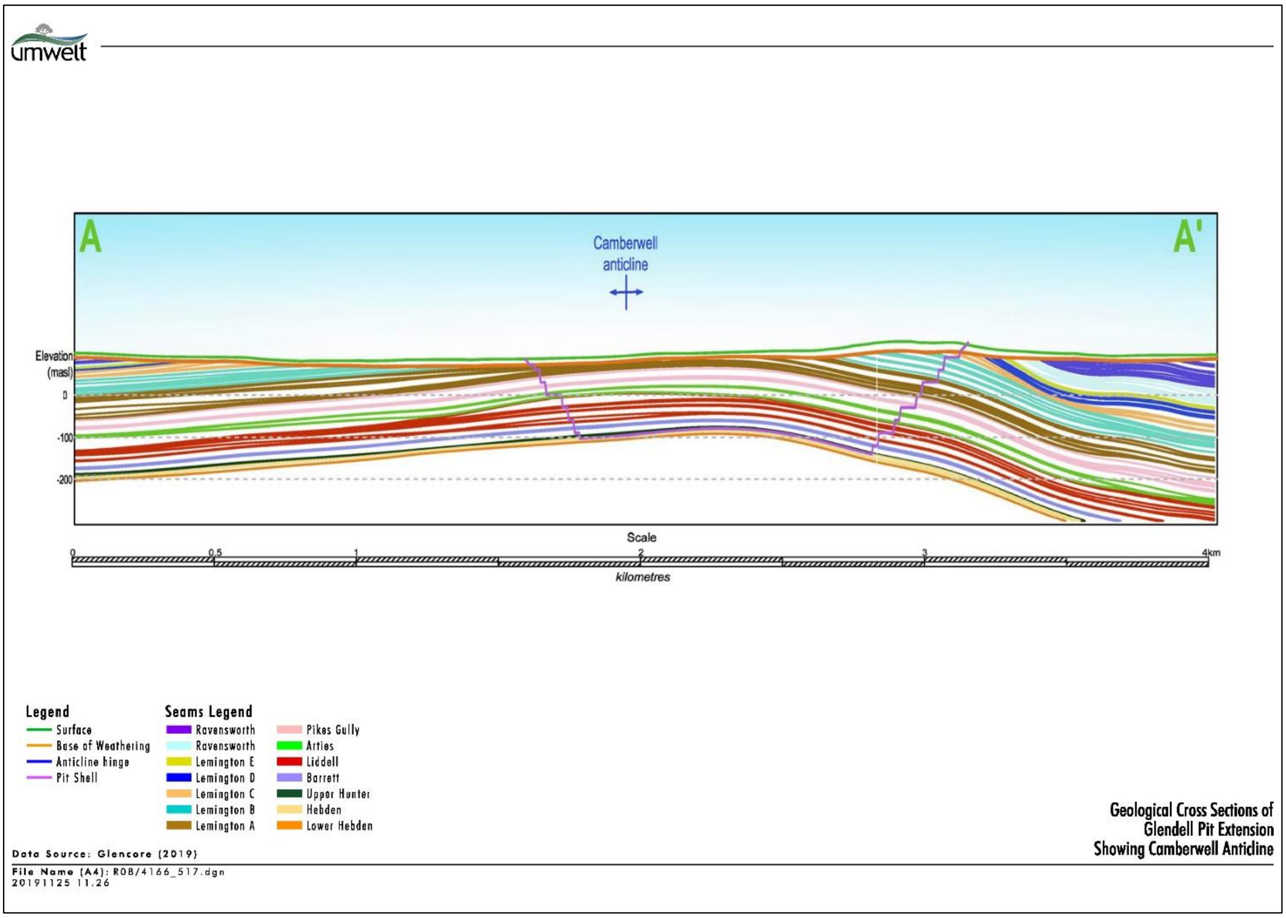

Figure 4 – Geological Cross-Section (east-west) for Glendell Pit Extension

The geology of the Glendell Pit Extension includes highly variable interburden strata conditions. The average interburden thickness between targeted coal seams could vary between 0.5 and 40 m. To accommodate for such high variation and dipping strata (i.e. associated with the Camberwell anticline) and ensure efficient coal seam recovery, the blasting method would typically include a through-seam blasting method using a single bench height (i.e. up to 15 m) and 30 m pre-split type blasts, the same method as currently used at Glendell Mine. There is a potential for conventional type blasting in the north-west section of the Glendell Pit Extension targeting up to 30 m benches, see **Figure 5**.

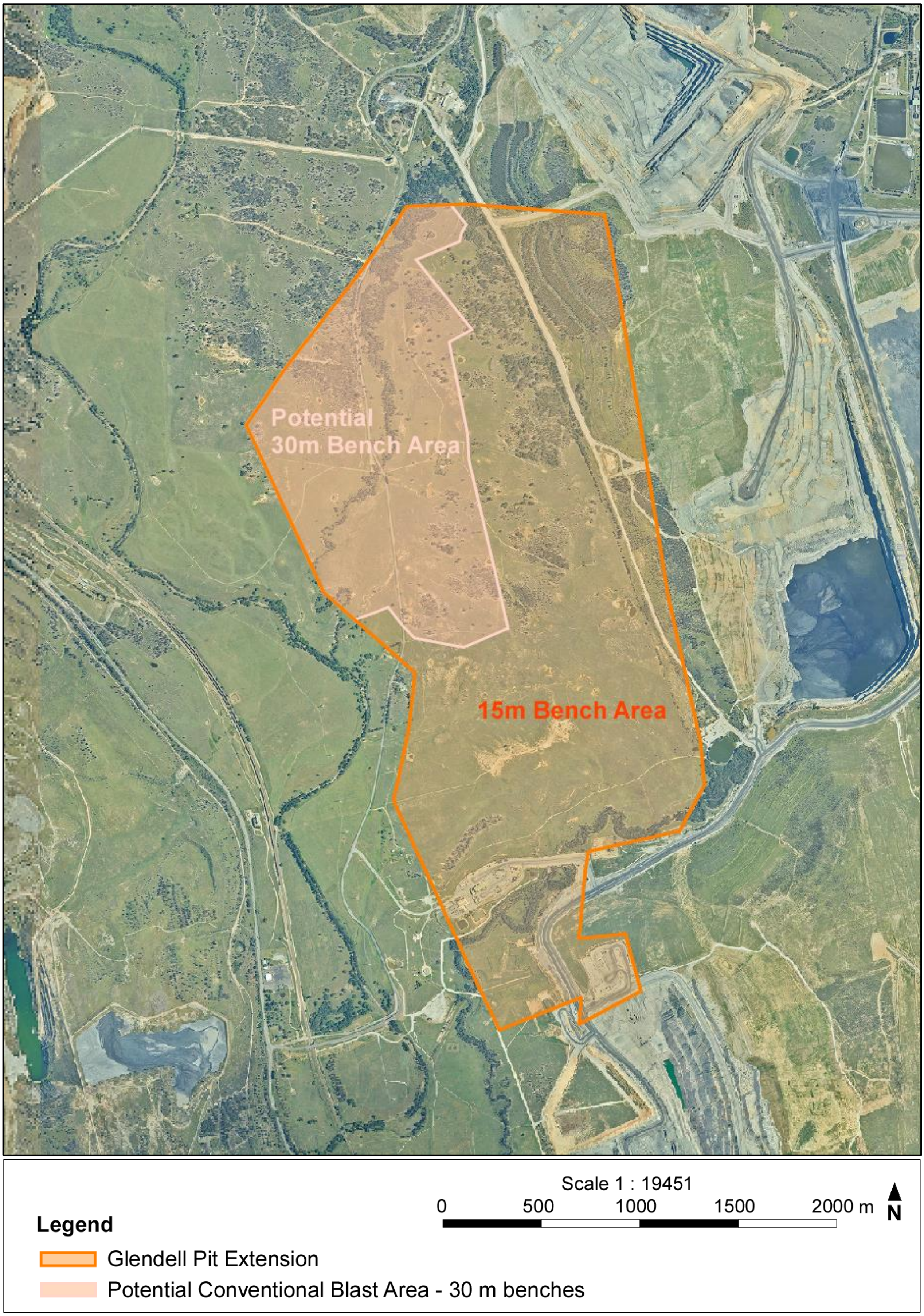

Figure 5 – Area Identified for Potential Conventional Type Blasting

3.2 MINING STAGES

The conceptual mine stage plans for Glendell Pit Extension representative for the Project are shown in **Figures 6** to **9.** The conceptual plans show commencement of mining extraction from the southern end and gradual advance in the northerly direction. The maximum extent of the Pit, and therefore the limit of blasting associated with the Project is also shown in **Figure 5**.

As the closest private residential receivers are located to the south and south-east directions the highest impact on residential receivers is to be expected in the initial stage of the Project and gradual decrease in blast impacts with time, as extraction progresses to the north.

The Project includes the relocation of non-mine infrastructure and the realignment of Yorks Creek. These activities mean that the location of these features relative to the areas where blasting may be carried out will change over the life of the Project. The indicative timing of these works is shown in **Table 1**.

Table 1: Indicative Construction Schedule

Feature	Indicative Construction Period
Construction of Hebden Road realignment and relocation of associated powerlines and telecommunications infrastructure	Year 1 – Year 2
Yorks Creek Realignment	Prior to Year 7 – some aspects constructed as part of Hebden Road realignment
Relocation of Ravensworth Homestead to 'Ravensworth Farm Site'[1]	Year 1 to Year 6

[1] *If selected as preferred relocation site.*

Construction activities in some areas will include blasting for cuttings (Hebden Road and Yorks Creek Realignment). Crushing of overburden and blasted material from cuttings and areas within the Glendell Pit Extension and other approved mining areas at the Mount Owen Complex identified as having suitable material may also be required for road and MIA construction fill.

Blasting associated with construction activities will only be undertaken between 9.00 am to 5.00 pm, Monday to Friday and 9.00 am to 1.00 pm Saturday. Blasting activities with potential to impact traffic using Hebden Road will be carried out to avoid peak travel times and in periods to avoid school bus movements. Operational blast criteria will apply to construction blasting.

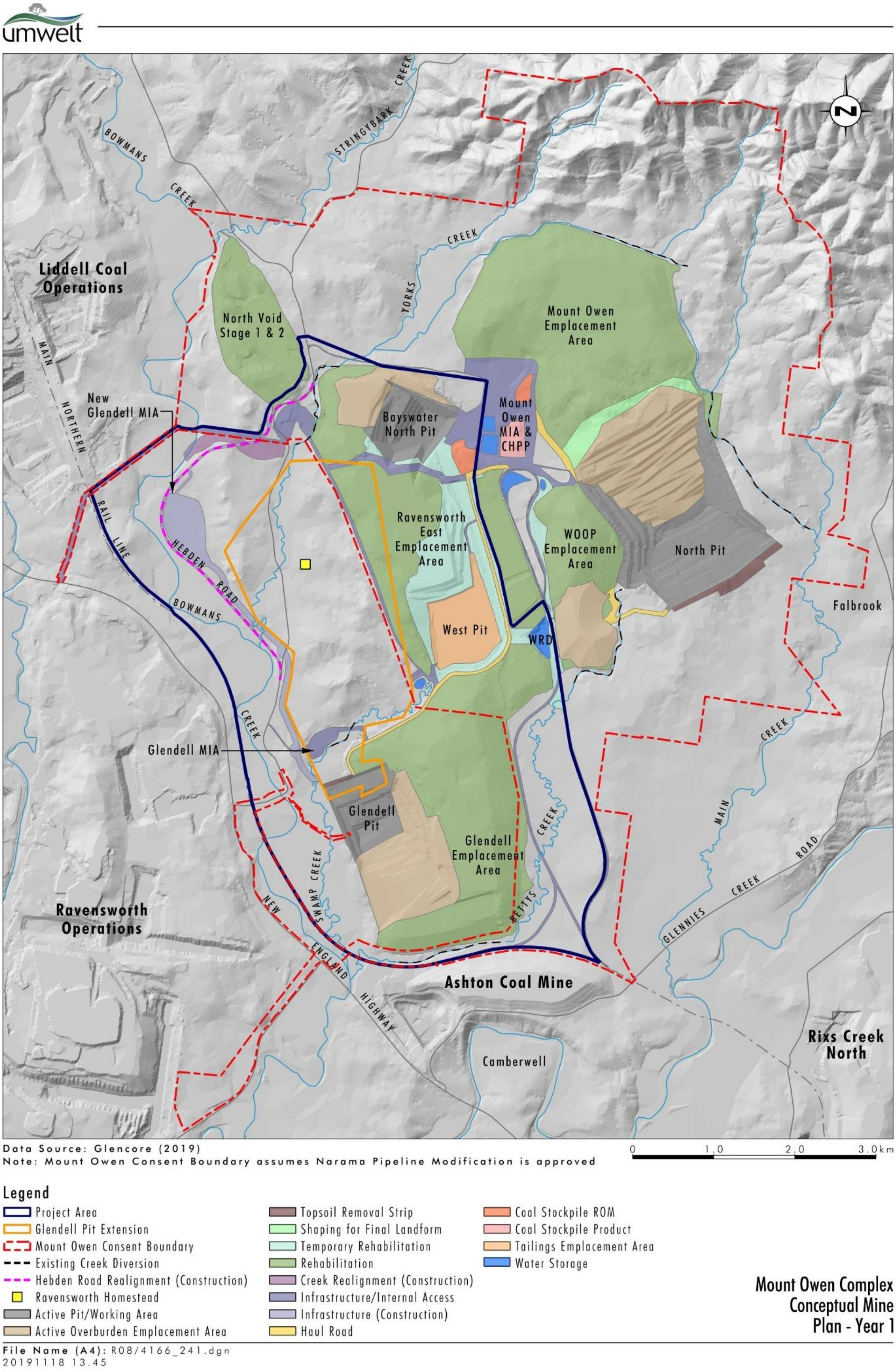

Figure 6 – Conceptual Mine Plan – Year 1 (2021)

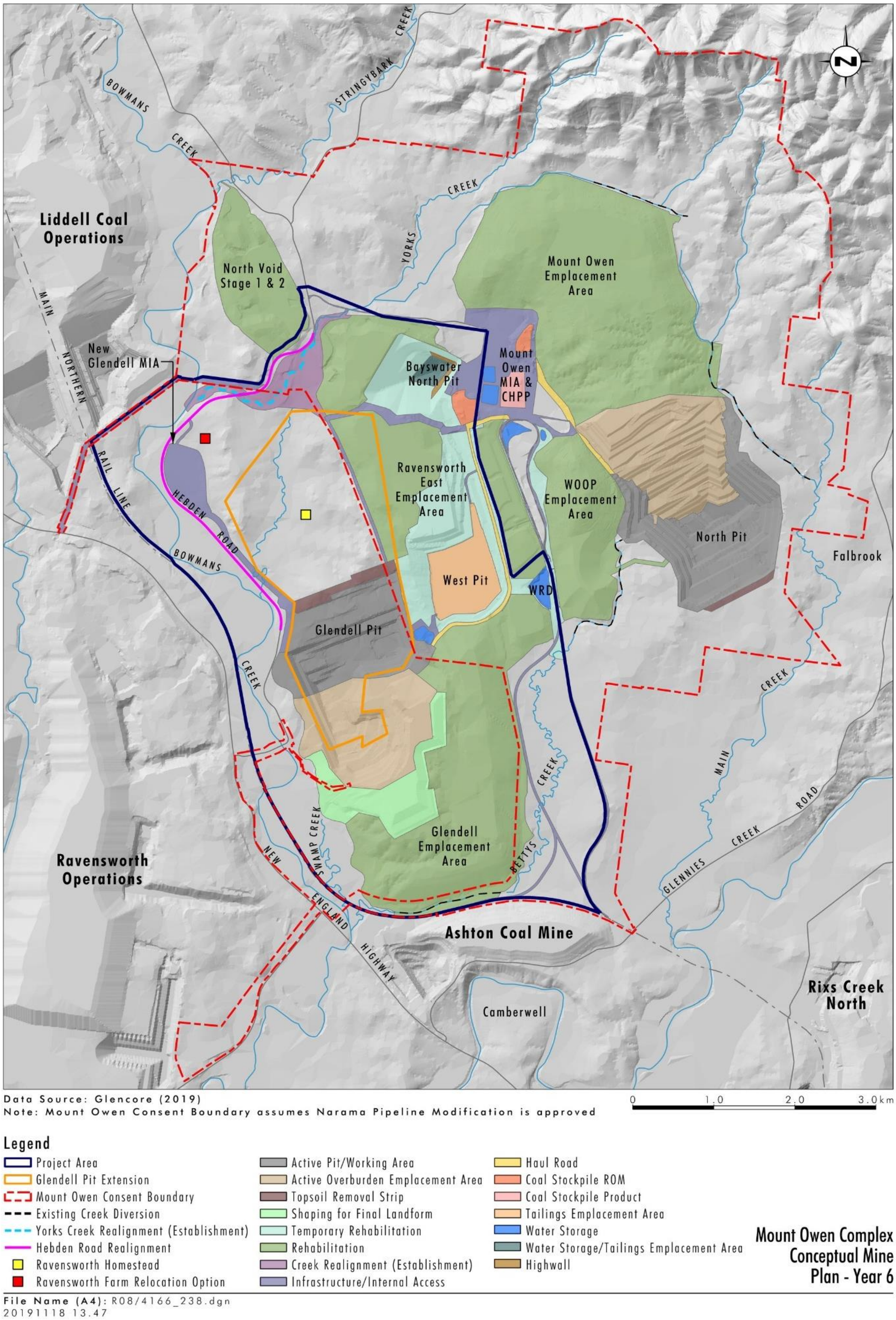

Figure 7 – Conceptual Mine Plan – Year 6 (2026)

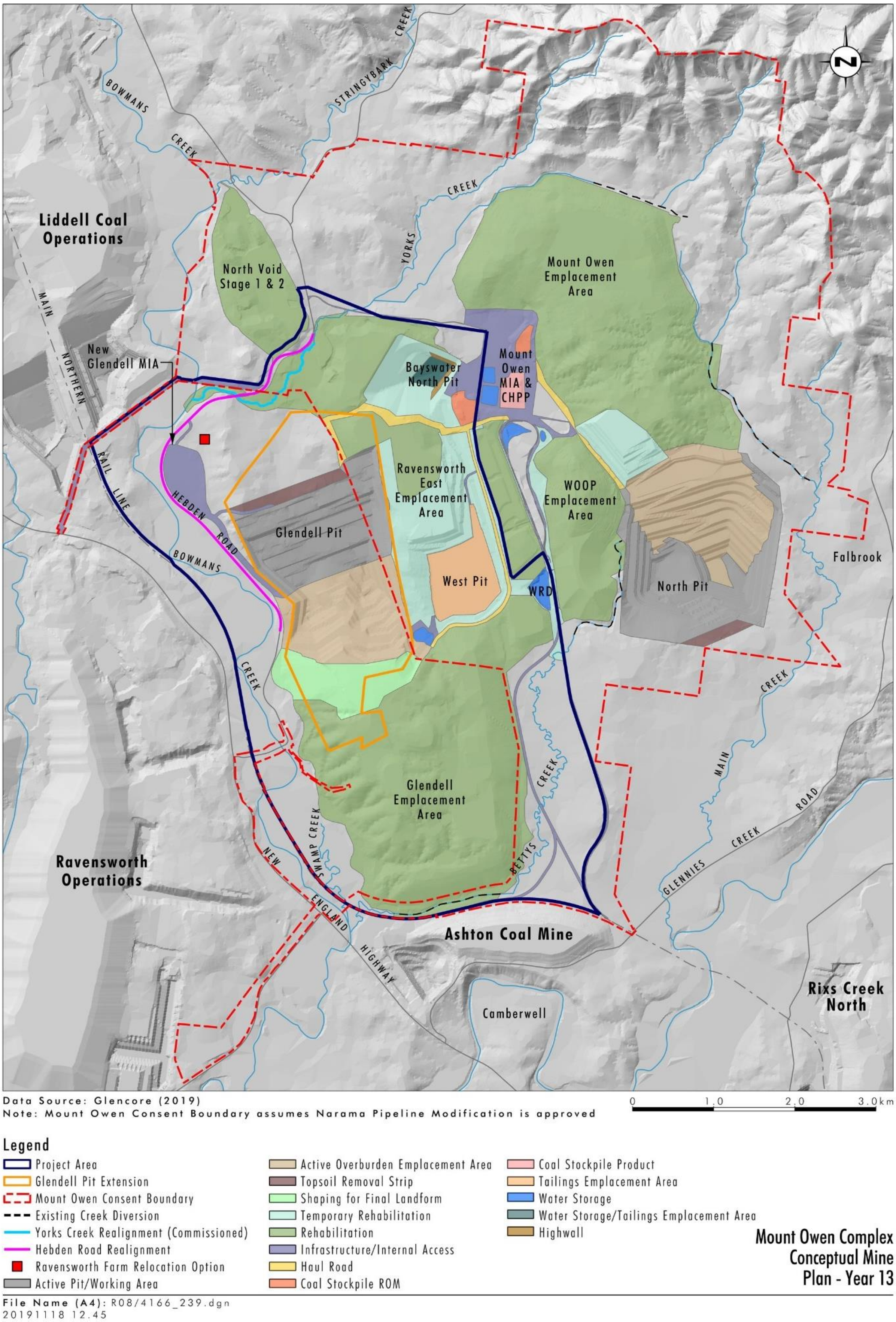

Figure 8 – Conceptual Mine Plan – Year 13 (2033)

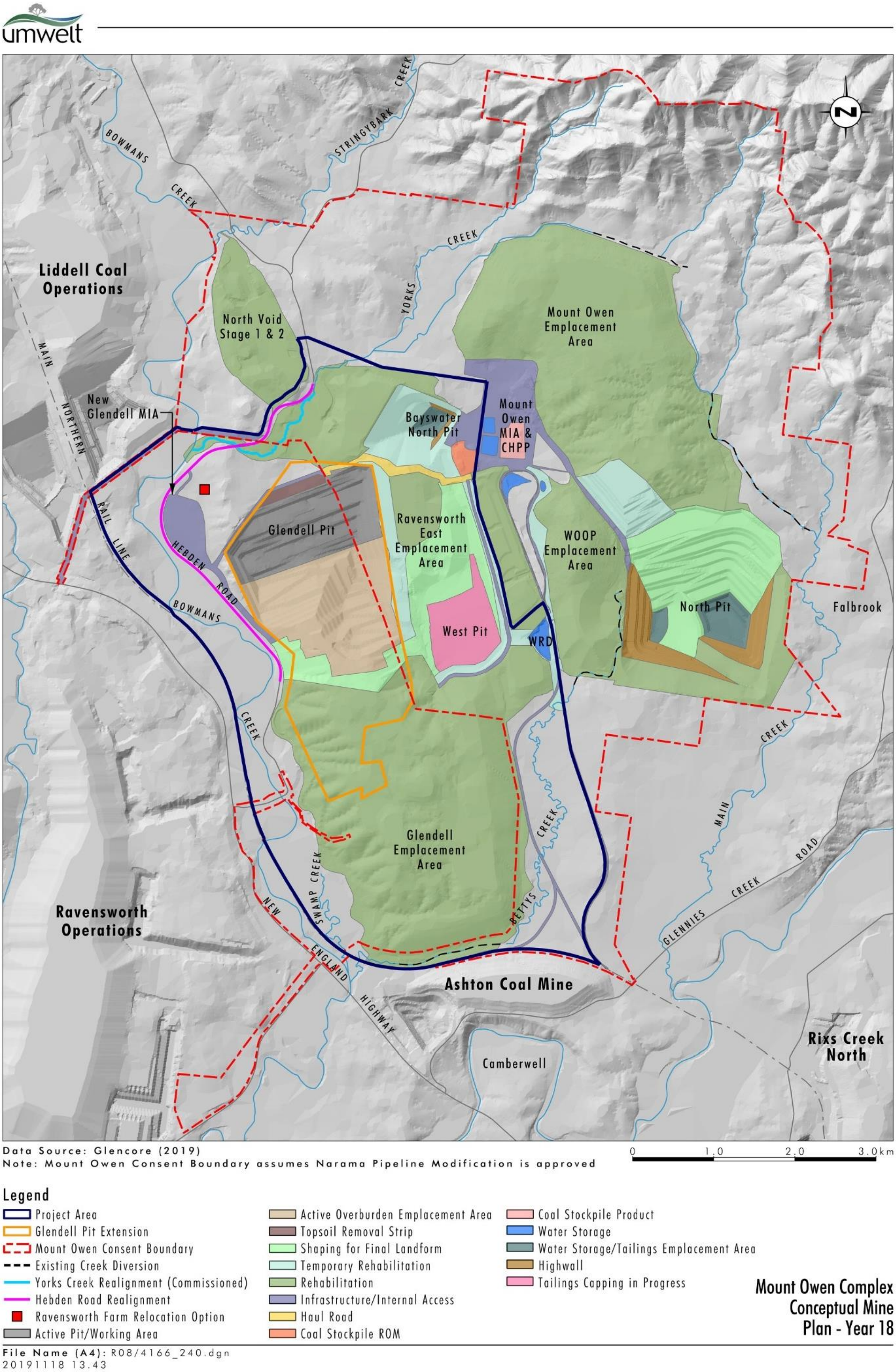

Figure 9 – Conceptual Mine Plan – Year 18 (2038)

3.3 CONCEPTUAL BLAST DESIGN

The coal recovery at Glendell Mine is based on drilling and blasting sequence followed by excavation and rock / coal haulage for further disposal or processing.

The operational sequence commences with an initial blast design followed by a bench survey and bench drilling using a drill rig. A typical bench at Glendell Mine is rectangular in shape with approximately 390 holes and a uniform drilling pattern. The holes are loaded with explosive material and then the top part of the holes is filled in with a gravel like material (i.e. stemming) to ensure that the energy is contained and a low airblast emission is achieved (i.e. lower environmental impact).

Due to the through-seam blasting specific for Glendell Mine conditions, typically the loaded explosives are then initiated using an electronic detonator system which delivers a signal to the primer / booster placed within each hole. The primer / booster then initiates the explosives. As an electronic detonator system is employed, precise timing is achieved which permits single hole initiation, allowing a small and precise delay between each blasted hole. This particular system controls the ground and air vibration impacts to the highest degree (i.e. facilitates lower environmental impact). Following firing of the blast, the blasted and fractured rock strata is then removed using a truck and excavator method for further coal processing in the coal processing plant or direct disposal as waste rock.

As the need arises, other blast design controls are implemented to minimise impacts including limiting charge mass, introduction of deck charges and the use of predictive meteorological monitoring of the surrounding area. The management process is detailed in the approved Blast Management Plan (BMP).

3.4 PROPOSED BLAST DESIGN

The Project will continue with open cut extraction activities utilising the drill and blasting method for coal recovery, the same as currently used at Glendell Mine. Blasting activities are undertaken in accordance with the Glendell Consent, the Environment Protection Licence (EPL) 12840 and the BMP.

The BMP enables the design of each blast to minimise dust, fumes, ground vibrations and airblast overpressure on the surrounding environment, while at the same time allowing to maximise blast efficiency. This approach to blast design has been developed to ensure compliance with the site-specific blasting conditions. This approach to blasting will be carried over for the Project.

Up to eight major coal seams (down to and including the Hebden seam) may be extracted within the Glendell Pit Extension. The extraction depth will vary and will reach up to 120 m in the southern section and up to 280 m below natural ground level in the north-eastern section (i.e. deepest section), as influenced by the presence of the Camberwell anticline.

No significant variations to the operational activities currently employed at Glendell Mine are proposed for the Project. For a typical drill and blast design used at Glendell Mine refer to **Table 2**.

Blasting activities at Glendell Mine employ combinations of products specific for given site conditions. Typically, the blasting products include standard ammonium nitrate fuel oil (ANFO) for dry conditions and emulsion blends for wet conditions, with variable product densities (i.e. 0.8, 1.1, and 1.15 kg/m^3). Similar explosive materials are proposed to be used for the Project.

Based on the geological model for the Glendell Pit Extension (accounting for the presence of the Camberwell anticline and dipping coal seam sections) a through-seam blasting method will be undertaken. The through-seam blasting is designed to maximise efficiency of extraction and minimise coal losses for dipping strata conditions. Typically blasting benches for the Project will utilise a 15 m bench height (plus 1 m sub-drill). The same method employing 15 to 20 m benches has been utilised at Glendell Pit. In addition, geology permitting, conventional blasting methods may also be used in the north-west section of the Glendell Pit Extension with benches up to 30 m. The Maximum Instantaneous Charge (MIC) for these blasts will be in the following approximate order: 544 kg for 15 m benches, 1,236 kg for 30 m benches, and 450 kg for pre-split blasts.

Accounting for the minimum and maximum charge masses for dry and wet conditions, projected charge masses could therefore be in the order of approximately 362 to 1,236 kg.

Table 2: Typical Drill and Blast Design Details used at Glendell Mine

Parameter	Typical Value
Drill Rig Hole Diameter (mm)	229
Number of Holes per Blast	390
Blast Types	Through-seam / Pre-split
Product Type / Density (kg/m^3)	ANFO (0.8) Fortan (1.1) Fortis (1.15)
Initiation System	Electronic
Bench Height (m)	15 – 20 – through-seam 30 – pre-split
Stemming Height (min - max) (m)	(3 - 7) variable
MIC (kg) - Through-seam (15 m bench) - Pre-split (30 m bench)	 362 dry / 544 wet 450 (5 holes simultaneously)

3.5 BLASTING FREQUENCY AND OPERATING CONDITIONS

Blasting will be undertaken on a regular basis for both overburden removal and coal extraction. Blast practices for the Glendell Pit Extension will include:

- up to 2 mining related blasts per day, and
- 8 blasts per week (averaged over a 12-month period).

As with current operations, blasting times will be restricted between the hours of 9 am to 5 pm, Monday to Saturday inclusive. No blasting will be conducted on Sundays or Public Holidays, except where approved by the Secretary.

The exceptions to these conditions are:

- blasts that generate a vibration level of 0.5 mm/s or less at any residence or privately-owned land,
- blast misfires, or
- blasts required to ensure the safety of the mine, its workers or the general public.

Temporary closures of Hebden Road will be required when blasting is within 500 m distance to the nearest point of Hebden Road. No blasts associated with the Project are proposed within 500 m of the New England Highway or Main Northern Rail Line.

Some construction activities (e.g. cuttings associated with the Hebden Road and Yorks Creek Realignment works) may also require some blasting. Construction related blasts will be in addition to the mining related blasts. These blasts will be significantly smaller than those associated with mining operations. Some of these blasts may be within 500 m of Hebden Road however blasting associated with these works is unlikely to be located within 500 m of either the Main Northern Rail Line or the New England Highway.

The timing of road closures on Hebden Road will have regard to key transport times for local residents and local businesses.

Blasting criteria is specified under the Glendell Consent and the Mount Owen Consent. The existing blasting criteria have been used, where possible, to assess blasting impacts of the Project and are outlined in **Table 3** in **Section 4.2**.

4.0 GROUND VIBRATION AND AIRBLAST PREDICTIVE MODELS

4.1 PREDICTIVE MODELS

4.1.1 Ground Vibration Predictive Model

To provide an assessment about the potential vibration levels generated from the Glendell Pit Extension for a given point of interest, a site law formula for the Glendell conditions was developed.

The site law formula recommended by the Australian Standard (AS 2187.2-2006) is accepted by relevant NSW Government agencies as being appropriate for mining blast assessments and has been used in determining the vibration impacts from the Glendell Pit Extension.

The site law formula is specified as follows:

$$PPV = k\left(\frac{D}{\sqrt{m}}\right)^{a}$$

where:	PPV	=	Ground vibration as vector Peak Particle Velocity (mm/s)
	D	=	Distance between charge and point of measurement (m)
	m	=	Maximum Instantaneous Charge (MIC), effective charge mass per delay (kg)
	a	=	Site exponent
	k	=	Site constant

The ground vibration predictive model used in the assessment is based on the model developed for the Glendell Pit, and is based on over two years of data from Glendell's permanent monitoring stations. The vibration monitoring data was collected at several locations from various types of blasts, undertaken within the Glendell Mine and hence is considered fully representative for the Project. The analysed sample of data incorporates data from the monitoring program representing 235 blasts collected from over a two-year period, including October 2015 – December 2017 data. Note that multiple vibration readings were collected for each blast, producing a large sample of results in the order of 1,048 monitoring points.

The data used in the assessment was generated by the monitoring stations strategically distributed in all directions in relation to the Glendell Mine. The collated results were used to develop a site law formula, which is specific for the Glendell conditions, see **Figure 10**, which is generally site-specific for the given strata conditions. The collected monitoring results were plotted using a standard log / log plot.

The parameters governing ground vibration behaviour for the Glendell conditions derived through the site law analysis (corresponding to the 95% confidence level) are specified as follows:

- site exponent a = -1.6
- site constant k = 1,780

The formula used for modelling purposes is therefore:

$$PPV = 1{,}780\left(\frac{\boldsymbol{D}}{\sqrt{\boldsymbol{m}}}\right)^{\mathbf{-1.6}}$$

Where:	PPV	=	Ground Vibration as vector Peak Particle Velocity (mm/s)
	D	=	Distance between charge and point of measurement (m)
	m	=	Maximum Instantaneous Charge (MIC), effective charge Mass per delay (kg)

The 95% confidence level, advocated by the Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines (1990), allows for an inherent variation in emission levels. This is by allowing for a 5% exceedance of the general blast criterion.

Also, for completeness, the site law diagram includes a median level, that is, Peak Particle Velocity (PPV) 50% level. The parameters summarising the site law analysis for a 50% level are specified as follows:

- site exponent $a = -1.6$
- site constant $k = 635$

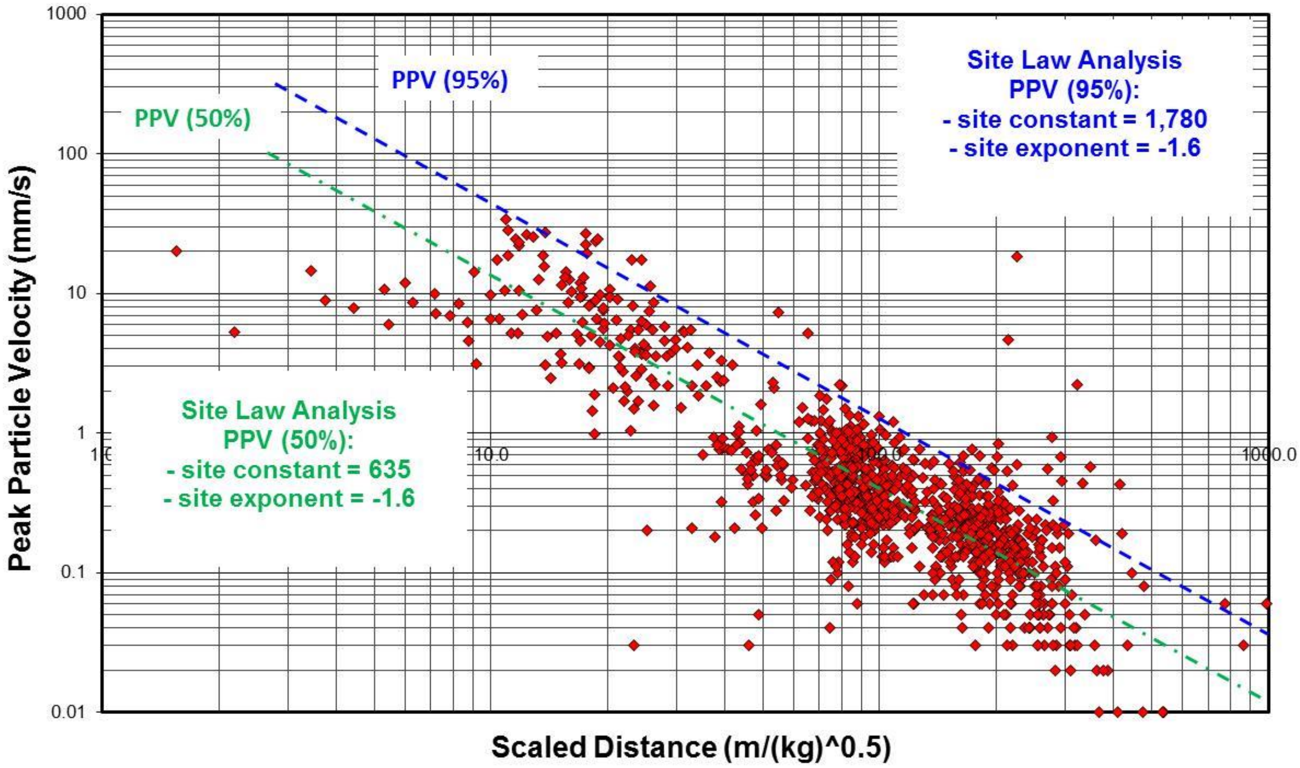

Figure 10 – Site Law Analysis for Glendell Mine Conditions

4.1.2 Airblast Overpressure Predictive Model

To address the airblast overpressure (or air vibration) impacts from the Project on the surrounding environment, including private residential receivers, infrastructure and historical / heritage sites, an airblast predictive model has been developed.

For that purpose, actual monitoring data has been used from Glendell blasts. The analysed sample of data is in excess of 235 blasts collected over a two-year period by permanent monitoring stations undertaken in the October 2015 – December 2017 period. Multiple airblast overpressure readings from a number of different monitoring stations were collected for each blast. This resulted in a large monitoring sample, being in the order of 813 monitoring points which are considered as being fully representative for Glendell's blasting conditions.

Impact of the generated airblast overpressure levels from the source of the blast is generally guided by the sonic decay law as recommended in the Australian Standard (AS 2187.2-2006). For the airblast overpressure impact assessment, the cube-root scaled distance is more appropriate than the square root used for ground vibration as detailed in the Australian Standard (AS 2187.2-2006).

The sonic decay formula is specified as follows:

$$P = k\left(\frac{D}{\sqrt[3]{m}}\right)^{a}$$

Where:	P	=	Peak Pressure (kPa)
	D	=	Distance between charge and point of measurement (m)
	m	=	Maximum Instantaneous Charge (MIC), effective charge Mass per delay (kg)
	a	=	Site exponent
	k	=	Site constant

The airblast overpressure monitoring results were plotted and together with other parameters gave rise to the airblast overpressure predictive model shown in **Figure 11.** The presented sonic decay law analysis features two lines corresponding to the median of the measured data set marked as Sound Pressure Level (SPL) 50% and SPL 95% corresponding to 95% of the total population of the data. Note that the 95% criterion is adopted in accordance with the ANZECC guidelines (1990), which allow for an inherent variation in emission levels, by allowing a 5% exceedance of the general blast criterion.

To facilitate the accuracy of the assessment, the forced exponent of -1.45 has been used, which corresponds to an attenuation rate of 8.6 dBL with a doubling of distance, as specified in the Australian Standard (AS 2187.2-2006).

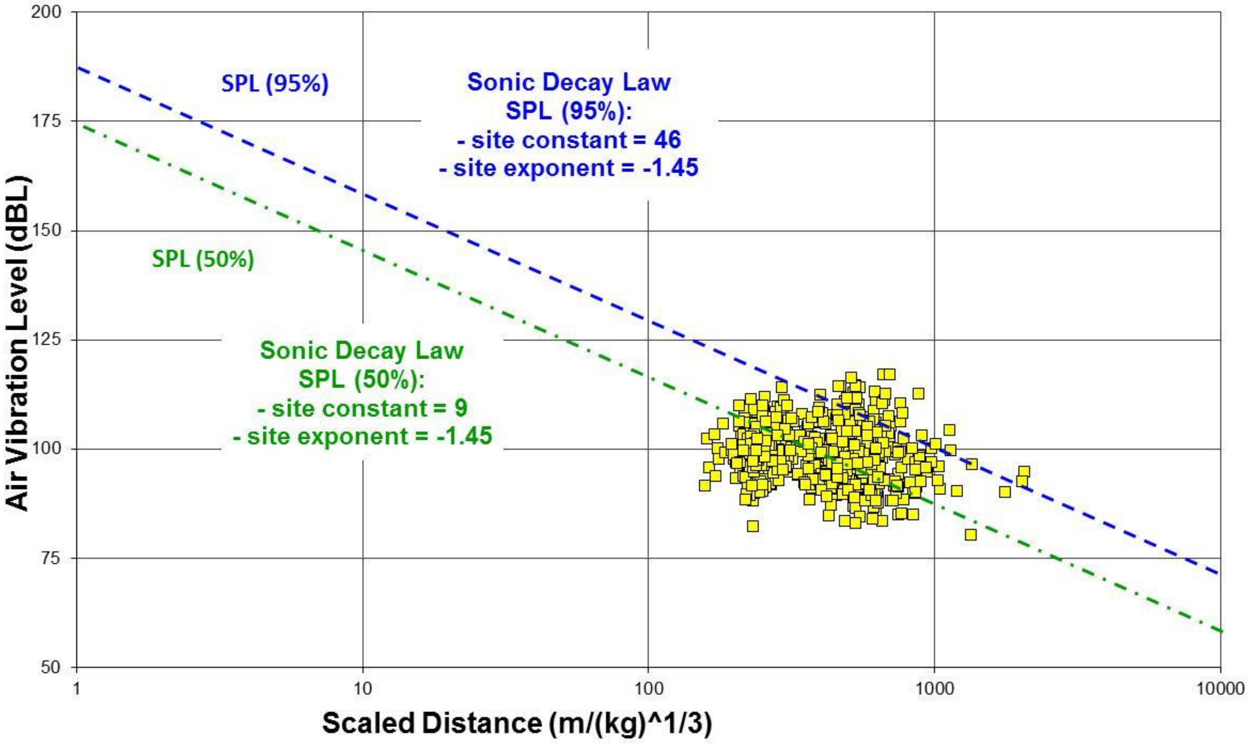

Figure 11 – Sonic Decay Law for Glendell Mine Conditions

Therefore, based on the above assessment, the estimated sonic decay parameters (using the 95% confidence level), used in the presented BIA, are as follows:

- site exponent a = -1.45
- site constant k = 46

The formula used for modelling purposes is therefore:

$$P = 46 \left(\frac{D}{\sqrt[3]{m}} \right)^{-1.45}$$

Where:	P	=	Peak Pressure (kPa)
	D	=	Distance between charge and point of measurement (m)
	m	=	Maximum Instantaneous Charge (MIC), effective charge Mass per delay (kg)

For completeness, the parameters summarising the site law analysis for a 50% level are specified as follows:

- site exponent a = -1.45
- site constant k = 9

4.2 BLAST EMISSION CRITERIA

4.2.1 Criteria for Private Residential Receivers

Blast Emission Criteria for Human Comfort

To minimise the impact on residential receivers, the Department of Planning, Industry and Environment adopts the ANZECC (1990) guidelines. The guidelines indicate the following:

- The general criterion for ground vibration is 5 mm/s, Peak Particle Velocity (PPV);
- The PPV of 5 mm/s may be exceeded on up to 5% of the total number of blasts over a period of 12 months. The upper PPV level of 10 mm/s should not be exceeded at any time;
- The general airblast overpressure criterion is 115 decibel linear (dBL);
- The level of 115 dBL may be exceeded on up to 5% of the total number of blasts over a period of 12 months. The airblast level should not exceed 120 dBL at any time.

The same criteria are specified in the Glendell Consent. Therefore, the impacts of the Project have been assessed against these criteria. The criteria are summarised in **Table 3**. The locations of privately-owned residences in the vicinity of the Project are presented in **Figure 12**.

4.2.2 Criteria for Heritage and Historical Sites

The current ground vibration and airblast overpressure emission criteria for the identified heritage and historical sites are presented below. These are also summarised in **Table 3**. The locations of these sites are presented in **Figure 13**.

St Clements Anglican Church, Camberwell

The church is of local heritage significance under the Singleton Local Environmental Plan (LEP) 2013. The church was deconsecrated in 2013 and is not currently in use. The applicable vibration limit criteria are specified in the Glendell Consent. These are specified as follows:

- The PPV of 2 mm/s may be exceeded on up to 5% of the total number of blasts over a period of 12 months.
- The upper PPV level of 5 mm/s should not be exceeded at any time.

These limits are used as the assessment criteria for the Project.

There are no airblast overpressure criteria for St Clements Anglican Church under the Glendell Consent.

The airblast overpressure criteria, as specified in the Mount Owen Consent are as follows:

- 115 dBL may be exceeded on up to 5% of the total number of blasts over a period of 12 months.
- The upper level of 120 dBL should not be exceeded at any time.

Ravensworth Homestead

The Ravensworth Homestead is of local heritage significance under the Singleton LEP 2013 however it is noted that the heritage assessment undertaken for the Project (Lucas Stapleton Johnson 2019) has identified that the Homestead forms part of a broader heritage precinct that has State heritage significance.

The Ravensworth Homestead is located within the boundary of the Glendell Pit Extension.

The Homestead will be removed as part of the Project and its relocation is proposed as a mitigation measure. Two relocation sites have been proposed, a local move to a site in proximity of the new Mine Infrastructure Area (MIA) (Ravensworth Farm option) and a site in the Broke township (Broke Village option). This BIA only assesses blast impacts on the Ravensworth Homestead in its current position and the Ravensworth Farm site option.

The relocation works will involve substantial upgrades to the foundation of the building and other minor stabilisation works to the buildings, some of which will be installed prior to the building relocation.

There are no blasting criteria for the Ravensworth Homestead under the Glendell Consent. The applicable limits for the Ravensworth Homestead in its current position are specified in the Mount Owen Consent and have been used as the assessment criteria in the BIA:

- 5 mm/s - for ground vibration; and
- 126 dBL - for airblast overpressure.

Vibration limits for the Ravensworth Homestead are expected to increase post relocation. This is due to the significant improvements to the building foundation as it will be relocated onto an engineered raft slab system (or similar) as well as an incremental increase in structural resilience of the walls due to the pre-move stabilisation works.

Once the relocation works have been completed, a staged testing program will be carried out to confirm the new vibration limit. The staged approach will enable adaptive management to blasting in the vicinity of the Homestead and inform both at-receptor mitigation measures (additional structural stabilisation measures) and/or at-source management measures (blast design control) if required. This program will be carried out with continual monitoring of vibration and air blast levels and corresponding structural behaviour of the buildings. Until any new limits have been confirmed, the current Mount Owen Consent criteria will continue to apply to the Homestead in its relocated position.

Chain of Ponds Inn

Chain of Ponds Inn is of State heritage significance under the NSW State Heritage Register (1999). There are no blasting criteria for the Chain of Ponds Inn under the Glendell Consent. The applicable limits specified in the Mount Owen Consent are:

- 10 mm/s - for ground vibration; and
- 133 dBL - for airblast overpressure.

These limits are used as the assessment criteria for the Project.

Community Hall in Camberwell

The structure is of local heritage significance under the Singleton LEP 2013. The building is a disused community hall which is in a derelict state. The property is owned by Ashton Coal. There are no blasting criteria for the Camberwell Hall under the Glendell Consent. The Ashton South East Open Cut (SEOC) blast assessment defined the following criteria for the hall:

- 10 mm/s - for ground vibration; and
- 133 dBL - for airblast overpressure.

These limits are used as the assessment criteria for the Project.

Ravensworth Public School

The former school is of local heritage significance under the Singleton LEP 2013. The former school was severely damaged due to arson in May 2019. There are no blasting criteria for the Ravensworth Homestead under the Glendell Consent. The applicable limits based on Australian Standard (AS 2187.2-2006) are:

- 25 mm/s - for ground vibration (applicable to occupied non-sensitive sites); and
- 133 dBL - for airblast overpressure – recommended airblast limit for damage control – this limit is recommended as a safe level that will prevent structural / architectural damage from blasting.

These limits are used as the assessment criteria for the Project.

Hebden Public School and John Winter Memorial Site

The former school and memorial site are non-listed historical sites. There are no blasting criteria for these sites under the Glendell Consent. The applicable vibration limits specified in the Mount Owen Consent are as follows:

- 16 mm/s for ground vibration for the former Hebden Public School; and
- 250 mm/s for John Winter Memorial.

The assessment of the site conditions and the applicable vibration limit criteria for the former Hebden Public School and John Winter Memorial were addressed in detail in a previous ESC assessment (ESC 2014).

These vibration limits are used as the assessment criteria for the Project.

Camberwell Glennies Creek Underbridge

The Camberwell Glennies Creek underbridge is a non-listed historical structure. The bridge is classed under the 'all other public infrastructure' category. There are no blasting criteria for the Camberwell Glennies Creek Underbridge under the Glendell Consent. The recommended vibration limit specified in the Mount Owen Consent is:

- 50 mm/s - for ground vibration

This vibration limit is used as the assessment criteria for the Project.

Aboriginal Engraving Site Bowmans Creek 16

Bowmans Creek 16 (37-3-0772) is an Aboriginal engraving site of high archaeological significance (Aboriginal Sites Register of NSW). It is located to the west of the Glendell Pit Extension. The site of the engraving has been assessed for vibration tolerances (ESC 2019a). The applicable vibration limit based on this study is:

- 50 mm/s - for ground vibration

This vibration limit is used as the assessment criteria for the Project.

4.2.3 Criteria for Infrastructure

The current ground vibration criteria for the identified infrastructure and adjacent mines are presented below. Generally, infrastructure items are not assessed in terms of airblast exposure as levels required to inflict damage are not applicable and/or not reached however, where relevant, the criteria used for the assessment of potential impacts on private infrastructure is discussed below. The criteria are summarised in **Table 3**. The locations of these items are presented in **Figures 14 - 17**.

Electricity Transmission Lines and Associated Infrastructure

Within and surrounding the Project Area there are a number of electricity transmission lines ranging from 11 kV up to 330 kV.

The 330 kV powerlines and transmission pylons located in proximity to the Project are managed by TransGrid who is the operator of the high voltage electricity transmission network in NSW.

The 132 kV and lower voltage (66 kV, 33 kV and 11 kV) powerlines, electricity transmission towers/poles and associated infrastructure located in proximity to the Project are operated by Ausgrid, NSW electricity grid operator. The Project will necessitate the relocation of the 11 kV powerlines that run parallel to Hebden Road as they are currently located within the boundary of the proposed Glendell Pit Extension. The 11 kV powerlines will be reinstated in the new services easement that will extend along the relocated Hebden

Road. A small section of 33 kV powerlines in the north of the Project Area will also need to be relocated due to the new alignment of Hebden Road.

The vibration limit specified in the Glendell Consent is:

- 50 mm/s - for ground vibration

This vibration limit is used as the assessment criteria for the Project.

The associated infrastructure in proximity to the Project includes an electrical substation and a pole mounted substation. The same criteria apply for poles with and without substations.

Prescribed Dams

There are five prescribed dams in the vicinity of the Project – four already existing and one proposed.

The vibration limit applicable to Tailings Pit 1 (TP1) (Mount Owen Rail Loop Tailings Dams Notification Area) is 50 mm/s, as imposed by the NSW Dam Safety Committee (Annexure “D” Standard Mining Conditions, 2011).

The same vibration limit of 50 mm/s is applicable to North Void Tailings Dam (i.e. including two dam walls) (Mount Owen North, Mount Owen and Ravensworth East Notification Areas), as imposed by the NSW Dam Safety Committee.

The Ravensworth Void 4 East Tailings Dam (Saddle Dam) and Ravensworth Void 5 (Ash Dam) have no imposed vibration limits. They will be assessed against the 50 mm/s limit applicable to the other dams.

The Ashton Coal proposed prescribed dam (Clean Water Dam 1), is yet to be constructed. For the purpose of this assessment, the criteria outlined above has also been adopted for Clean Water Dam 1.

A 50 mm/s vibration limit is to be used as the assessment criteria for the Project for all prescribed dams.

Railway Lines - Main Northern Railway, Culverts, Bridges and Associated Infrastructure

The applicable vibration limit specified in the Glendell Consent is:

- 25 mm/s - for ground vibration*

This vibration limit is used as the assessment criteria for the Project.

***Note:** There is a private agreement in place, which allows for blasting within 0.5 km of infrastructure owned, leased or controlled by ARTC at Camberwell; vibrations may exceed 25 mm/s for the Main Northern Railway culverts and bridges, providing Clause 5 conditions of the “ARTC Blasting Deed (2013)” have been satisfied.

Public Roads and Bridges

The Project will necessitate the realignment of a section of Hebden Road as it is located within the boundary of the Glendell Pit Extension. The relocated road will include a new bridge over the realigned Yorks Creek.

There are no blasting criteria for public roads under the Glendell Consent. The recommended vibration limit for public roads is specified in the Mount Owen Consent. The same limit for public roads and concrete bridges was presented in ACARP Report No. C14057. The recommendations in regards to vibration exposures for concrete bridges are also provided in the Australian Standard AS 2187.2-2006 (i.e. for unoccupied structures of reinforced concrete or steel construction). Vibration levels for roadways / concrete bridges are specified as follows:

- Public roads – 100 mm/s
- Concrete bridges – 100 mm/s

These vibration limits are used as the assessment criteria for the Project.

Telecommunication Infrastructure

A Telstra telecommunication tower is located within the Glendell Pit Extension boundary. As indicated, the tower will be relocated to a new location north of the Project Area. There are no blasting criteria for this infrastructure under the Glendell Consent. The applicable vibration limit for the repeater tower (based on Australian Standard AS 2187.2-2006) is:

- 100 mm/s - for ground vibration (applicable to unoccupied structures of reinforced concrete or steel construction)

Buried Telstra communication cables are located along Hebden Road. Part of these communication cables will be reinstated in the new services easement that will extend along the relocated Hebden Road. A comprehensive overview of the existing allowable vibration limits for various infrastructure (including buried communication cables and pipelines) is presented in ACARP Report No. C14057. The recommendations in regards to vibration exposures for buried cables and pipelines are specified as follows:

- Buried communication cables and pipelines – 100 mm/s

These vibration limits are used as the assessment criteria for the Project.

Private Infrastructure

The site office of Daracon Mining Pty Limited was identified as private infrastructure located in proximity of the Project.

The site office represents industrial type buildings and sheds. The applicable vibration limits for these items are based on Australian Standard (AS 2187.2-2006) and are:

- 25 mm/s - for ground vibration (applicable to occupied non-sensitive sites); and

- 133 dBL - for airblast overpressure – recommended airblast limit for damage control – this limit is recommended as a safe level that will prevent structural / architectural damage from blasting.

These limits are used as the assessment criteria for the Project.

Mine Infrastructure – Non-Glencore Owned

The closest non-Glencore owned mining operation is Ashton Coal Mine. There is a range of infrastructure including offices, processing plants, workshops, rail and loading facilities and other.

Guidelines in regards to vibration limits for mine infrastructure are provided in Australian Standard AS 2187.2-2006 “Explosives - Storage and Use - Part 2: Use of Explosives”. The relevant vibration limits include:

- 25 mm/s for occupied non-sensitive sites, such as factories and commercial premises
- 100 mm/s for unoccupied structures of reinforced concrete or steel construction
- 133 dBL - recommended airblast overpressure limit for damage control; this limit is recommended as a safe level that will prevent structural / architectural damage from blasting

These limits are used as the assessment criteria for the Project.

Mine Infrastructure – Glencore Owned

There is a range of Glencore owned surface infrastructure associated with Glendell, Ravensworth East, Mount Owen, Liddell Coal Operations and Integra Underground in operation within the vicinity of the Project. The blast impact assessment for all these infrastructure items will be managed internally and is not included in this assessment.

The Project will coincide with the operations at the Integra Underground. These interactions will be managed internally according to the vibration limits as specified in the approved BMP and relevant technical reports. The recommended vibration limits specified in the Mount Owen Consent for the Integra Underground infrastructure are as follows:

- 10 mm/s – used as a “safety and personnel withdrawal limit for occupied underground workings”
- 250 mm/s – used as a “structural limit for unoccupied underground workings”

Other relevant vibration criteria for Integra Underground are:

- 225 mm/s – ground vibration limit applicable to ventilation shaft 4 (ESC 2018)
- 250 mm/s - ground vibration criteria applicable to Middle Liddell seam dewatering borehole (ESC 2019c)
- 100 mm/s – ground vibration criteria applicable to gas bores and pipelines based on recommendations presented in ACARP Report No. C14057

These vibration limits are used as the assessment criteria for the Project.

4.2.4 Criteria for Natural Features

The proposed ground vibration emission criteria for the identified natural features are presented below. These are also summarised in **Table 3**. The locations of these features are presented in **Figure 19**.

Bowmans Creek and Associated Alluvium

Bowmans Creek and its associated alluvium are located to the west of the Glendell Pit Extension. At the closest point, the western highwall of the Glendell Pit Extension will be approximately 200 m from the top of high bank of Bowmans Creek. This area has been assessed for potential risks of strata fracturing from blasting (ESC 2019b). The applicable vibration limit based on this study is:

- 100 mm/s **-** for ground vibration, for the banks of Bowmans Creek

This vibration limit is used as the assessment criteria for the Project.

Generally, natural features are not assessed in terms of airblast overpressure exposure as levels required to inflict damage are not applicable and/or not reached.

Yorks Creek Realignment

Yorks Creek is located within the boundary of the Glendell Pit Extension. As part of the Project, it is proposed to realign a section of the existing creek. This realignment will include a deep cutting with the channel designed to provide a more natural bank profile of varying grades. The final bank profile will be designed based on detailed geotechnical investigation and will consider blasting impacts. The realignment outside of the cutting will also incorporate design elements to make it generally representative of natural streams; as such it is proposed to use the same vibration limit recommended for Bowmans Creek for the assessment of the Yorks Creek Realignment:

- 100 mm/s **-** for ground vibration, for the Yorks Creek Realignment

This vibration limit is used as the assessment criteria for the Project.

4.2.5 Summary of assessment criteria used in BIA

A summary of all criteria used in this assessment is presented in **Table 3.**

Table 3: Summary of Blast Emission Criteria used in the Assessment

Receiver	Peak Particle Velocity (mm/s)	Allowable Exceedance of Peak Particle Velocity	Airblast Overpressure (dBL)	Allowable Exceedance of Airblast Overpressure
Residence on privately-owned land[1, 3]	5	5% of the total number of blasts over a 12- month period	115	5% of the total number of blasts over a 12- month period
	10	0%	120	0%
Heritage and Historical Sites				
St Clements Anglican Church, Camberwell[1]	2	5% of the total number of blasts over a 12- month period	n/a	
	5	0%	n/a	
Ravensworth Homestead (Current Site)[2, 4]	5	0%	126	0%
Chain of Ponds Inn[2]	10	0%	133	0%
Community Hall in Camberwell[5]	10	0%	133	0%
Ravensworth Public School[6]	25	0%	133	0%
Hebden Public School[2]	16	0%	n/a	
John Winter Memorial[2]	250	0%	n/a	
Camberwell Glennies Creek Underbridge[6]	50	0%	n/a	
Bowmans Creek 16 Engraving	50	0%	n/a	
Infrastructure				
Electricity Transmission Towers and Associated Infrastructure[1]	50	0%	n/a	
Prescribed Dams[1]	50	0%	n/a	
Main Northern Railway (including Culverts, Bridges and Associated	25 [7]	0%	n/a	

Receiver	Peak Particle Velocity (mm/s)	Allowable Exceedance of Peak Particle Velocity	Airblast Overpressure (dBL)	Allowable Exceedance of Airblast Overpressure
Infrastructure)[1]				
Public Roads[2] and Concrete Bridges	100	0%	n/a	
Telstra Tower	100	0%	n/a	
Buried (Telstra) Cables	100	0%	n/a	
Industrial Type Buildings and Sheds - Occupied	25	0%	133	0%
Integra Underground: – Underground Workings[2]	10 or 250[8]	0%	n/a	
Non-Glencore Surface Mine Infrastructure - occupied	25	0%	133	0%
Non-Glencore Surface Mine Infrastructure - unoccupied	100	0%	133	0%
All other public infrastructure[2]	50	0%	n/a	
Bowmans Creek[9]	100	0%	n/a	
Yorks Creek Realignment	100	0%	n/a	

1 *– Item listed under Glendell Consent*

2 *– Item listed under Mount Owen Consent*

3 *– Items consistent with ANZECC (1990) guidelines*

4 *– Structure to be relocated and assessed by a specialist consultant to establish new – applicable criteria*

5 *– Item assessed in Ashton South East Open Cut blast assessment*

6 *– Item referenced in Mount Owen Consent; under no applicable compliance limit*

7 *– Private Agreement - Blasting within 0.5 km of infrastructure owned, leased or controlled by ARTC at Camberwell may exceed 25 mm/s for the Main Northern Railway culverts and bridges, providing Clause 5 conditions of the "ARTC Blasting Deed (2013)" have been satisfied*

8 *– 10 mm/s safety and personnel withdrawal limit for occupied underground workings and 250 mm/s structural limit for unoccupied workings*

9 *– Refer to ESC (2019b) for definition of this criterion*

5.0 BLAST IMPACT ASSESSMENT

The assessment undertaken included six different simulations, incorporating proposed production and pre-split blasts and various blasting products, to be used for the Project. The simulations performed involved charge masses ranging from 362 to 1,236 kg, representative of the range of MICs to be used during the life of the Project (according to the proposed bench heights). The results of the modelling are summarised in tables which also include minimum distances between the receivers and the Glendell Pit Extension. Where relevant the distances were calculated to both 15 and 30 m bench blasting areas.

The modelling accounts for the worst-case scenario, i.e. blasting from the edge of the Glendell Pit Extension, which corresponds to the minimum distance between the blasting area and the receivers. In other words, the table highlights the maximum vibrations that could be generated during the life of the Project. Receivers that are located further from the proposed Glendell Pit Extension than those identified below, where an equal or less stringent criteria applies, are assumed to comply with the relevant criteria and have been excluded from the assessment.

A separate vibration assessment has been undertaken for construction type blasting (see **Section 6**) to account for blast vibration generated when blasting during the construction of the Yorks Creeks realignment and cuttings associated with the Hebden Road realignment.

5.1 PRIVATE RESIDENTIAL RECEIVERS

The section presented below addresses the potential blast impacts associated with the Project on the surrounding area, specifically the private residential receivers. The aim is to identify the potential impacts including ground vibration and airblast exposure as well as flyrock, which could be generated when undertaking blasting within the Glendell Pit Extension. The estimated ground and air vibration exposure levels are discussed in the context of applicable limits detailed in **Section 4**. The impacts of fumes / odour on the surrounding environment are addressed in the Air Quality Impact Assessment (Jacobs 2019). Potential visual impacts associated with blasting are assessed in the main text of the EIS.

5.1.1 Location of Private Residential Receivers

The locations of the adjacent private residential receivers located within 5 km of the Glendell Pit Extension are shown in **Figure 12.** The residences shown in **Figure 12** are all privately-owned (i.e. it excludes mine owned residences); all of these residences considered are subject to acquisition rights under existing consents. Residences in the Hebden area to the north of the Project are considered to be too distant from the operations for vibration impacts to be exceeded, particularly given the restrictions on blast design required to meet other criteria associated with features located between the areas of blasting and these residences. Impacts at residences in the Hebden area are considered to experience only low to negligible blasting impacts (i.e. generally beyond human perception level).

The main points of note regarding the distribution of the privately-owned residences are as follows:

- From an environmental perspective, the Project is favourably located away from private residential receivers. The closest private residences are located to the south-east of the Project Area; they represent the Camberwell locality and are in excess of 3.5 km distance and will increase in distance over the life of the Project as the mine progresses north, away from Camberwell. The closest private residential receiver (ID 156) is located at a distance of 3.58 km away from the Glendell Pit Extension.
- Residential receivers located to the east in the vicinity of Middle Falbrook area generally are located in excess of 5 km from the Glendell Pit Extension and are therefore considered to experience low to negligible blasting impacts (i.e. generally beyond human perception level).

Figure 12 – Locations of Privately-owned Residences in the Vicinity of the Project

5.1.2 Assessment Results

5.1.2.1 Ground Vibration

The potential impact of ground vibrations from the Glendell Pit Extension on private residential receivers was assessed in detail using ground vibration modelling. The modelling utilised the site law formula developed for Glendell conditions as explained in **Section 4.1.1**.

The ground vibration modelling provides ground vibration estimates for private residential receivers located within approximately 5 km radius of the Glendell Pit Extension, see **Figure 12**. The impact of blasting on residences located beyond the 5 km radius is considered negligible (i.e. beyond a human perception level).

Table 4 shows the distances for each potentially affected private residential receiver within a 5 km radius and the estimated vibration using proposed charge masses.

The modelling presents the worst-case scenario (i.e. blasting from the edge of the Glendell Pit Extension), which corresponds to the minimum distance (between the blasting area and residential receivers) and highlights the maximum vibrations that could be generated during the Project.

Table 4: Results of Ground Vibration Modelling for Privately-owned Residences (all already subject to acquisition rights) – Maximum Vibration Estimates

<table>
<tr><th rowspan="4">Residential ID</th><th rowspan="4">Minimum Distance (m)</th><th colspan="5">Estimated Maximum Ground Vibration (mm/s) (229 mm hole diameter)
MIC (kg)</th><th rowspan="4">Applicable Vibration Criteria</th></tr>
<tr><th colspan="2">15 m bench (4 m stemming)</th><th colspan="2">30 m bench(1) (5 m stemming)</th><th>Presplit (5-hole)</th></tr>
<tr><th>ANFO</th><th>Heavy ANFO</th><th>ANFO</th><th>Heavy ANFO</th><th>ANFO</th></tr>
<tr><th>362</th><th>544</th><th>824</th><th>1,236</th><th>450</th></tr>
<tr><td rowspan="2">127a</td><td>4,920</td><td>0.2</td><td>0.3</td><td>n/a</td><td>n/a</td><td>0.3</td><td rowspan="11">5 mm/s
(for a minimum of 95% blasts)

10 mm/s
(not to be exceeded)</td></tr>
<tr><td>6,850(2)</td><td>0.1</td><td>0.2</td><td>0.3</td><td>0.4</td><td>0.2</td></tr>
<tr><td rowspan="2">127b</td><td>4,630</td><td>0.3</td><td>0.4</td><td>n/a</td><td>n/a</td><td>0.3</td></tr>
<tr><td>6,480(2)</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.4</td><td>0.2</td></tr>
<tr><td rowspan="2">127c</td><td>3,760</td><td>0.4</td><td>0.5</td><td>n/a</td><td>n/a</td><td>0.4</td></tr>
<tr><td>5,670(2)</td><td>0.2</td><td>0.3</td><td>0.4</td><td>0.5</td><td>0.2</td></tr>
<tr><td rowspan="2">127d</td><td>4,010</td><td>0.3</td><td>0.5</td><td>n/a</td><td>n/a</td><td>0.4</td></tr>
<tr><td>5,900(2)</td><td>0.2</td><td>0.3</td><td>0.4</td><td>0.5</td><td>0.2</td></tr>
<tr><td rowspan="2">143</td><td>4,060</td><td>0.3</td><td>0.5</td><td>n/a</td><td>n/a</td><td>0.4</td></tr>
<tr><td>6,000(2)</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.5</td><td>0.2</td></tr>
<tr><td>150</td><td>3,920</td><td>0.4</td><td>0.5</td><td>n/a</td><td>n/a</td><td>0.4</td></tr>
</table>

Residential ID	Minimum Distance (m)	Estimated Maximum Ground Vibration (mm/s) (229 mm hole diameter) MIC (kg) 15 m bench (4 m stemming) ANFO 362	Heavy ANFO 544	30 m bench(1) (5 m stemming) ANFO 824	Heavy ANFO 1,236	Presplit (5-hole) ANFO 450	Applicable Vibration Criteria
	5,900(2)	0.2	0.3	0.4	0.5	0.2	
152	3,900	0.4	0.5	n/a	n/a	0.4	
	5,880(2)	0.2	0.3	0.4	0.5	0.2	
154	3,820	0.4	0.5	n/a	n/a	0.4	
	5,790(2)	0.2	0.3	0.4	0.5	0.2	
155	3,770	0.4	0.5	n/a	n/a	0.4	
	5,730(2)	0.2	0.3	0.4	0.5	0.2	
156	3,580	0.4	0.6	n/a	n/a	0.5	
	5,530(2)	0.2	0.3	0.4	0.5	0.2	

1 – 30 m bench applicable to north-west section of the Glendell Pit Extension where conventional blasting may be employed (see Figure 5)

2 – minimum distance from the area where conventional blasting may be employed, that is north-west section of the proposed Glendell Pit Extension (see Figure 5)

n/a – not applicable

The estimated vibration exposure for all assessed private residential receivers using the proposed charge masses of 362 to 1,236 kg is in the order of 0.2 to 0.6 mm/s. This is well below the applicable vibration criteria of 5 mm/s (for 95% of blasts) and 10 mm/s (not to be exceeded). No exceedances of the vibration assessment criteria at private residential receivers are therefore expected as a result of blasting undertaken for the Project.

5.1.2.2 Airblast Overpressure

To perform the airblast overpressure modelling, the sonic decay formula specified in **Section 4.1.2** was utilised. The modelling provides estimations for airblast overpressure levels using the same variable charge masses as used for the ground vibration analysis.

Table 5 presents detailed estimations of potential airblast overpressure exposure for the private residential receivers located within a 5 km radius of the Glendell Pit Extension.

The modelling accounts for the worst-case scenario, i.e. blasting from the edge of the Glendell Pit Extension. The table therefore highlights the maximum airblast overpressure levels that could be generated during the Project.

Table 5: Results of Airblast Modelling for Privately-owned Residences (all already subject to acquisition rights) – Maximum Airblast Estimates

Residential ID	Minimum Distance (m)	Estimated Maximum Airblast Overpressure (dBL) (229 mm hole diameter)					Applicable Over-pressure Criteria
		MIC (kg)					
		15 m bench (4 m stemming)		30 m bench[1] (5 m stemming)		Presplit (5-hole)	
		ANFO 362	Heavy ANFO 544	ANFO 824	Heavy ANFO 1,236	ANFO 450	
127a	4,920	105	107	n/a	n/a	106	115 dBL (for a minimum of 95% blasts) 120 dBL (not to be exceeded)
	6,850[2]	101	102	104	106	102	
127b	4,630	106	107	n/a	n/a	107	
	6,480[2]	101	103	105	107	102	
127c	3,760	108	110	n/a	n/a	109	
	5,670[2]	103	105	107	108	104	
127d	4,010	107	109	n/a	n/a	108	
	5,900[2]	103	104	106	108	104	
143	4,060	107	109	n/a	n/a	108	
	6,000[2]	102	104	106	108	103	
150	3,920	108	109	n/a	n/a	109	
	5,900[2]	103	104	106	108	104	
152	3,900	108	110	n/a	n/a	109	
	5,880[2]	103	104	106	108	104	
154	3,820	108	110	n/a	n/a	109	
	5,790[2]	103	105	106	108	104	
155	3,770	108	110	n/a	n/a	109	
	5,730[2]	103	105	106	108	104	
156	3,580	109	111	n/a	n/a	110	
	5,530[2]	103	105	107	109	104	

1 – 30 m bench applicable to north-west section of the Glendell Pit Extension where conventional blasting may be employed (see Figure 5)

2 – minimum distance from the area where conventional blasting may be employed, that is north-west section of the proposed Glendell Pit Extension (see Figure 5)

n/a – not applicable

The estimated airblast overpressure exposure for all assessed private residential receivers using the proposed charge masses of 362 to 1,236 kg is in the order of 101 to 111 dBL. This is below the applicable vibration criteria of 115 dBL (for 95% of blasts) and 120 dBL (not to be exceeded). No exceedances of the assessment overpressure criteria at private residential receivers are therefore expected as a result of blasting undertaken for the Project.

5.1.2.3 Flyrock and Other Issues

To manage flyrock, the Project will operate using an appropriate exclusion zone (i.e. 0.5 km radius from the blasting area). This distance is considered appropriate for managing the risk of flyrock as it is used widely across the mining industry.

The closest private residence (i.e. ID 156) is located approximately 3.58 km from the Glendell Pit Extension. Therefore, the potential risks of flyrock on the surrounding private residential receivers are negligible.

5.2 HERITAGE AND HISTORICAL SITES

The analysis presented below is an assessment of ground vibration (and where relevant airblast) exposures from the Project on the adjacent historical / heritage sites. The analysis is based on vibration modelling using the applicable vibration predictive models, see **Section 4.1**. The vibration modelling estimates have been assessed, including references to relevant vibration limit criteria.

5.2.1 Location of Historical Sites

The assessed sites include all identified sites located within approximately 5 km radius of the Glendell Pit Extension. Refer to **Figure 13** for the location of the assessed items.

The historical / heritage sites covered in this report include the following:

- Bowmans Creek 16 Aboriginal engraving site,
- Ravensworth Homestead (current and proposed Ravensworth Farm site),
- Ravensworth Public School,
- St Clements Anglican Church, Camberwell,
- Community Hall, Camberwell,
- Camberwell Glennies Creek Underbridge,
- Chain of Ponds Inn,
- Hebden Public School and John Winter Memorial Site.

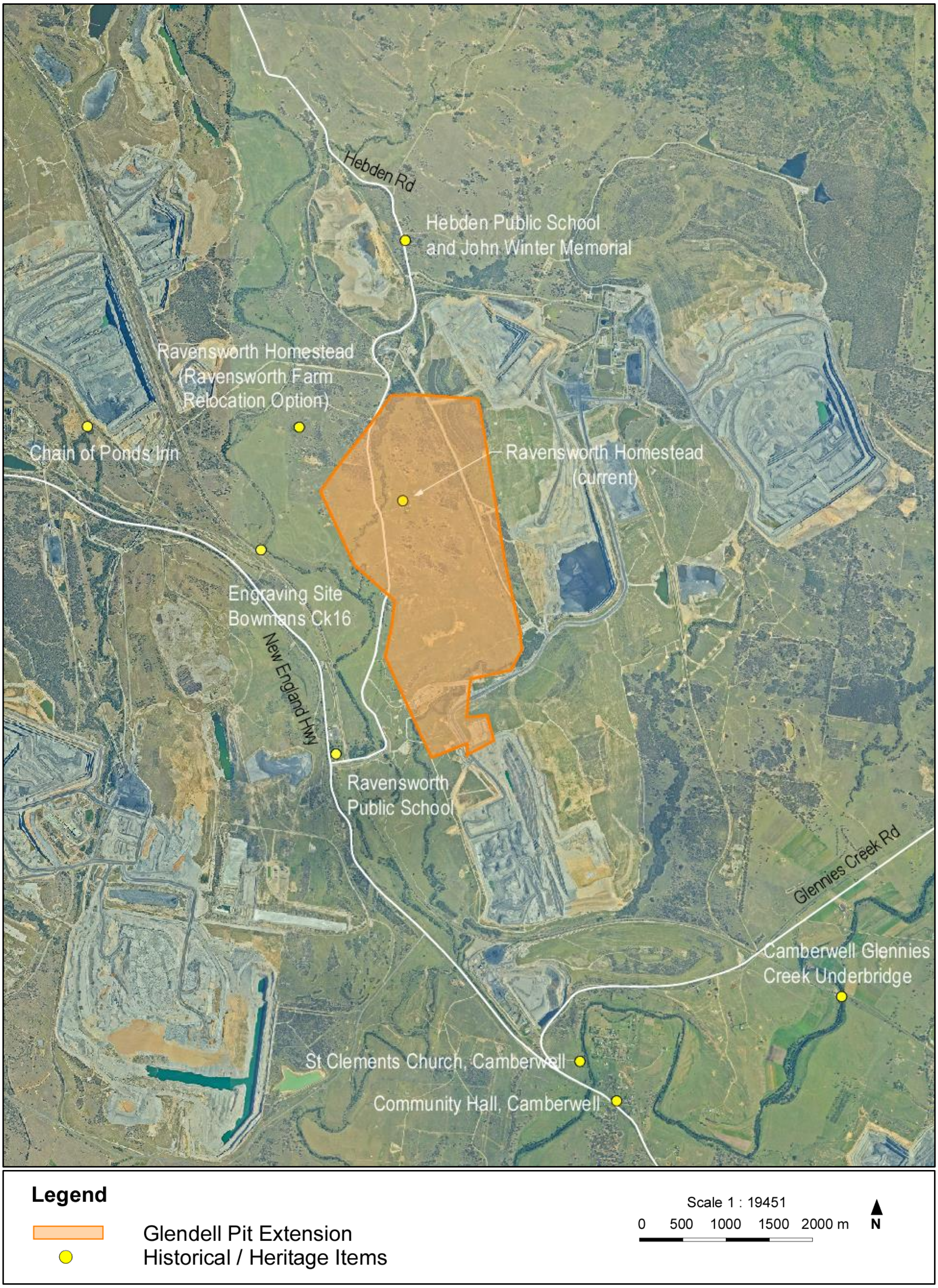

Figure 13 – Locations of Historical / Heritage Sites in the Vicinity of the Project

5.2.2 Assessment Results

5.2.2.1 Ground Vibration

The vibration modelling undertaken in this section has been performed according to the formula specified in **Section 4.1.1**. It should be noted that the assessment takes a conservative approach assuming all blasts will be unconstrained, however in practice this will not occur, as the need arises, other blast design controls are implemented to minimise impacts. The results of the modelling are summarised in **Table 6**.

Table 6: Results of Ground Vibration Modelling for Heritage/Historical Sites – Maximum Vibration Estimates

Heritage / Historical Site	**Min. Distance (m)**	**Estimated Maximum Ground Vibration (mm/s)**						**Applicable Vibration Criteria (mm/s)**
		MIC (kg)						
		7 m bench (3.5 m)	**15 m bench** (4 m stemming)		**30 m bench(1)** (5 m stemming)		**Presplit** (5-hole)	
		ANFO 115	**ANFO 362**	**Heavy ANFO 544**	**ANFO 824**	**Heavy ANFO 1,236**	**ANFO 450**	
Ravensworth Homestead (Current Site)	1,100(3)	1.1	2.7	3.7	n/a	n/a	3.2	5
Ravensworth Homestead (Proposed Ravensworth Farm Site)	630(2)	2.6	6.6	9.1	13	18	7.8	To be assessed when relocated (4)
Ravensworth Public School	980 2,070(2)	1.3 0.4	3.2 1.0	4.5 1.4	n/a 1.9	n/a 2.6	3.9 1.2	25
St Clements Church, Camberwell	3,770 5,750(2)	0.2 0.1	0.4 0.2	0.5 0.3	n/a 0.4	n/a 0.5	0.4 0.2	2 and 5
Community Hall, Camberwell	4,330 6,310(2)	0.1 0.1	0.3 0.2	0.4 0.2	n/a 0.3	n/a 0.4	0.4 0.2	10
Camberwell Glennies Creek Underbridge	4,990 6,720(2)	0.1 0.1	0.2 0.1	0.3 0.2	n/a 0.3	n/a 0.4	0.3 0.2	50
Chain of Ponds Inn	2,790	0.2	0.6	0.8	1.2	1.6	0.7	10
Hebden Public School	1,780	0.5	1.2	1.7	2.4	3.3	1.5	16
John Winter Memorial, Hebden	1,780	0.5	1.2	1.7	2.4	3.3	1.5	250
Bowmans Ck 16 Aboriginal Engraving Site	900	1.5	3.7	5.2	7.2	9.9	4.4	50

1 – 30 m bench applicable to north-west section of the Glendell Pit Extension where conventional blasting may be employed (see Figure 5)

2 – minimum distance from the area where conventional blasting may be employed, that is north-west section of the proposed Glendell Pit Extension (see Figure 5)

3 – approximate minimum distance in Year 5 (approximately 2025) according to the proposed mining progression

4 – ground vibration criteria to be determined subject to further specialist assessment accounting for foundation upgrades and other stabilisation works to the buildings

n/a – not applicable

The ground vibration impact assessment for heritage and historical sites can be summarised as follows:

- The Ravensworth Homestead is positioned within the boundary of the Glendell Pit Extension. The vibration modelling indicates that to limit constraints on blasting, relocation of the Ravensworth Homestead is required by the end of Year 5 (approximately 2025) according to the proposed mining progression; this corresponds to an approximate minimum distance from blasting of 1,100 m. Until approximately Year 5 the Ravensworth Homestead could be exposed to vibrations of up to 3.7 mm/s.
- In the relocated Ravensworth Farm position, at a minimum distance of approximately 630 m from the Glendell Pit Extension, the results of the modelling show that impacts can be managed effectively to remain below the currently imposed vibration limit of 5 mm/s by using lower charge masses which can be achieved either by blasting smaller benches (e.g. 7 m benches) or by the application of deck charges, together with the application of precise initiation timing. As previously discussed, once the relocation works have been completed, a staged testing program will be carried out to confirm the new vibration limit. The staged approach will enable adaptive management to blasting in the vicinity of the Homestead and inform both at-receptor mitigation measures (additional structural stabilisation measures) and/or at-source management measures (blast design control) if required. This program will be carried out with continual monitoring of vibration and airblast overpressure levels and corresponding structural behaviour of the buildings.
- The Bowmans Creek 16 Aboriginal engraving site is located approximately 900 m from the Glendell Pit Extension will be exposed to vibrations no higher than 9.9 mm/s. This is below the vibration criteria of 50 mm/s (ESC 2019a).
- The vibration modelling for all other historical / heritage sites assessed revealed the maximum exposure to be between 0.1 and 4.5 mm/s. All vibration predictions are below the applicable criteria for the considered items.

In summary, the estimated maximum vibration exposures for all assessed historical / heritage items are either below the applicable limits or can be managed effectively (as for Ravensworth Homestead) to remain below the applicable vibration limit by using lower charge masses.

5.2.2.2 Airblast

The results of airblast overpressure modelling are presented in **Table 7**.

Table 7: Results of Airblast Overpressure Modelling for Historical Sites – Maximum Overpressure Estimates

Infrastructure	Min. Distance (m)	Estimated Maximum Airblast Overpressure (dBL) – MIC (kg): 7 m bench (3.5 m) ANFO 115	15 m bench (4 m stemming) ANFO 362	15 m bench (4 m stemming) Heavy ANFO 544	30 m bench(1) (5 m stemming) ANFO 824	30 m bench(1) (5 m stemming) Heavy ANFO 1,236	Presplit (5-hole) ANFO 450	Applicable Over-pressure Limit (dBL)
Ravensworth Homestead (Current Site)	1,100(3)	119	124	125	n/a	n/a	125	126
Ravensworth Homestead (Proposed Ravensworth Farm Site)	630(2)	126	131	132	134	136	132	To be assessed when relocated (4)
Ravensworth Public School	980	120	125	127	n/a	n/a	126	133
	2,070(2)	111	116	118	119	121	117	
St Clements Church, Camberwell	3,770	103	108	110	n/a	n/a	109	n/a
	5,750(2)	98	103	105	106	108	104	
Community Hall, Camberwell	4,330	102	107	108	n/a	n/a	107	133
	6,310(2)	97	102	103	105	107	103	
Camberwell Glennies Creek Underbridge	4,990	100	105	106	n/a	n/a	106	n/a
	6,720(2)	96	101	103	104	106	102	
Chain of Ponds Inn	2,790	107	112	114	115	117	113	133
Hebden Public School	1,780	113	118	119	121	123	119	n/a
John Winter Memorial, Hebden	1,780	113	118	119	121	123	119	n/a
Engraving Site/Bowmans Ck 16	900	121	126	128	130	131	127	n/a

1 – 30 m bench applicable to north-west section of the Glendell Pit Extension where conventional blasting may be employed (see Figure 5)

2 – minimum distance from the area where conventional blasting may be employed, that is north-west section of the proposed Glendell Pit Extension (see Figure 5)

3 – approximate minimum distance in Year 5 (approximately 2025) according to the proposed mining progression

4 – airblast overpressure criteria to be determined subject to further specialist assessment accounting for foundation upgrades and other stabilisation works to the buildings

n/a – not applicable

The estimated maximum airblast overpressure exposures according to the airblast predictive model for listed items are assessed as follows:

- Ravensworth Homestead – in its current location until approximately Year 5 (which corresponds to an approximate minimum distance from blasting of 1,100 m) airblast overpressure will be no higher than 125 dBL, which is below the 126 dBL limit. Ravensworth Homestead – in the proposed Ravensworth Farm site, the airblast limit is to be determined subject to further specialist assessment accounting for new footings, upgrades to the foundation and stabilisation works to the buildings. The airblast overpressure will be managed to below the applicable limit by employing lower charge masses, for example an MIC of 80 kg will generate up to 125 dBL airblast level, which is below the current overpressure criteria.
- Ravensworth Public School – airblast overpressure no higher than 127 dBL, which is below the 133 dBL limit.
- St Clements Anglican Church in Camberwell – airblast overpressure no higher than 110 dBL, which is below the 115 dBL limit (for adjacent private residences).
- Community Hall, Camberwell – airblast overpressure no higher than 108 dBL, which is below the 133 dBL limit.
- Chain of Ponds Inn – airblast overpressure no higher than 117 dBL, which is below the 133 dBL limit.

In summary, the estimated maximum airblast overpressure exposure for all historic / heritage items with imposed overpressure limits are below the imposed airblast emission limits.

5.2.2.3 Flyrock

The proposed Project will operate using an appropriate exclusion zone to manage the risk of flyrock (i.e. 0.5 km exclusion zone as indicated in the BMP). Based on the above assessment, the heritage and historical sites are located in excess of 600 m (including the proposed relocation site for the Ravensworth Homestead) from the Glendell Pit Extension. Therefore, the risk from flyrock is negligible.

5.3 INFRASTRUCTURE

The analysis presented below is an assessment of ground vibration (and where relevant airblast) exposures from the Project on the adjacent infrastructure. The analysis is based on vibration modelling using the applicable vibration predictive models, see **Section 4.1**. The vibration modelling estimates have been assessed, including references to relevant vibration limit criteria.

5.3.1 Location of Infrastructure

The assessed infrastructure sites include items identified within approximately 5 km radius of the Glendell Pit Extension. Refer to **Figures 14 - 17** for the location of the infrastructure.

The infrastructure sites assessed in this report include the following:

- Infrastructure:
  - Ausgrid 132 kV and lower voltage (66 kV, 33 kV and 11 kV) powerlines and pole mounted substation (some subject to realignment)
  - Transgrid 330 kV powerlines
  - Electrical substation
  - Telstra telecommunication infrastructure (telecommunication tower (subject to relocation) and buried telecommunication cable and fibre optics (subject to realignment))
  - Prescribed dams including: North Void Tailings Dam walls 1 and 2, Tailings Pit 1 (TP1), Ravensworth Void 4 East Tailings, Ravensworth Void 5 and Ashton Clean Water Dam 1
  - Main Northern Railway and associated infrastructure
  - Public roads, bridges and overpasses including Hebden Road (subject to realignment)
  - Proposed bridge over the Yorks Creek Realignment on the realigned portion of Hebden Road
- Private infrastructure:
  - Daracon Mining Pty Limited – site office.
- Non-Glencore owned mining infrastructure:
  - Ashton Coal Mine – offices, processing plant and workshops,
- Glencore owned mining infrastructure:
  - Integra Underground workings

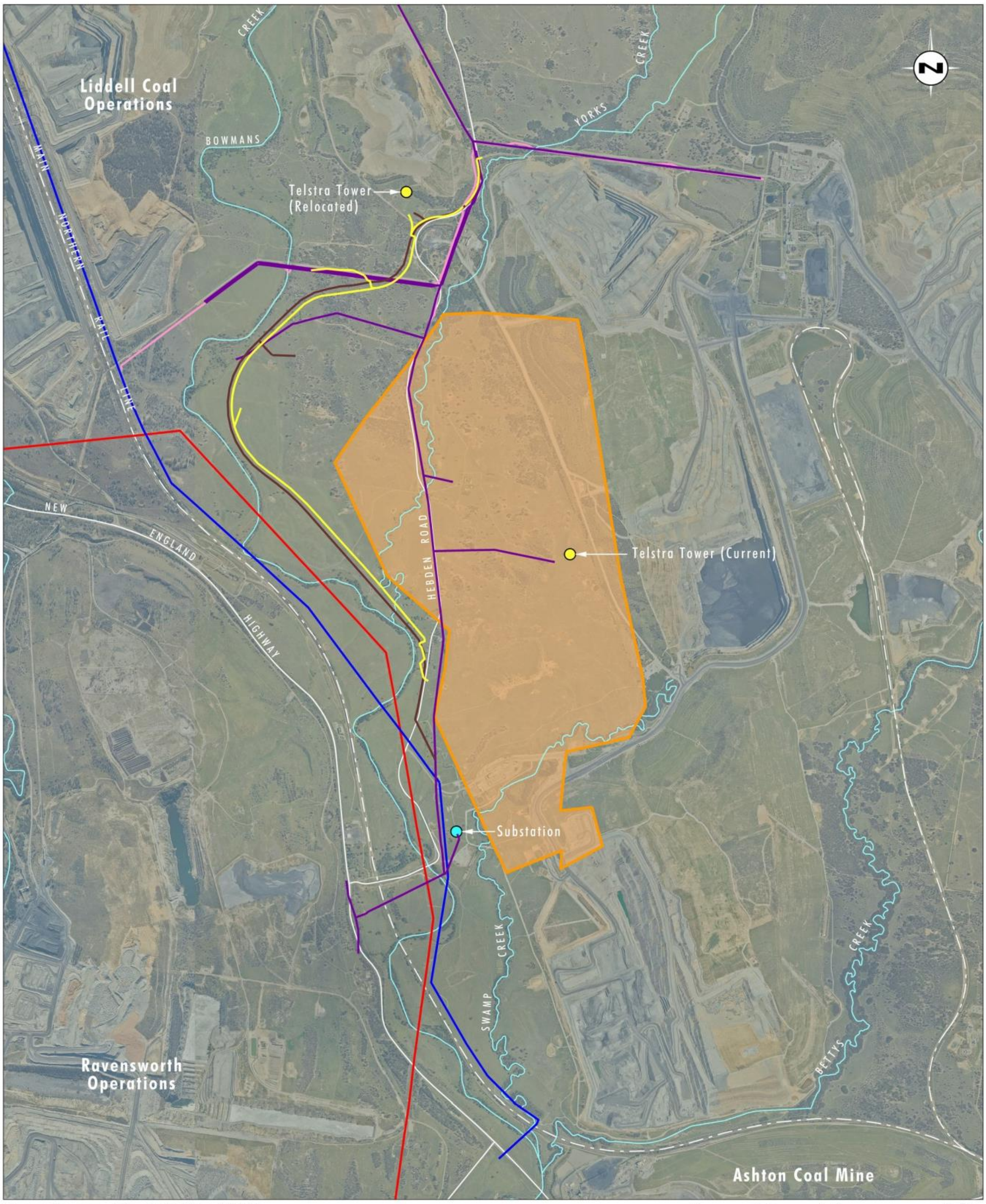

Image Source: Glendell (Dec 2018)
Data Source: Glendell (2019)

0 0.5 1.0 2.0km
1:40 000

Legend

- Glendell Pit Extension
- 330 kV Transgrid Power Line
- 132 kV Ausgrid Power Line
- 11 kV Ausgrid Power Line
- 11 kV Ausgrid Power Line (Relocated)
- Electrical Substation
- Telstra Tower
- Telstra buried Communication Cable
- Telstra buried Communication Cable (Relocated)

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Figure 14 – Locations of Power Supply and Communications Infrastructure in the Vicinity of the Project

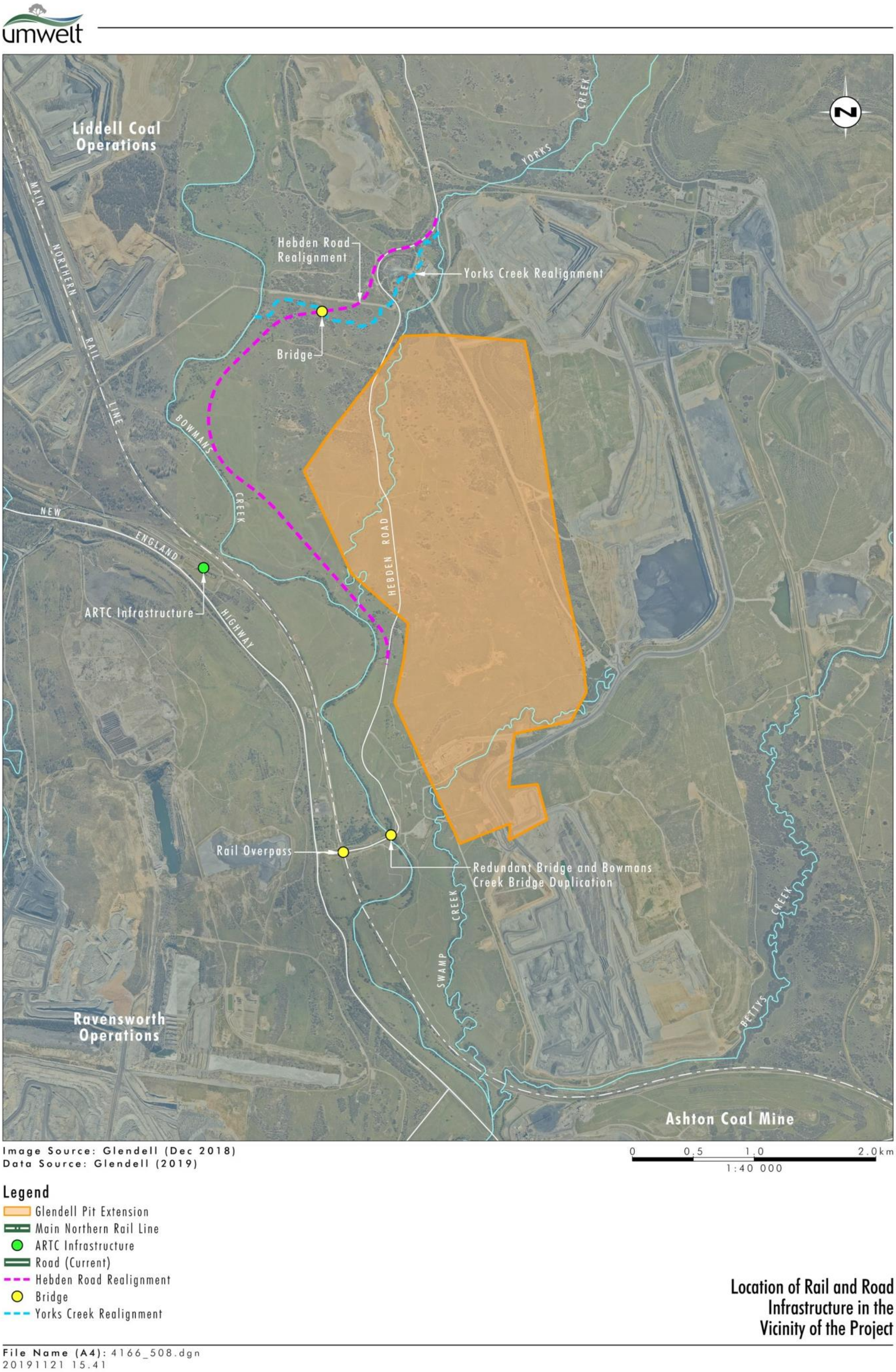

Figure 15 – Location of Rail and Roads Infrastructure in the Vicinity of the Project

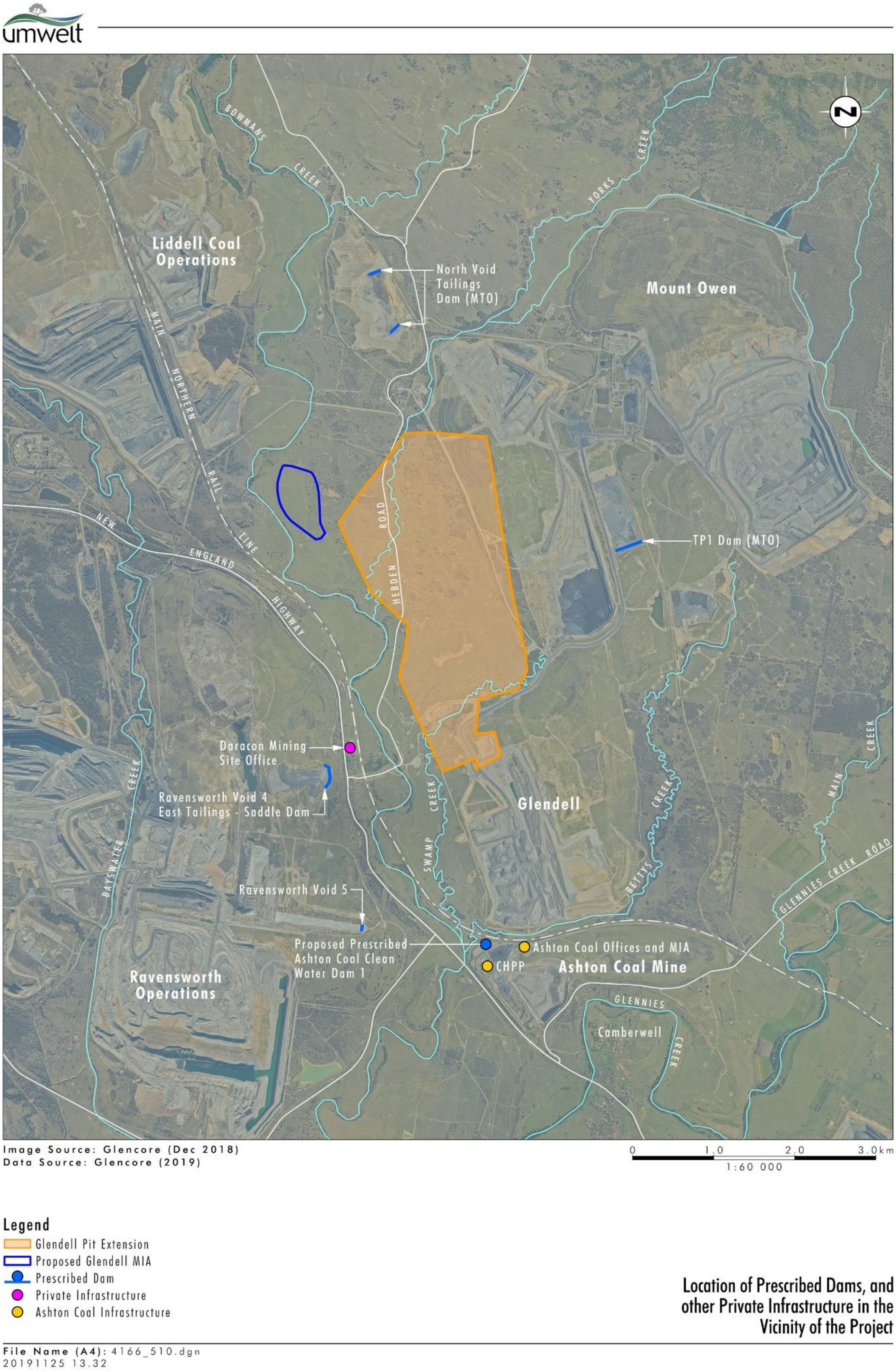

Figure 16 – Location of Prescribed Dams and other Private Infrastructure in the Vicinity of the Project

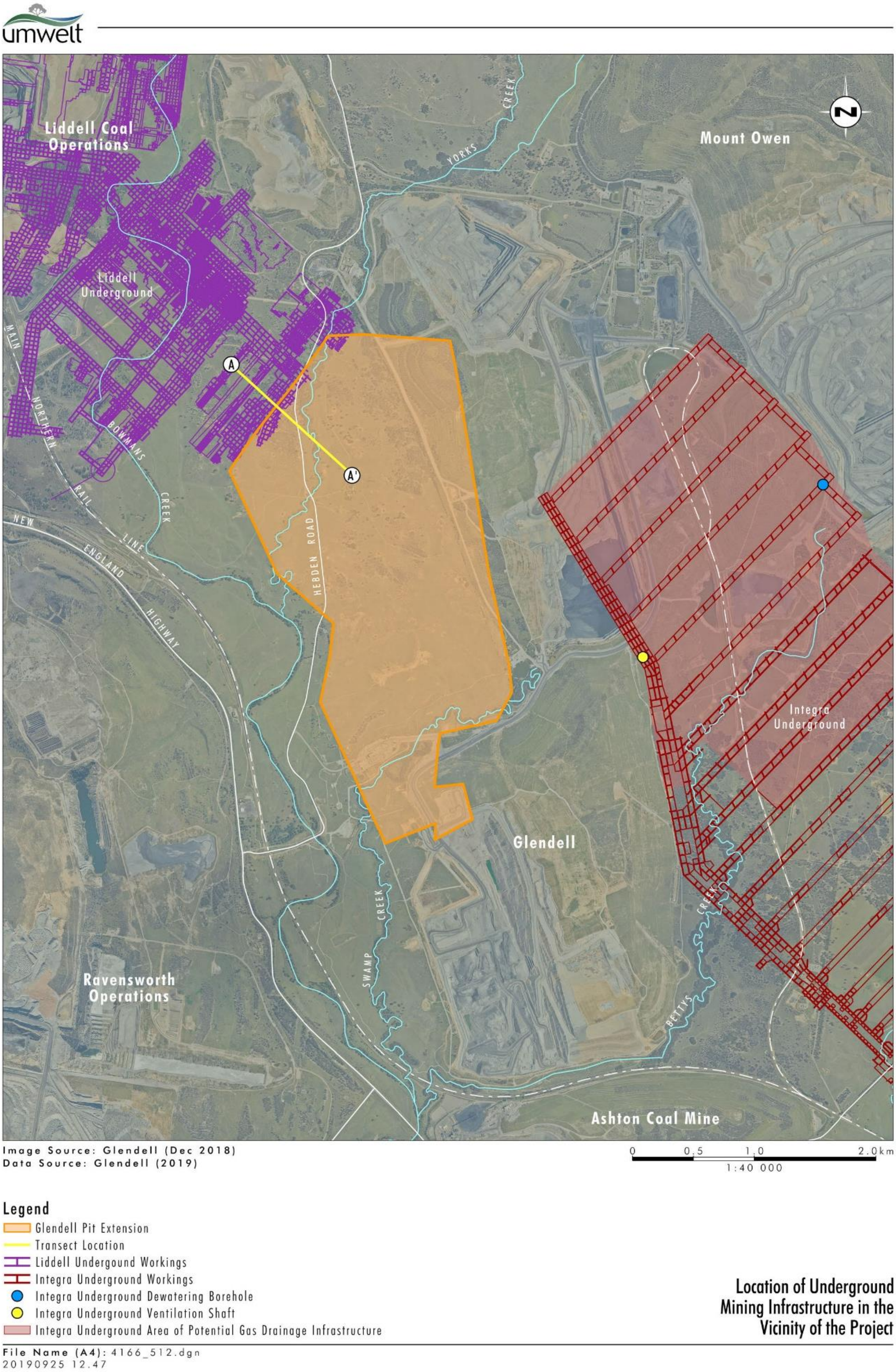

Figure 17 – Location of Integra Underground and former Liddell Underground Workings in the Vicinity of the Project

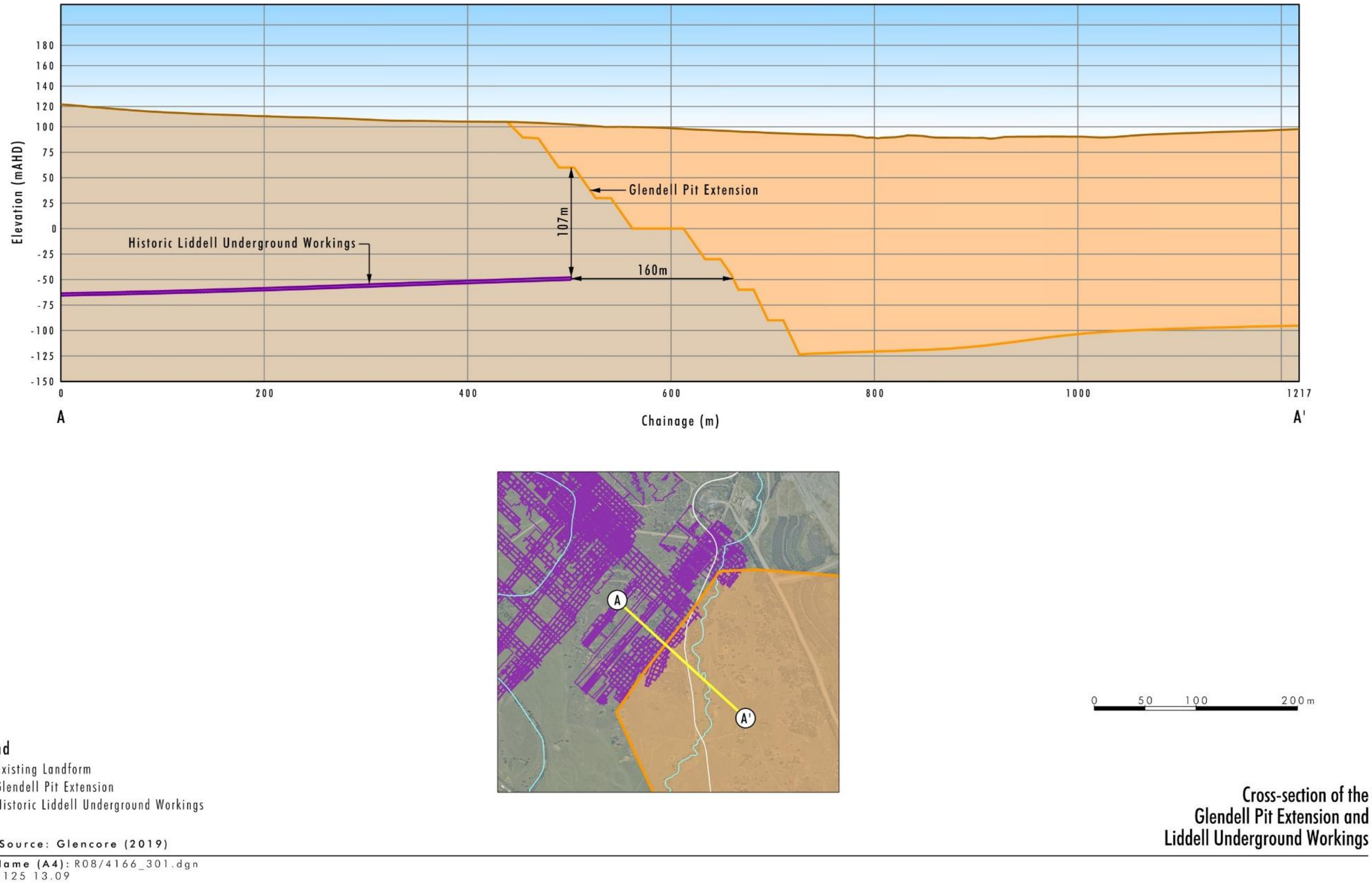

Figure 18 – Cross-Section of the Glendell Pit Extension and Liddell Underground Workings

5.3.2 Assessment Results

5.3.2.1 Ground Vibration

The vibration modelling has been performed according to the formula specified in **Section 4.1.1**. The results of the vibration modelling are summarised in **Table 8**.

Table 8: Results of Ground Vibration Modelling for Infrastructure – Maximum Vibration Estimates

Infrastructure	**Min. Distance (m)**	**Estimated Maximum Ground Vibration (mm/s)**						**Applicable Vibration Criteria (mm/s)**
		MIC (kg)						
		7 m bench (3.5 m stemming)	**15 m bench** (4 m stemming)		**30 m bench**(1) (5 m stemming)		**Presplit** (5-hole)	
		ANFO 115	**ANFO 362**	**Heavy ANFO 544**	**ANFO 824**	**Heavy ANFO 1,236**	**ANFO 450**	
Powerlines								
11- 66 kV Ausgrid (Current Alignments)	110(4, 8)	43	107	149	not applicable, will be relocated before 30 m bench blasting starts		128	50
11- 66 kV Ausgrid (Proposed Alignments)								50
- (at Tension Tower)	110	43	107	149	n/a	n/a	128	
- (at Powerline)	130(2)	33	82	114	159	220	98	
132 kV Ausgrid	160	24	59	82	n/a	n/a	70	50
	600(2)	3	7	10	14	20	9	
330 kV Transgrid	280	10	24	33	n/a	n/a	29	50
	400(2)	5	14	19	26	36	16	
Electrical Substation	190	18	45	62	n/a	n/a	53	50
	1,300(2)	1	2	3	4	6	2	
Communication								
Telstra Tower (Current Site)	150(5, 8)	26	65	91	not applicable, will be relocated before 30 m bench blasting starts			100
Telstra Tower (Proposed Site)	930(2)	1	4	5	7	9	4	100
Telstra Buried Communication Cables (Current Alignment)	105(4, 8)	46	116	160	n/a	n/a	138	100
	540(2)	3	8	12	16	23	10	
Telstra Buried Communication	120	37	93	129	n/a	n/a	111	100

Infrastructure	Min. Distance (m)	Estimated Maximum Ground Vibration (mm/s)						Applicable Vibration Criteria (mm/s)
		MIC (kg)						
		7 m bench (3.5 m stemming)	15 m bench (4 m stemming)		30 m bench[1] (5 m stemming)		Presplit (5-hole)	
		ANFO 115	ANFO 362	Heavy ANFO 544	ANFO 824	Heavy ANFO 1,236	ANFO 450	
Cables (Proposed Alignment)	110[2]	43	107	149	207	287	128	
Telstra / Glencore Buried Communication Fibre to new MIA	430	5	12	17	23	32	14	100
Prescribed Dams								
Mount Owen - North Void Tailings Dam (Two Walls)	1,930[2, 7] 1,200[2,7]	<1 1	1 2	2 3	2 5	3 6	1 3	50
Mount Owen - Tailings Pit 1 (TP1)	1,380 2,230[2]	1 <1	2 1	3 1	n/a 2	n/a 2	2 1	50
Ashton Coal Clean Water Dam 1 (proposed)	2,220 4,150[2]	<1 <1	1 <1	1 <1	n/a 1	n/a 1	1 <1	50
Ravensworth Void 4 East Tailings (Saddle Dam)	1,230 2,120[2]	1 <1	2 1	3 1	n/a 2	n/a 3	3 1	50
Ravensworth Void 5 (Ash Dam)	2,150 3,940[2]	<1 <1	1 <1	1 1	n/a 1	n/a 1	1 <1	50
Railway and Associated Infrastructure								
Main Northern Rail Line	620 700	3 2	7 6	9 8	n/a 11	n/a 15	8 7	25
ARTC Infrastructure	1,040	1	3	4	6	8	4	
Local Roads, Bridges								
New England Hwy	760 1,040[2]	2 1	5 3	7 4	n/a 6	n/a 8	6 4	100
Glennies Creek Rd	3,030 5,000[2]	<1 <1	1 <1	1 <1	n/a <1	n/a 1	1 <1	100
Hebden Rd (Existing Alignment)	110[4, 8] 540[2]	43 3	107 8	149 12	n/a 16	n/a 23	128 10	100
Hebden Rd (Proposed Alignment)	120 110[2]	37 43	93 107	129 149	n/a 207	n/a 287	111 128	100
Proposed Yorks Ck Bridge on Relocated Hebden Rd	590	3	7	10	14	20	9	100
Redundant Bridge and Bowmans Ck Bridge Duplication on Hebden Rd	460 1,880[2]	4 <1	11 1	15 2	n/a 2	n/a 3	13 1	100
Rail Overpass on Hebden Rd	870	2	4	5	n/a	n/a	5	100

Infrastructure	Min. Distance (m)	Estimated Maximum Ground Vibration (mm/s) — MIC (kg) — 7 m bench (3.5 m stemming) — ANFO 115	15 m bench (4 m stemming) — ANFO 362	15 m bench (4 m stemming) — Heavy ANFO 544	30 m bench(1) (5 m stemming) — ANFO 824	30 m bench(1) (5 m stemming) — Heavy ANFO 1,236	Presplit (5-hole) — ANFO 450	Applicable Vibration Criteria (mm/s)
	2,070(2)	<1	1	1	2	3	1	
Private Infrastructure								
Daracon Mining Pty Limited – Site Office	950	1	3	5	n/a	n/a	4	25
	1,840	<1	1	2	2	3	1	
Adjacent Mines								
Integra Underground								
Ventilation Shaft 4	1,050	1	3	4	n/a	n/a	3	225
	2,100(2)	<1	1	1	2	3	1	
Gas Bores & Pipes (Potential)	500	4	10	13	n/a	n/a	11	100
	1,360(2)	1	2	3	4	5	2	
Dewatering Borehole	2,720	<1	1	1	n/a	n/a	1	250
	3,550(2)	<1	<1	1	1	1	<1	
Underground Workings (*horizontal distance*)	540	3	8	12	n/a	n/a	10	10 or 250(3)
	1,400(2)	1	2	3	4	5	2	
Ashton Coal Mine								
Site Office and MIA	2,270	<1	1	1	n/a	n/a	1	25 or 100(6)
	4,250(2)	<1	<1	<1	1	1	<1	

1 – 30 m bench applicable to north-west section of the Glendell Pit Extension where conventional blasting may be employed (see Figure 5)

2 – minimum distance from the area where conventional blasting may be employed, that is north-west section of the proposed Glendell Pit Extension (see Figure 5)

3 – 10 mm/s safety and personnel withdrawal limit for occupied underground workings and 250 mm/s structural limit for unoccupied workings

4 – approximate minimum distance from blasting before prior to relocation

5 – approximate minimum distance from blasting in Year 6 (approximately 2026) according to the proposed mining progression

6 – 25 mm/s safety limit for MIA when occupied and 100 mm/s structural limit for MIA when unoccupied

7 – minimum distance to one of the two walls of North Void tailings dam

8 – Item located within the Glendell Pit Extension, scheduled for relocation

n/a – not applicable

Shaded cells – indicate ground vibrations levels equal to or exceeding the applicable criteria. To ensure compliance with the specified criteria, blast impacts will be managed via a reduction in MIC.

The ground vibration impact assessment for infrastructure can be summarised as follows:

- The assessment determined that the vibration impacts for all assessed infrastructure items can be managed effectively to remain below the applicable vibration limit criteria, via the application of lower MIC which can be achieved either by blasting smaller benches or by the application of deck charges, together with the application of precise initiation timing. In addition, for close range blasting, the impact on the public roads and adjacent infrastructure can be managed effectively through the blast management measures similar to the current system already in place at Glendell.
- The vibration modelling indicates that vibration levels at the 330 kV powerlines will be below the applicable limit of 50 mm/s.
- The vibration modelling indicates that vibration levels at the 11 – 132 kV powerlines (existing and relocated) can be managed effectively to remain below the applicable limit of 50 mm/s via the application of lower MIC.
- At present the Telstra communication tower is located within the boundary of the Glendell Pit Extension. Based on the proposed mining progression, the vibration modelling indicates that vibration criteria will not be exceeded at the tower for blasting up to 150 m away (the predicted pit position at approximately Year 6). The applicable criteria can be achieved at the tower for blasting closer than this through appropriate blast design. In its relocated position, the vibration modelling indicates the tower will be exposed to vibration levels no higher than 9 mm/s (at a distance in excess of 900 m). This is well below the applicable vibration limit of 100 mm/s.
- The vibration modelling indicates that vibration levels at the Telstra buried communication cables (existing and relocated) (along Hebden Rd) can be managed effectively to remain below the applicable limit of 100 mm/s via the application of lower MIC.
- All prescribed dams will be exposed to vibrations no higher than 6 mm/s, which is well below the applicable vibration criteria of 50 mm/s.
- The Main Northern Railway and ARTC infrastructure will be exposed to vibrations no higher than 15 mm/s, which is below the applicable vibration criteria of 25 mm/s.
- Based on the vibration modelling, vibration levels at Hebden Road (existing and realigned) can be managed effectively to remain below the applicable limit of 100 mm/s via the application of lower MIC.
- All other infrastructure items including roads (other than Hebden Road), bridges and private infrastructure are located in excess of 460 m from the Glendell Pit Extension and will be exposed to vibration levels no higher than 20 mm/s, which is below any of the applicable criteria.
- Liddell Underground – blast impacts have the potential to destabilise remnant pillars with resulting surface subsidence impacts. This pillar failure risk exists irrespective of blasting impacts and currently exists in relation to sections of the existing Hebden

Road alignment and Yorks Creek. Surface infrastructure and the realignment of Yorks Creek will be designed having regard to these potential subsidence impacts. Monitoring will be undertaken throughout the life of the Project to identify any remedial action that may be required associated with subsidence impacts whether or not caused by blasting.

- Integra Underground – all assessed infrastructure items including their current and future locations will be exposed to vibration levels no higher than 13 mm/s. This is below the applicable vibration limits. The underground workings will be exposed to a maximum vibration of 12 mm/s. This is below the applicable 250 mm/s structural limit for unoccupied workings. For occupied underground workings the assessment determined that the vibration impacts can be managed effectively to remain below the applicable 10 mm/s criteria, via the application of lower MIC.
- The maximum predicted vibration for the occupied surface infrastructure of the adjacent Ashton Coal mine will be 1 mm/s which is below the applicable vibration limit of 25 mm/s.

5.3.2.2 Airblast Overpressure

Following are the results of the estimated maximum airblast overpressure exposures for the relevant assessed infrastructure:

- Private infrastructure will be exposed to a maximum of 108 dBL which is below the applicable criterion of 133 dBL.
- Site offices of the adjacent mines will be exposed to a maximum of 120 - 122 dBL which is below the applicable criterion of 133 dBL.

The estimated maximum airblast overpressure exposures for all infrastructure with imposed limits are below the relevant criteria of 133 dBL.

5.3.2.3 Flyrock

The proposed Project will operate using an appropriate exclusion zone to manage the risk of flyrock (i.e. 0.5 km exclusion zone).

The closest relevant infrastructure facilities located within a 0.5 km radius include the electricity transmissions lines (current and proposed alignments), electrical substation, Hebden Road (current and proposed alignments) and bridges on Hebden Road.

Sections of Hebden Road (both existing and proposed realignment) and some of its associated bridges and culverts will be located within a 0.5 km radius of blasting. There will be a requirement to implement a Road Closure Management Plan.

There are several types of other infrastructure facilities located within 0.5 km of the Glendell Pit Extension including Telstra buried communication cables (current and proposed alignments), electricity transmission lines (current and proposed alignments) and electrical substation.

Specific flyrock management measures are not required for the management of underground infrastructure. The potential impact of flyrock on other infrastructure items will be managed in accordance with the current procedure when blasting adjacent to powerlines and ARTC infrastructure. These management measures will be documented in the BMP as it is updated for the Project. The owners/operators of relevant infrastructure will be consulted as part of the development of any relevant updates to the BMP.

5.4 NATURAL FEATURES

The analysis presented below addresses blast impacts from the Project on Bowmans Creek and the Yorks Creek Realignment. The analysis is based on vibration modelling using the applicable vibration predictive model, see **Section 4.1.1** and with reference to relevant vibration limit criteria, see **Section 4.2.3**.

5.4.1 Location of Natural Features

The natural features assessed include Bowmans Creek and the Yorks Creek Realignment. The locations of these features are shown on **Figure 19**. At the closest point, the western highwall of the Glendell Pit Extension will be approximately 200 m from the top of the high bank of Bowmans Creek. The shortest distance between the high bank of Yorks Creek Realignment and the Glendell Pit Extension is approximately 255 m.

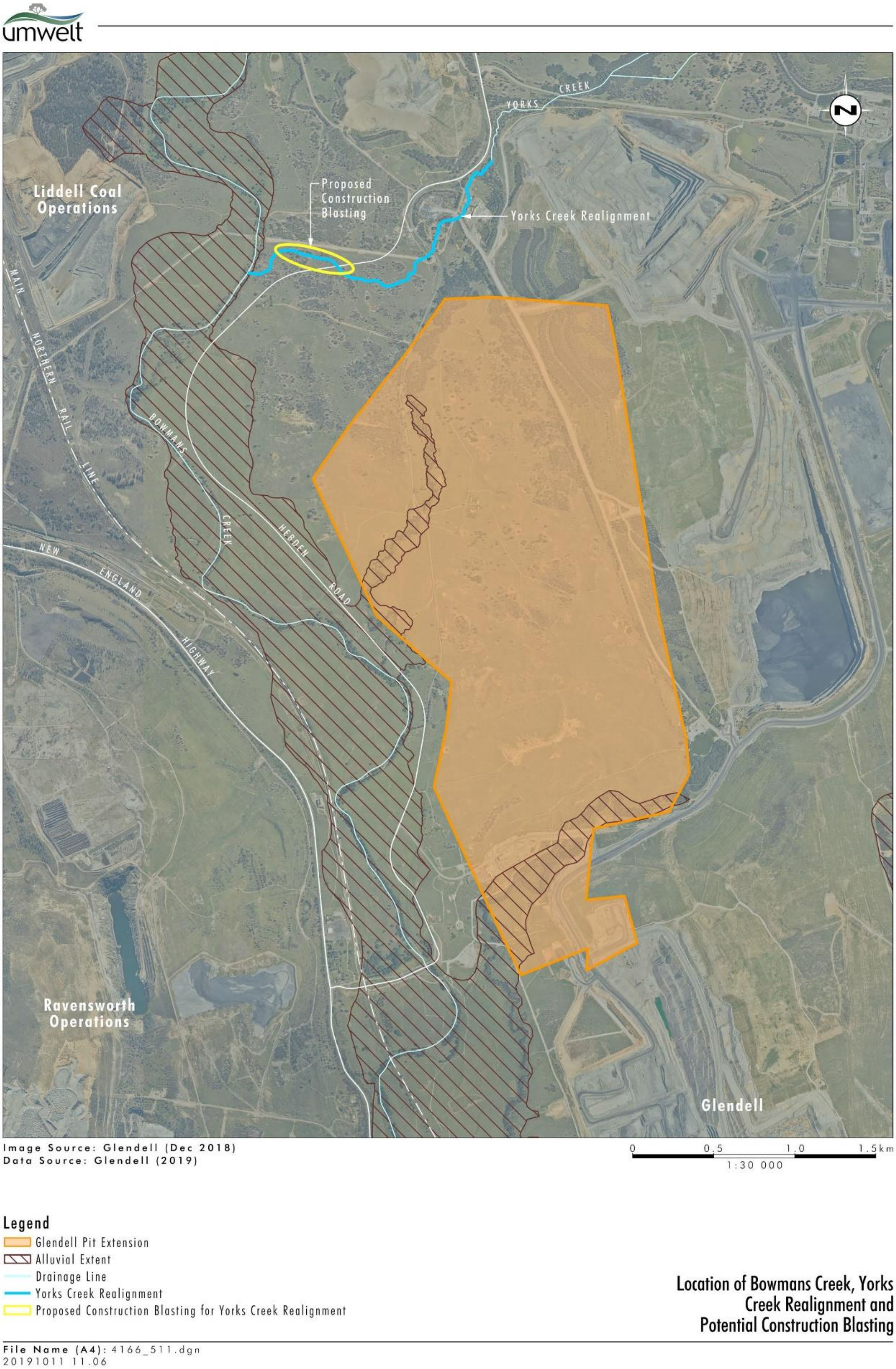

Figure 19 – Location of Bowmans Creek, Yorks Creek Realignment and Potential Construction Blasting

5.4.2 Assessment Results

5.4.2.1 Ground Vibration

The results of the ground vibration modelling are presented in **Table 9.**

Table 9: Results of Ground Vibration Modelling for Natural Features – Maximum Vibration Estimates

Infrastructure	**Min. Distance (m)**	**Estimated Maximum Ground Vibration (mm/s)**						**Applicable Vibration Criteria (mm/s)**
		MIC (kg)						
		7 m bench (3.5 m stemming)	**15 m bench** (4 m stemming)		**30 m bench**(1) (5 m stemming)		**Presplit (5-hole)**	
		ANFO 115	**ANFO 362**	**Heavy ANFO 544**	**ANFO 824**	**Heavy ANFO 1,236**	**ANFO 450**	
Bowmans Creek - High Bank	200 220(2)	16 14	41 35	57 49	n/a 68	n/a 95	49 42	100
Yorks Creek Realignment	255	11	28	39	54	75	33	100

1 – 30 m bench applicable to north-west section of the Glendell Pit Extension where conventional blasting may be employed (see Figure 5)

2 – minimum distance from the area where conventional blasting may be employed, that is north-west section of the proposed Glendell Pit Extension (see Figure 5)

n/a – not applicable

The assessment can be summarised as follows:

- At the shortest distances between the high bank of Bowmans Creek and the Glendell Pit Extension, the expected vibration levels will be no higher than 57 mm/s (for a 15 m bench) and 95 mm/s (for a 30 m bench). This is below the applicable vibration limit of 100 mm/s.
- At the shortest distance to the Glendell Pit Extension, Yorks Creek Realignment will be exposed to a maximum of 82 mm/s (for a 30 m bench) ground vibration level. This is below the applicable vibration criterion of 100 mm/s.

5.4.2.2 Airblast Overpressure

Overpressure limits are not applicable to the creeks being assessed.

5.4.2.3 Flyrock

The proposed Project will operate using an appropriate exclusion zone to manage the risk of flyrock (i.e. 0.5 km exclusion zone).

As both, Bowmans Creek and the Yorks Creek Realignment are located within the exclusion zone, at distances of approximately 0.2 and 0.255 km respectively, it is possible that there will be some flyrock occurrence. However due to the nature of the assessed items, the impact of flyrock is considered to be negligible.

5.5 ANIMALS AND LIVESTOCK

The SEARs for the Project require a detailed assessment of the likely blasting impacts of the development on people, animals, buildings/structures, infrastructure and significant natural features. The majority of the land surrounding the Project Area is used for cattle grazing and other neighbouring mining operations.

Previous investigations of potential blasting impacts have been completed within the area surrounding the Project. Investigations undertaken by Neil Nelson Advice Pty Limited (Agriculture Consultancy Service) in 2011 included observations made at a Colinta Holdings feedlot, located on Falbrook Road approximately 1 km southeast of the Project Area.

Observations were made during four separate blasts with no disturbance of the livestock observed within the feedlot or within the paddocks adjoining the feedlot during blasting activities. The report concludes that while blasting can result in immediate noise disruption, so does that of passing traffic and general farming equipment.

Given the history of mining activities within the Project Area and surrounding mining operations, blast noise associated with the Project will not be an additional noise source to the area, livestock and other animals (including native animals) are likely to be accustomed to blast noise, overpressure and vibration impacts.

Potential impacts to livestock related to flyrock will be managed as part of pre-blast inspection activities, with the clearing of all livestock from within the blast exclusion zone if required. Currently the closest private grazing land is approximately 4 km from the Project Area.

Refer to the Agricultural Impact Statement (Umwelt 2019a) and the Biodiversity Development Assessment Report (Umwelt 2019b) prepared for the Project for further detail regarding impacts on animals.

6.0 CONSTRUCTION BLASTING

The existing alignment of Yorks Creek is located within the Glendell Pit Extension. The Project includes the realignment of Yorks Creek prior to the lower reaches being mined through. These realignment works may require small scale construction type blasting to achieve required ground level for effective water flow. The construction blasting is to be undertaken to the north-west of the Glendell Pit Extension, as marked in **Figure 19**.

The impact assessment for the proposed construction blasting involved blast vibration modelling using MIC charges based on blasting parameters including benches in the range of 5 to 15 m, see **Table 10**. The modelling accounts for the worst-case scenario, i.e. blasting from the edge of Yorks Creek Realignment construction area which corresponds to the minimum distance between the blasting area and the receivers. The assessment covers items located within 5 km from the Project Area.

The construction blasting will occur prior to, and as part of the construction of the Hebden Road realignment. Accordingly, the potential impacts on the Hebden Road realignment infrastructure (including the proposed bridge of the realigned Yorks Creek) have not been assessed. Similarly, infrastructure to be installed adjacent to the realigned Hebden Road will not be installed until after construction related blasting has been completed; accordingly, impacts on this infrastructure has not been assessed. While the construction blasting will occur prior to the relocation of the Ravensworth Homestead; the potential impacts from construction blasting on the Ravensworth Homestead in the proposed Ravensworth Farm site have been assessed in the event that earlier relocation occurs.

Table 10: Vibration Modelling Summary for Construction Blasting

Infrastructure	**Min. Distance (m)**	**Estimated Maximum Ground Vibration (mm/s)**						**Applicable Vibration Criteria (mm/s)**
		MIC (kg)						
		5 m bench (3.5 m stemming)		**10 m bench** (3.5 m stemming)		**15 m bench** (4 m stemming)		
		ANFO 39	**Heavy ANFO 58**	**ANFO 168**	**Heavy ANFO 252**	**ANFO 285**	**Heavy ANFO 427**	
HISTORICAL SITES								
Ravensworth Homestead (Current Site)	1,660	0.2	0.3	0.8	1.0	1.2	1.6	5
Ravensworth Homestead (Proposed Site)	700	0.9	1.3	3.0	4.2	4.6	6.3	To be assessed when relocated(2)
Ravensworth Public School	4,350	0.1	0.1	0.2	0.2	0.2	0.3	25
Chain of Ponds Inn	2,800	0.1	0.1	0.3	0.5	0.5	0.7	10
Hebden Public School	1,680	0.2	0.3	0.7	1.0	1.1	1.6	16
John Winter Memorial	1,680	0.2	0.3	0.7	1.0	1.1	1.6	250

Infrastructure	Min. Distance (m)	Estimated Maximum Ground Vibration (mm/s) — MIC (kg) — 5 m bench (3.5 m stemming) — ANFO 39	5 m bench (3.5 m stemming) — Heavy ANFO 58	10 m bench (3.5 m stemming) — ANFO 168	10 m bench (3.5 m stemming) — Heavy ANFO 252	15 m bench (4 m stemming) — ANFO 285	15 m bench (4 m stemming) — Heavy ANFO 427	Applicable Vibration Criteria (mm/s)
Bowmans Creek 16 Engraving	2,200	0.1	0.2	0.5	0.7	0.7	1.0	50
INFRASTRUCTURE								
Powerlines								
11-66 kV (Current Alignment) – (South from Construction Blasting)	250	5	7	16	22	24	33	50
11-66 kV (Current Alignments) – (East from Construction Blasting)	570	1	2	4	6	6	9	50
132 kV powerline	1,760	<1	<1	1	1	1	1	50
330 kV powerline	1,650	<1	<1	1	1	1	2	50
Electrical Substation	4,140	<1	<1	<1	<1	<1	<1	50
Communication								
Telstra Tower (Current Site)	2,540	<1	<1	<1	1	1	1	100
Telstra Tower (Proposed Site)	680	1	1	3	4	5	7	100
Telstra buried communication cables (Existing Alignment)	450	2	3	6	8	9	13	100
Prescribed Dams								
Mount Owen - North Void Tailings Dam (Two Walls)	1,530(1)	<1	<1	1	1	1	2	50
	990(1)	1	1	2	2	3	4	
Mount Owen - Tailings Pit 1 (TP1)	3,670	<1	<1	<1	<1	<1	<1	50
Ravensworth Void 4 East Tailings (Saddle Dam)	4,350	<1	<1	<1	<1	<1	<1	50
Railway and Associated Infrastructure								
Main Northern Railway	1,850	<1	<1	1	1	1	1	25
ARTC Infrastructure	2,360	<1	<1	<1	1	1	1	25
Local Roads, Bridges								
New England Hwy	2,420	<1	<1	<1	1	1	1	100
Hebden Rd (Existing Alignment)	450	2	3	6	8	9	13	100
Redundant Bridge and Bowmans Creek Bridge Duplication on Hebden Rd	4,330	<1	<1	<1	<1	<1	<1	100
Rail Overpass on Hebden Rd	4,420	<1	<1	<1	<1	<1	<1	100

Infrastructure	Min. Distance (m)	Estimated Maximum Ground Vibration (mm/s)						Applicable Vibration Criteria (mm/s)
		MIC (kg)						
		5 m bench (3.5 m stemming)		10 m bench (3.5 m stemming)		15 m bench (4 m stemming)		
		ANFO 39	Heavy ANFO 58	ANFO 168	Heavy ANFO 252	ANFO 285	Heavy ANFO 427	
Private Infrastructure								
Daracon Mining Pty Limited – Site Office	4,080	<1	<1	<1	<1	<1	<1	25
Natural Features								
Bowmans Creek - High Bank	360	3	4	9	12	13	18	100

1 – minimum distance to one of the two walls of North Void tailings dam

2 – ground vibration criteria to be determined subject to further specialist assessment accounting for foundation upgrades and other stabilisation works to the buildings

The assessment concluded that the blast impacts on the surrounding environment can be managed effectively below the applicable vibration limit criteria. To ensure compliance, the presented assessment concluded that the proposed construction blasting is to be undertaken prior to the relocation of the Hebden Road and associated infrastructure. This is due to a short distance between the construction blasting area and the proposed relocated section of the Hebden Road (including associated infrastructure).

As pointed out earlier (**section 5.3.2.1**) blast impacts have the potential to destabilise remnant pillars at Liddell Underground, with resulting surface subsidence impacts. This pillar failure risk exists irrespective of blasting impacts and currently exists in relation to sections of the existing Hebden Road alignment and Yorks Creek. Surface infrastructure and the realignment of Yorks Creek will be designed to having regard to these potential subsidence impacts.

It is recommended to undertake vibration monitoring for the closest critical infrastructure items when undertaking construction type blasting.

7.0 REVIEW OF MONITORING DATA COMPLIANCE

A detailed review of monitoring data was undertaken by ESC (ESC (2019)) and included a review of ground vibration and airblast overpressure monitoring results for the Mount Owen Complex (Glendell Mine) from 2015 to 2018 (i.e. a 4-year period) to confirm compliance against consent conditions. The analysis also aimed to assess the adequacy of the coverage of the existing blast monitoring system. A summary of the assessment is presented in **Table 11**.

Table 11: Summary of Monitoring Data Compliance for Years 2015 to 2018

Assessment Type / Criterion	Strategic Objective	Current Standing	Deficiency
Private Residences			
Quantitative: Ground Vibration *Criterion 1*	No more than 5% of all yearly blasts may produce vibration values between 5 mm/s and 10 mm/s	Year 2015 – 0% Year 2016 – 0% Year 2017 – 0% Year 2018 – 0% percentage of yearly blasts with ground vibration values between the specified limits	None
Quantitative: Ground Vibration *Criterion 2*	No blast may exceed 10 mm/s	No blast has exceeded the vibration limit	None
Quantitative: Airblast *Criterion 3*	No more than 5% of all yearly blasts may produce overpressure values between 115 and 120 dBL	Year 2015 – 0% Year 2016 – 0% Year 2017 – 1% Year 2018 – 0% percentage of yearly blasts with overpressure values between the specified limits	None
Quantitative: Airblast *Criterion 4*	No blast may exceed 120 dBL	No blast has exceeded the airblast limit	None
Infrastructure - Electricity Transmission Towers			
Quantitative: Ground Vibration *Criterion 5*	No blast may exceed 50 mm/s	No blast has exceeded the vibration limit	None
Infrastructure - Main Northern Rail Line			
Quantitative: Ground Vibration *Criterion 6*	No blast may exceed 25 mm/s* *Private agreement in place, see below	No blast has exceeded the vibration limit	None
Historical Site – Church			
Quantitative: Ground Vibration *Criterion 7*	No more than 5% of all yearly blasts may produce vibration values between 2 and 5 mm/s	No blast has exceeded the vibration limit	None
Quantitative: Ground	No blast may exceed 5 mm/s	No blast has exceeded the vibration limit	None

Assessment Type / Criterion	Strategic Objective	Current Standing	Deficiency
Vibration *Criterion 8*			
Quantitative: Airblast *Criterion 10*	No more than 5% of all yearly blasts may produce overpressure values between 115 dBL and 120 dBL	Year 2015 – 0% Year 2016 – 0% Year 2017 – 0% Year 2018 – 0% percentage of yearly blasts with overpressure values between the specified limits	None
Quantitative: Airblast *Criterion 11*	No blast may exceed 120 dBL	No blast has exceeded the airblast limit	None
Historical Site – Ravensworth Homestead			
Quantitative: Ground Vibration *Criterion 9*	No blast may exceed 5 mm/s	No blast has exceeded the vibration limit	None
Quantitative: Airblast *Criterion 12*	No blast may exceed 126 dBL	No blast has exceeded the airblast limit	None

** **Private Agreement** - Blasting within 0.5 km of infrastructure owned, leased or controlled by ARTC at Camberwell may exceed 25 mm/s for the Main Northern Railway culverts and bridges, providing Clause 5 conditions of the "ARTC Blasting Deed (2013)" have been satisfied.*

The results of the study are summarised as follows:

- The assessment included a review of ground vibration and airblast overpressure monitoring results for a 4-year period (2015 – 2018). The results were analysed in the context of airblast overpressure and ground vibration limits imposed on the mine.
- The assessment concluded a good overall blast performance with a low impact on the local community, infrastructure and historical / heritage sites.
- The current Glendell Mine multi-station vibration monitoring system was assessed for its adequacy. The stations are placed strategically in various directions (i.e. the majority of stations are located to the south of Glendell Mine) with two of the stations monitoring the impact on private residences, two dedicated to historical sites and six dedicated to infrastructure. It was concluded that the current monitoring system is considered to provide an adequate coverage to monitor the vibration impacts from the existing approved Glendell Mine, see **Figure 20**. As the Project is planned to advance in a northerly direction, some modification to the number and locations of monitoring stations is recommended; for details see **Section 8**.

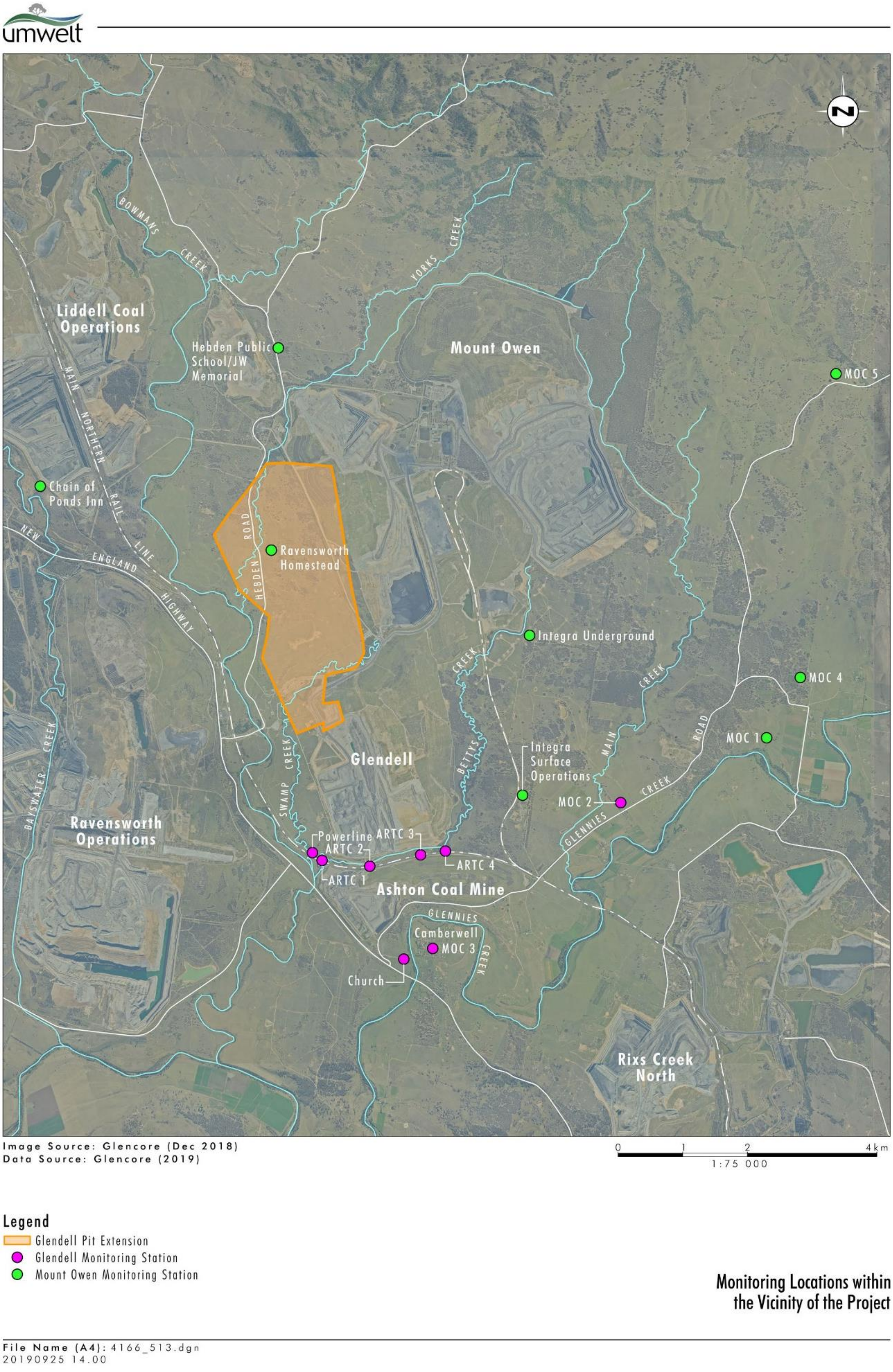

Figure 20 – Locations of the Existing Mount Owen Complex Vibration Monitoring Stations

8.0 MANAGEMENT AND MITIGATION MEASURES

Glendell Mine currently utilises a number of blast control measures and technologies (as detailed in the BMP, which minimise blast impacts on the environment and enable blasts to be designed to comply with the relevant criteria. Blast impacts associated with the Project can be effectively managed in accordance with the existing BMP.

The blast control measures already in place include:

Weather Monitoring and Assessment System

The weather conditions can potentially affect the blast impact outcome (especially noise distribution and intensity), as well as post-blast dust distribution.

Glendell Mine operates using a well-developed weather assessment protocol utilising three weather monitoring stations and the EnvMet weather predictive model.

The system takes into account the environmental forecast for a day, followed by detailed assessment of wind speed, wind direction and inversion impacts. The mine also utilises fume prediction.

Weather impacts are assessed in the morning when an initial decision on whether to blast is undertaken. This is followed by a second review of weather impacts just prior to the blast firing time. Each blast is video recorded and fume is assessed according to the standard fume rating system.

The system operates effectively and therefore no changes to the system are recommended.

Pre-Blasting Assessment Process and Recommendations

Glendell Mine operates using a well-developed pre-blast assessment protocol. It utilises the following:

- Weather monitoring - allows for the assessment of wind speed / wind direction and temperature inversion,
- EnvMet weather assessment system - allows for the assessment of inversion and wind shear conditions,
- Pre-blast fume assessment - allows for the assessment of potential fume generation for each blast,
- Pre-blast dust assessment - allows for the assessment of potential dust generation for each blast,
- Pre-blast community and stakeholder notification,
- The Mount Owen Complex blast-pack includes documentation for all activities, including a checklist to be signed off by environmental and community staff.

As stated above, there is a comprehensive pre-blast management system in place. This allows for a thorough assessment of conditions on the day of a proposed blast, when a decision on whether to blast or not needs to be made. This is in the format of an operational procedure, which then needs to be addressed by a number of operators.

The system operates effectively and therefore no major changes to the system are recommended.

The proposed Project will result in the continuation of the blasting operations to the north. Based on the proposed mining plans and due to the change in distances to private residences, infrastructure and historical sites, it is recommended to undertake a review of the Pre-Blasting Assessment Process.

Blast Monitoring System and Recommendations

The current multi-station vibration monitoring system (consisting of eight permanent monitoring stations) at Glendell Mine has been reviewed for its adequacy for the Glendell Pit Extension, with recommendations, as highlighted below.

Due to the Glendell Pit Extension being located to the north of the current operations and resulting increased distance to habitable areas and currently monitored infrastructure, it is recommended to reduce the number of monitoring stations located in the south. It is recommended to remove the five infrastructure monitoring stations (i.e. ARTC1, ARTC2, ARTC3, ARTC4 and Powerlines) and instead to install two new monitoring stations to the west of the Glendell Pit Extension, representative of the closest locations to infrastructure such as electricity transmission lines. Note that these stations can be used as "semi-permanent" i.e. portable monitoring stations. As the mine progresses in a northerly direction, the powerline and rail line monitors can be re-located to new locations i.e. to represent the shortest distance between blasting activities and infrastructure.

The existing Ravensworth Homestead monitoring station which is a requirement of the Mount Owen Consent should be included in the Glendell monitoring program and should be retained until the removal of the Ravensworth Homestead. If the Ravensworth Homestead is relocated to the Ravensworth Farm option a blast monitoring station should be established at this site.

In summary, based on the undertaken assessment for the Glendell Pit Extension, the eight monitoring stations currently used can be reduced down to six stations (including relocated stations).

Fume Management

Glendell Mine manages blast fume as specified in the BMP (Appendix D – Blast Fume Management). Blast fume impacts and management are discussed in the Air Quality Impact Assessment (Jacobs 2019).

Interaction with Nearby Mines

The risks associated between different open cut and underground operations acting simultaneously can be effectively managed via the implementation of an appropriate protocol.

There is a well-developed system of email notification and interaction with the adjacent mines already in place. This system is used to avoid concurrent blasts and therefore minimise blast impacts on the adjacent community. The system operates effectively and therefore no changes to the system are recommended.

Interaction with Integra Underground Mine

The Integra Underground Mine is located to the east and south-east of the Project, with the proposed Ventilation Shaft 4 being the closest surface infrastructure, see **Figure 17**. The impact of blasting from the Project on Integra Underground will be managed according to management measures (including mines interaction) and according to the imposed blast limit criteria as specified in the BMP.

To manage the interaction, it is recommended to develop / update an appropriate blast protocol to manage risks and provide notification on the impact of blasting from the Project on Integra Underground where operations occur concurrently. This type of protocol has already been developed between Mount Owen Mine and Integra Underground including vibration and fume risk management as well as a notification system.

All operational and safety measures currently implemented will continue and will be enhanced through the common ownership of these mining operations by Glencore. Therefore, the risks between the two operations in such close contact will be managed effectively.

Blasting in Geologically Affected Areas

Besides the management measures specified in the BMP, below are other potential management and mitigation measures which are recommended for the Project and are mainly related to blast impacts when blasting in geologically affected areas (e.g. block fault zone area and others) and in the vicinity (less than 300 m) of adjacent Bowman Creek:

Identify any geological features and address possible impacts on blasting outcomes via:

Control measures for ground vibration:

- Account for the presence of geological features including cracks / crevices and possible loss of explosives / overcharging issue, which can potentially impact on a vibration level;
- Account for a possible magnification effect along a wide fault zone area when blasting through. If required, undertake an alternative blast design to manage the issue.

Control measures for airblast overpressure:

- Undertake an alternative blast design around identified geological features to avoid a face burst / collar burst and related excessive airblast emission.

Control measures for flyrock:

- Use of a modified blast design to account for the presence of geologically affected rock strata to avoid a potential flyrock incident around the identified geological features.

Inspections/monitoring for Bowmans Creek and Yorks Creek Realignment

Site inspections including inspections along the western highwall of the existing operations at the Glendell Mine are undertaken with the aim to identify and monitor blast induced surface impacts such as cracking. Existing monitoring does not indicate any risk of strata fracturing extending to Bowmans Creek. It is recommended that these inspections continue along the western and northern highwall of the Glendell Pit Extension. This would allow for an accurate assessment of rock strata response when blasting in the vicinity of Bowmans Creek and the Yorks Creek Realignment.

As the vibration limits for Hebden Road and other infrastructure located between the proposed blasting area and Bowmans Creek are the same as or lower than the criteria for Bowmans Creek, specific vibration monitoring of the high bank is not required. Inspections of bank stability can be undertaken as part of the channel stability monitoring program associated with the Surface Water Management and Monitoring Plan. Inspections of bank stability in the Yorks Creek Realignment can be undertaken as part of the diversion monitoring program associated with the Creek Diversion Plan. These inspections will also include visual monitoring of any evidence of subsidence impacts associated with pillar failure in the Liddell underground workings.

Road Closure Management Plan

Blasting activities for the Project will be undertaken within close proximity to Hebden Road i.e. less than 0.5 km. This will require the development of a Road Closure Management Plan in consultation with the relevant road authorities and Council.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The report presents an assessment of blast impacts associated with the Glendell Continued Operations Project on the surrounding environment, including private residential receivers, historical / heritage sites, infrastructure and natural features. The results of the assessment are summarised as follows:

- The Glendell Pit Extension will extend mining activities in a northerly direction, progressing away from the current Glendell Pit. The blasting parameters were reviewed based on the geological model of the area. For the assessment, blasting benches were identified as a maximum of 15 m for through-seam blasts and 30 m for conventional blasts. The charge masses were identified and are in the order of 362 to 1,236 kg.
- The impacts of air and ground vibrations on the surrounding private residences, historical / heritage sites, infrastructure and natural features were assessed using ground vibration and airblast predictive models developed for Glendell Mine conditions; the models are considered fully representative of blasting activities likely to be undertaken for the Glendell Pit Extension.

- MONITORING DATA COMPLIANCE REVIEW
    - A review of ground vibration and airblast overpressure monitoring results for a 4-year period (2015 – 2018) was undertaken in the context of ground vibration and airblast overpressure limits imposed on the mine. The assessment concluded a good overall blast performance with a low impact on the local community and environment. The current multi-station vibration monitoring system (eight stations) was determined to provide adequate coverage for the existing approved operations at Glendell Mine.

- IMPACT ON PRIVATE RESIDENTIAL RECEIVERS:
    - The blast emission criteria for private residential receivers are specified in **Section 4.2.1**.
    - The ground vibration modelling for private residences within a 5 km radius of the Glendell Pit Extension identified that vibration impacts can be managed effectively within the specified blasting parameters. The estimated ground vibration exposure for all private residential receivers using proposed charge masses is predicted to be no higher than 0.6 mm/s. This is below the applicable vibration limit specified as 5 mm/s (for 95% of blasts) and 10 mm/s (not to be exceeded).
    - The airblast modelling for all private residential receivers within a 5 km radius of the Glendell Pit Extension revealed that airblast overpressure impacts can be managed effectively within the specified blasting parameters. The estimated airblast overpressure exposure for all private residences using specified charge masses is predicted to be no higher than 111 dBL. This is below the applicable airblast overpressure limits specified as 115 dBL (for 95% of blasts) and 120 dBL (not to be exceeded).
    - Due to the substantial distances to all private residences (i.e. in excess of 3.5 km) the issue of flyrock impacts on the private residences is considered to be fully managed and the potential risks are considered negligible.

- IMPACT ON HISTORICAL / HERITAGE SITES:
    - The blast emission criteria for historical / heritage sites are specified in **Section 4.2.2**.
    - The modelling indicates that relocation of the Ravensworth Homestead is required no later than the end of Year 5 (approximately 2025) according to the proposed mining progression, to ensure compliance with the applicable ground vibration limit. In the relocated position, vibration impacts can be managed effectively to remain below the currently imposed vibration limit of 5 mm/s by using lower charge masses, consistent with existing blast management practices as outlined in the BMP. If relocated to the Ravensworth Farm position, limit criteria are to be reviewed and determined subject to further specialist assessment accounting for footing upgrades and other stabilisation works to the buildings.

      The airblast overpressure will be managed to below the applicable limit by employing lower charge masses.
    - Blast vibration and airblast overpressure impacts for all other historical / heritage sites will be below the assessed criteria levels.
    - The Glendell Pit Extension will operate using a standard 0.5 km exclusion zone for flyrock management. The closest historical / heritage site is approximately 630 metres away (excluding the current Ravensworth Homestead location). The issue of flyrock impact is therefore considered to be fully managed and the potential risks are considered negligible.

- IMPACT ON INFRASTRUCTURE:
    - The blast emission criteria for infrastructure sites are specified in **Section 4.2.3**.

- The vibration impacts for all assessed infrastructure items can be managed effectively to below the applicable vibration limit criteria by controlling the MIC, which can be achieved either by blasting smaller benches or by the application of deck charges, together with the application of precise initiation timing.
- The vibration modelling indicates that the Telstra communication tower potentially may remain in its current location (within the boundary of the Glendell Pit Extension) for blasting up to 150 m away (the predicted pit position at approximately Year 6), to comply with the applicable vibration criteria. In the relocated position the tower will be exposed to vibration levels below the applicable vibration limit.
- The modelling indicates that vibration impacts on Hebden Road (in its current and realigned configuration) can be managed effectively to remain below the applicable limit via the application of lower MIC.
- The estimated maximum airblast overpressure exposures for all infrastructure with imposed limits are below the relevant criteria.
- The risks of flyrock on sections of Hebden Road (both existing and proposed realignment) and some of its associated bridges and culverts located within a 0.5 km from blasting will be managed via the implementation of the developed Road Closure Management Plan. The potential impact of flyrock on other infrastructure items will be managed in accordance with the current procedure when blasting adjacent to powerlines and ARTC infrastructure.
- Liddell Underground – blast impacts have the potential to destabilise remnant pillars with resulting surface subsidence impacts. This pillar failure risk exists irrespective of blasting impacts and currently exists in relation to sections of the existing Hebden Road alignment and Yorks Creek. Surface infrastructure and the realignment of Yorks Creek will be designed having regard to these potential subsidence impacts. Monitoring will be undertaken throughout the life of the project to identify any remedial action that may be required associated with subsidence impacts whether or not caused by blasting.
- The impacts on Integra Underground Mine will be managed in order to maintain safe work practices. All operational and safety measures currently implemented through the existing protocol will continue.
- Glencore will consult with the asset owner to seek agreement to modify any vibration limits on infrastructure, where deemed relevant. The BMP will be updated following any changes to the relevant vibration limits.

- INTERACTIONS WITH NEARBY MINES:
  - Glendell Mine already operates a successful blast notification and management system with nearby mines in relation to the coordination of blasts to avoid concurrent blasting and therefore reduce the potential for cumulative airblast overpressure and ground vibration impacts.

- IMPACT ON NATURAL FEATURES
  - The impact of ground vibration from the Glendell Pit Extension on the high banks of Bowmans Creek and Yorks Creek Realignment will be below the applicable vibration limit criteria.

- A detailed assessment of blast impacts on integrity of Bowmans Creek rock strata (ESC 2019) did not identify any significant risks from blasting for Bowmans Creek.

- IMPACT ON ANIMALS:
  - Due to the substantial distances to private grazing lands (i.e. approximately 4 km) the potential risks of flyrock on adjacent grazing land, (including the potential presence of livestock) are considered negligible.
  - Blast related impacts associated with the Project will be similar to those of existing operations and no additional impacts on native fauna or flora are expected.

- CONSTRUCTION BLASTING IMPACT:
  - Construction blasting will have limited impact on the existing environment and can be managed effectively below the applicable vibration limit criteria. To ensure compliance, the proposed construction blasting is to be undertaken prior to the relocation of the Hebden Road and associated infrastructure. The construction blasting is to be supplemented by vibration monitoring of the closest critical infrastructure / historical sites.

- MANAGEMENT AND MITIGATION MEASURES:
  - To facilitate compliance with the vibration and airblast overpressure limits it is recommended to continue with the existing blast management measures in accordance with the current BMP. The BMP should be updated to reflect the management and mitigation measures proposed in this report.
  - A Road Closure Management Plan should be developed and implemented for the Project to manage the impacts on public roads and infrastructure and flyrock risks.
  - Additional blast management measures for the Glendell Pit Extension when blasting through geologically affected areas were specified in **Section 8**. In addition, Glendell Mine will continue to undertake site inspections along the western and northern high walls of the Glendell Pit Extension to identify and monitor blast induced surface impacts such as cracking to allow for an accurate assessment of rock strata response when blasting in the vicinity of Bowmans Creek and the Yorks Creek Realignment. Inspections of bank stability will be undertaken as part of the channel stability and diversion monitoring programs.
  - Furthermore, the study concluded that the number of vibration monitoring stations can be reduced from eight (currently used by Glendell Mine) to six, as recommended in **Section 8**.

Thomas Lewandowski
26th November 2019
Enviro Strata Consulting

REFERENCES

1. Aboriginal Sites Register of NSW.
2. ACARP Report Reference No. C14057 'Effect of Blasting on Infrastructure' Alan Richards, Adrian Moore, 2008.
3. Ashton Coal (2010); Ashton South East Open Cut (SEOC- South East Open Cut Project) Blasting Impact Assessment.
4. Australian & New Zealand Environment and Conservation Council (ANZECC) 'Guidelines Technical Basis for Guidelines to Minimise Annoyance due to Blasting Overpressure and Ground Vibration' September 1990.
5. Australian Standard AS 2187.2:2006, Explosives – Storage and use, Part 2 – Use of explosives (AS 2187 Part 2).
6. BMP 2018, Blast Management Plan MGO MT Owen / Glendell, 2018. Document number: MGOOC-1779562647-11183. Version 2.0, dated 12.10.18.
7. Dam Safety Committee NSW 2011, Annexure "D" Standard Mining Conditions. Correspondence regarding 'Xstrata Mount Owen Pty Ltd application to open cut mine adjustment to Mount Owens Rail Loop Tailings Dam within the Mount Owen Notification Area', 16.12.2011.
8. Douglas Partners (2019). Feasibility Level Design of Hebden Road Relocation – MIA Component Glendell Mine Hebden. Project no. 91435.00. April 2019.
9. Enviro Strata Consulting (ESC 2014), Report, September 2014, "Vibration Limits for Former Hebden Public School and John Winter's Memorial Site", Report no. UM-1411- 040914.
10. Enviro Strata Consulting (ESC 2018), Report, September 2018, "Assessment of Blast Impacts on the Proposed Integra Underground Ventilation Shaft 4", Report no. IN-1811-180918.
11. Enviro Strata Consulting (ESC 2019), Report, April 2019, "Gap Analysis – Blast Impacts from Glendell Mine on the Surrounding Environments (2015-2018). Report no. UM-1835-170419.
12. Enviro Strata Consulting (ESC 2019a), Report, June 2019, "Assessment of Integrity and Vibration Limit Estimation for Bowmans Creek 16 Aboriginal Engraving Site", Report no. UM-1914-180619.
13. Enviro Strata Consulting (ESC 2019b), Report, November 2019, "Assessment of Blast Impacts on the Integrity of Rock Strata Between Bowmans Creek and the Glendell Continued Operations Project", Report no UM-1840-100419.
14. Enviro Strata Consulting (ESC 2019c), Report, May 2019, "Assessment of Blast Impacts on the Proposed Dewatering Borehole for Integra Underground", Report no. IN-19121-250519.
15. Environment Protection Licence no. 12840 Glendell Mine.

16. Glendell Mine Development Consent (DA 80/952) 1983, including subsequent modifications.
17. Jacobs (2019), Report, Air Quality Impact Assessment.
18. Lucas Stapleton Johnson & Partners (2019), Report, Statement of Heritage Impact.
19. Mount Owen Continued Operations Project Development Consent (SSD-5850) 2016, including subsequent modifications.
20. Mount Owen Continued Operations – MOCO Hebden Road Upgrade Project, 2016. Detailed Design Criteria. Report no. MOCO-PB-55.00.00.00-DC-0001. September 2016.
21. Nelson, N. (2011). Xstrata Coal Queensland Pty Ltd & Ors V Friends of the Earth – Brisbane Co-op & Ors (MLA's 50229, 50230 & 50231), a report prepared to support mining lease application made by Xstrata Coal Queensland Pty Ltd.
22. The New South Wales State Heritage Register (1999).
23. Pre-feasibility Report (Glencore 2018). Pre-feasibility Report for Glendell Continued Operations (GCO) Project, Chapter 8 Geology and Mineral Resources. February 2018.
24. Pre-feasibility: PSW MP Data (Glencore 2018)
25. SEARS - the Secretary of the Department of Planning and Environment's Environmental Assessment Requirements for the Glendell Continued Operations Project, application no. SSD 9349. Document dated 11.07.2018.
26. The Singleton Local Environmental Plan (LEP) 2013.
27. Umwelt (Australia) Pty Limited. (2019a) Glendell Continued Operations Project: Agricultural Impact Statement.
28. Umwelt (Australia) Pty Limited. (2019b) Glendell Continued Operations Project: Biodiversity Development Assessment Report.

Appendix 15b

Blast Geotechnical Assessment

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UMWELT (AUSTRALIA) PTY LIMITED
on behalf of
GLENDELL TENEMENTS PTY LIMITED

ASSESSMENT OF BLAST IMPACTS ON THE INTEGRITY OF ROCK STRATA BETWEEN BOWMANS CREEK AND THE GLENDELL CONTINUED OPERATIONS PROJECT

FINAL

Report No: UM-1840-251119

Thomas Lewandowski
25th November 2019

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1. INTRODUCTION

Enviro Strata Consulting Pty Ltd (ESC) was engaged by Umwelt Australia Pty Limited (Umwelt) on behalf of Glendell Tenements Pty Ltd (Glendell) to assess the potential risks of strata fracturing from blasting in the vicinity of Bowmans Creek and adjacent area.

Proposed mining operations associated with the Glendell Continued Operations Project (the Project) will include blasting activities in the vicinity of Bowmans Creek, see **Figure 1**. This proximity will result in potential blast-related risks such as vibration exposure and rock strata fracturing for Bowmans Creek (rock bed), high bank, strata between the Project and Bowmans Creek.

For the purpose of this assessment, two creek Study Areas were selected representing the closest sections between the Project mining area where mining related blasting will occur and the high bank of Bowmans Creek. In these locations the Glendell Pit Extension is located at approximately 200 and 400 m distance from the high bank of Bowmans Creek, see **Figure 1**.

The main objectives of the undertaken assessment are specified as follows:

- Review of local geological conditions for the Bowmans Creek Study Areas and implications for rock strata damage
- Assessment of potential risks related to the adjacent open cut surface blasting and blasting impacts on Bowmans Creek bed and strata between the Project and Bowmans Creek
- Assessment of an allowable vibration limit for Bowmans Creek.

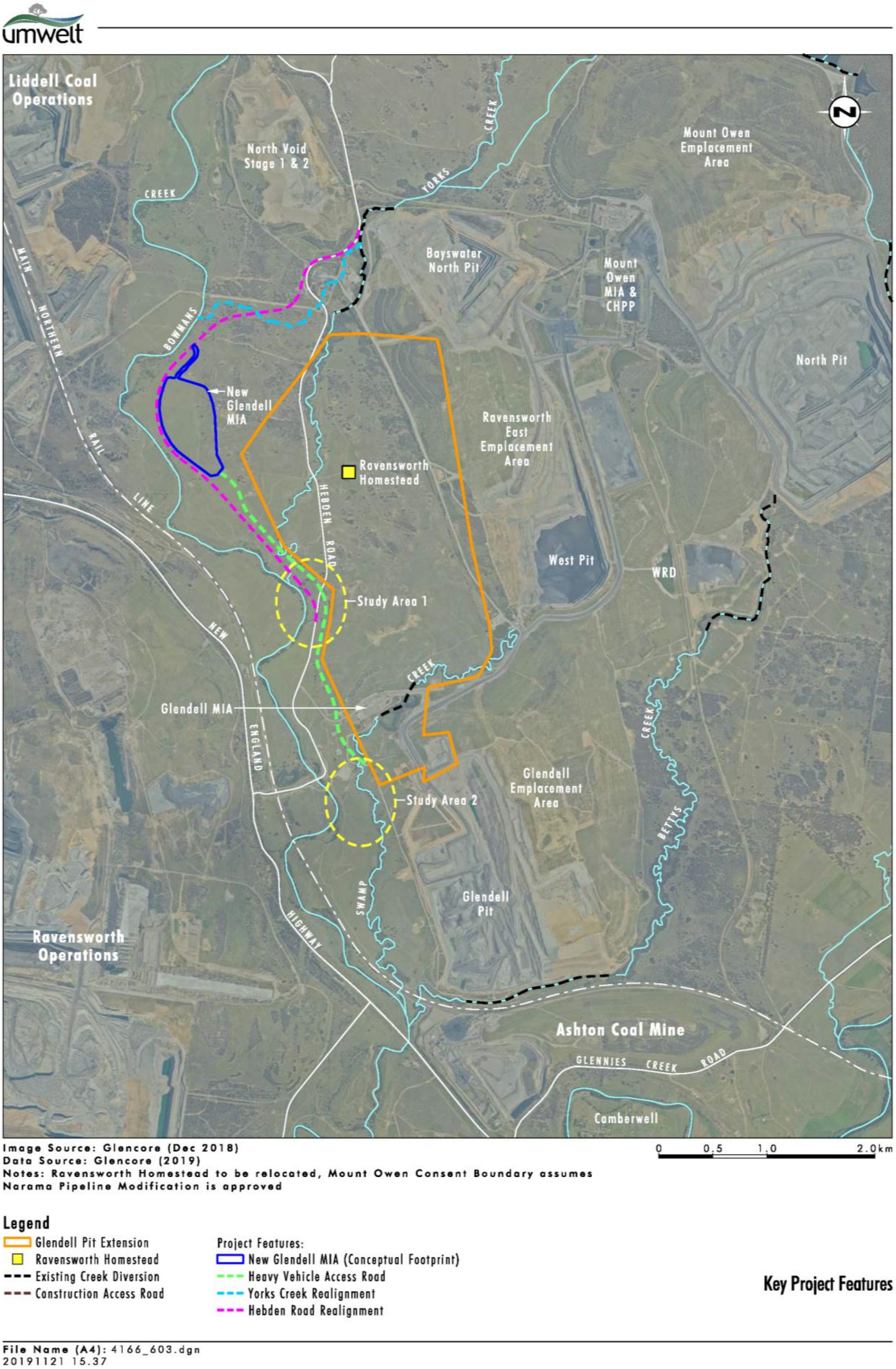


Figure 1 – Proposed Glendell Continued Operations Project and Bowmans Creek Study Areas (after Umwelt 2019)

2. GEOLOGY OF THE AREA AND SOILS CONDITIONS

A layout of the proposed Glendell Pit Extension and adjacent Bowmans Creek are shown on **Figure 1**.

Based on the proposed extraction plans the Project mining area is positioned a substantial distance from the Bowmans Creek high banks. The distance between the western side of the Glendell Pit Extension and Bowmans Creek varies, ranging from 200 to 850 m. In Study Area 1 (the closest section) the boundary of the Glendell Pit Extension extends almost parallel to Bowmans Creek at approximately 200 m distance to the high bank. Study Area 2 is located in the vicinity of the Hebden Road crossing over Bowmans Creek. In this area the Glendell Pit Extension is located at approximately 400 m distance from the high bank of Bowmans Creek.

These two areas marked as Study Areas 1 and 2 on **Figure 1**, were inspected, assessed and analysed in detail. The results of the assessment are presented in this section.

2.1 Project Geology and Pit Wall Conditions

Geology of the Area

The undertaken assessment of the rock strata conditions is based on a review of geological conditions for the area. The information about the local geology was obtained in the form of borehole logs. The locations of the boreholes which are representative for the area of interest are highlighted in **Figure 2**. In total 36 borehole logs were inspected, three representative borehole logs from the northern, central and southern parts of the Project (GNC009, GNOH08 and GNC011 respectively) are presented in **Figure 3**.

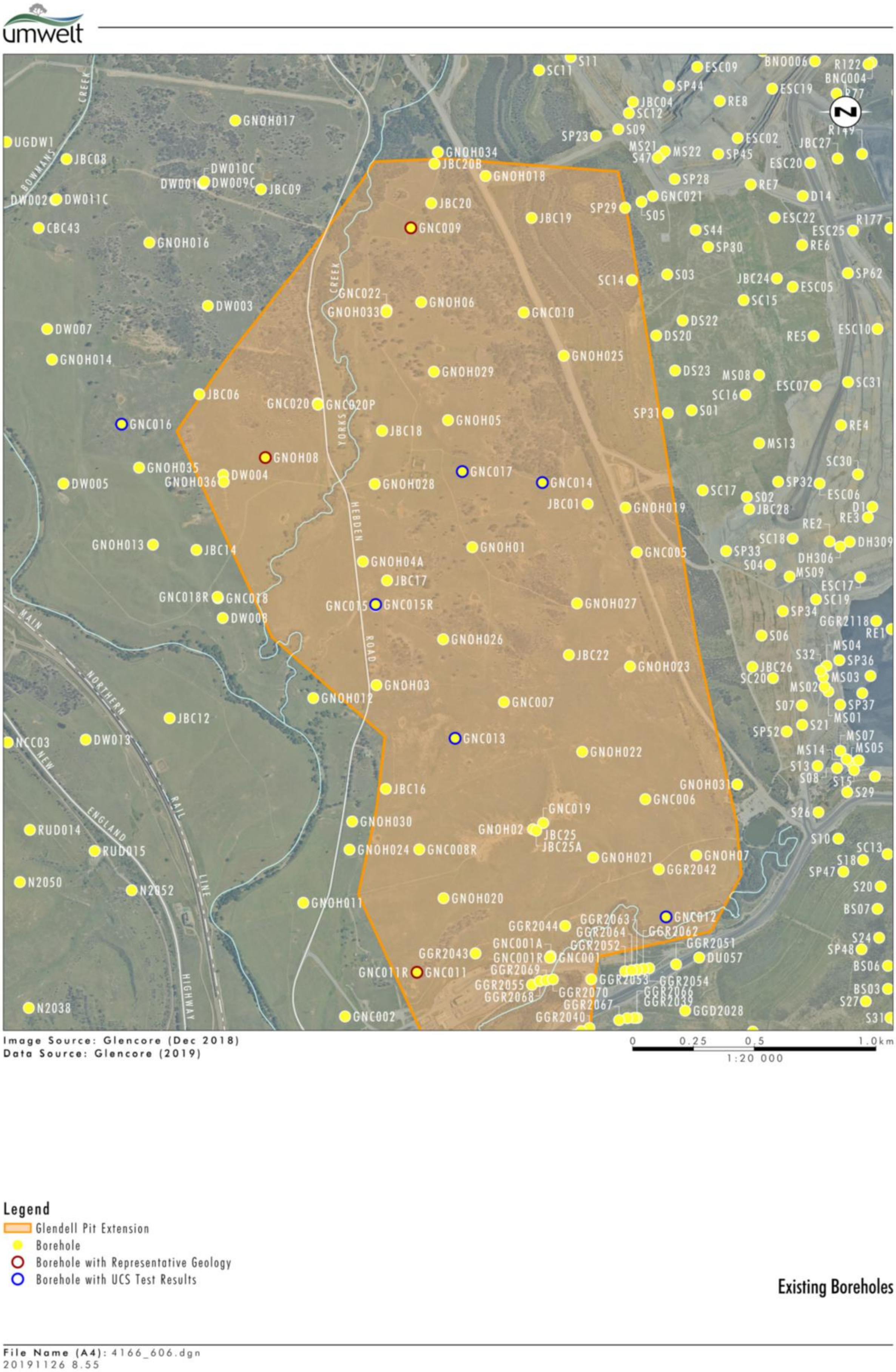


Figure 2 – Project Mining Area and Boreholes (after Umwelt (2019))

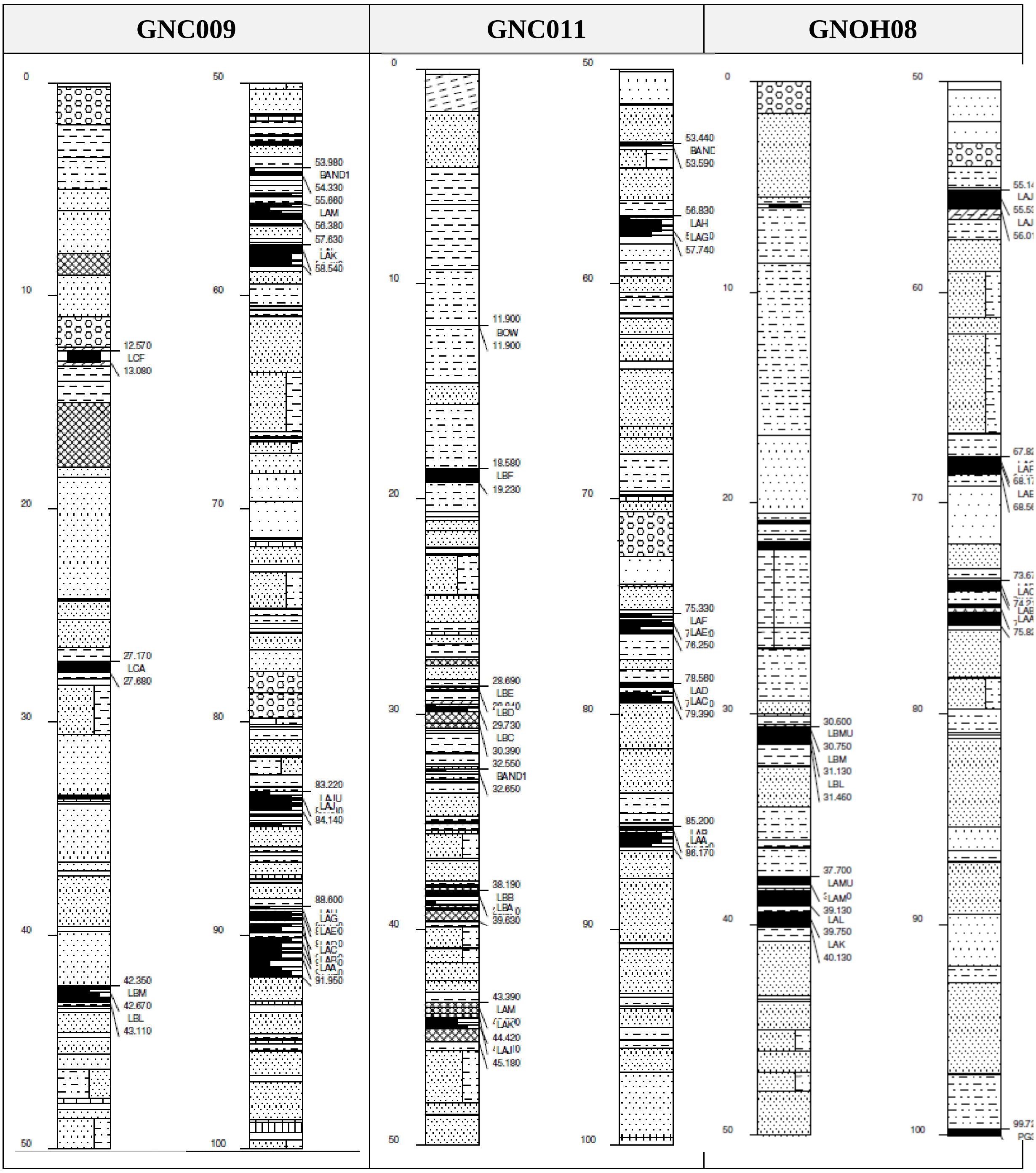


Figure 3 – Three Representative Borehole Logs for the Project Area

The reviewed borehole log data (based on 36 logs, see **Appendix 1**) is summarised as follows.

In general, the boreholes indicate highly variable geology of the area with occasional intersected conglomerate pockets.

The assessed borehole log data revealed only a limited number of boreholes included a soil material. The extent of weathered material is highly variable across the 36 boreholes ranging between 7.5 and 18.7 metres. The strata is well bedded and greatly varies from hole to hole. At greater depths, there are a number of rock strata measures including sandstone, mudstone, siltstone, coal and occasional tuff. There are a high number of holes which intercepted a significant amount of conglomerate.

The rock strength values obtained from the six boreholes as indicated in **Figures 2** and **9** (i.e. obtained by standard Unconfined Compressive Strength (UCS) rock testing undertaken by Strata Testing Services (rock testing laboratory) in 2018), presented in **Table 1**, indicate moderately strong to strong rock types being present within the Project Area with majority being above 30 MPa (comparable to a typical concrete strength value). Overall, the rock strength in the strata tested varies between 6 and 85 MPa. Generally, for these types of rocks the extent of damage due to blasting is relatively limited, as cracks are not readily transmitted through such strong strata medium, i.e. over 30 MPa.

Generally, it is concluded that none of the boreholes included significant amount of soft strata material prone to fracturing and extending to a substantial distance away from the final pit wall area. There was only one softer claystone layer of approximately 6 MPa strength value identified.

Generally, for the described strata quality the risk of damage and fracture propagation is low / negligible. In such a configuration, thin layers of weaker strata are interlocked between thicker layers of stronger strata providing adequate resistance to blast vibration and subsequent strata fracturing, as the system acts as a single cohesive unit.

In summary, the described geological conditions for the Project are fully comparable to geological conditions of the current Glendell Mine. The obtained rock strength data (refer to **Table 1**) showed moderately strong rock strata materials, which are resistant to rock strata fracturing induced by the adjacent open cut blasting. Therefore, blasting impact on the strata adjacent to the Glendell Pit Extension will have similar effect as for the current Glendell Mine; see following section for detailed assessment.

Table 1: Summary of Unconfined Compressive Strength (UCS) Results for the Proposed Project Area (after Strata Testing Services 2018)

Rock Type	Depth (m)	UCS Maximum (MPa)
Borehole GNC012 (coordinates: 319054.95, 6410162.08)		
Claystone	31.56 - 31.86m	6.01
Claystone	56.43 - 56.73	31.4
Conglomerate	77.53 - 77.77m	61.1
Sandstone	85.22 - 85.61m	62.4
Siltstone	88.41 - 88.76m	35.2
Siltstone	106.47 - 106.88m	32.5
Claystone	109.80 - 110.10m	35.4
Siltstone	129.79 - 130.07m	39.4
Claystone	133.40 - 133.72m	85.3
Claystone	151.46 - 151.70m	50.7
Mudstone, Carbonaceous	155.71 - 155.95m	61.1
Claystone	170.41 - 170.71m	48

Rock Type	**Depth (m)**	**UCS Maximum (MPa)**
Siltstone	174.06 - 174.31m	36.3
Siltstone	181.36 - 181.66m	55.2
Borehole GNC013 (coordinates: 318187.55, 6410895.63)		
Siltstone	31.10 - 31.40m	14.1
Siltstone	45.96 - 46.32m	20.2
Claystone	52.77 - 53.19m	27.4
Borehole GNC014 (coordinates: 318546.4, 6411946.28)		
Sandstone	31.87 - 32.13	70.2
Siltstone	59.74 - 59.96	28.3
Siltstone	61.90 - 62.15	37.7
Sandstone	71.70 - 71.96	52.6
Sandstone	80.25 - 80.49	27.5
Siltstone	103.10 - 103.42	41.1
Siltstone	108.44 - 108.66	62.1
Siltstone / Sandstone	134.33 - 134.61	80.9
Siltstone, carbonaceous	136.92 - 137.16	25.8
Siltstone - Coal Bands	138.14 - 138.37	24
Siltstone / Sandstone	162.31 - 162.62	47.9
Siltstone	172.09 - 172.34	59.8
Siltstone / Sandstone	182.02 - 182.37	56.5
Siltstone	229.97 - 230.25	31.9
Borehole GNC015 (coordinates: 317860.16, 6411440.03)		
Siltstone	67.52 - 67.84	44.4
Claystone	82.13 - 82.53	40
Siltstone	85.32 - 85.52	39.6
Siltstone	118.58 - 118.81	65
Siltstone	126.27 - 126.47	59.6
Borehole GNC016 (coordinates: 316816.7, 6412186)		
Siltstone	37.36 – 37.73	68.1
Sandstone / Siltstone	83.13 – 83.56	72.3
Siltstone	162.78 – 163.16	61.2
Claystone	195.94 – 196.26	71.2
Claystone	211.19 – 211.52	56.1
Claystone	235.39 – 235.65	86.6
Borehole GNC017 (coordinates: 318217.2, 6411992)		
Siltstone	96.51 – 96.94	36.7
Siltstone	121.0 – 121.38	29.6
Siltstone	163.08 – 163.50	60

Rock Type	Depth (m)	UCS Maximum (MPa)
Sandstone / Siltstone	199.38 – 199.68	19.8

Pit Wall Conditions

The geological conditions, pit wall design and blasting parameters will be similar to the current open cut operations at Glendell Mine. Therefore as the proposed Project will mimic the current Glendell open cut design conditions, a detailed site inspection of the current Glendell open cut area was undertaken to gauge the potential for rock strata damage behind the final pit walls and therefore identify possibility of rock strata damage to extend towards the Bowmans Creek area.

A general inspection of the Glendell open cut pit conditions was undertaken by ESC's Principal Consultant on 21 September 2018. The inspected sections are highlighted in **Figure 4**.

The site inspection included an overview of the western and southern highwall conditions of Glendell Mine (Barrett Pit) as well as the condition of the top surface strata near the western and southern highwall areas. The aim was to identify rock strata response following blasting and excavation operations and assess extent of potential rock strata damage spreading from the edge of the final pit walls. The areas inspected represent the full extent of the pit in these locations, meaning the strata inspected is reflective of the conditions following the completion of mining (and associated blast impacts) adjacent to these areas.

A typical cross-section through the final highwall showing Glendell geotechnical highwall design criteria is shown in **Figure 5**. For long term stability the final highwall includes a total of six benches, each 30 metres high.

Figure 4 – Glendell Mine Showing Inspected Sections of the Barrett Pit

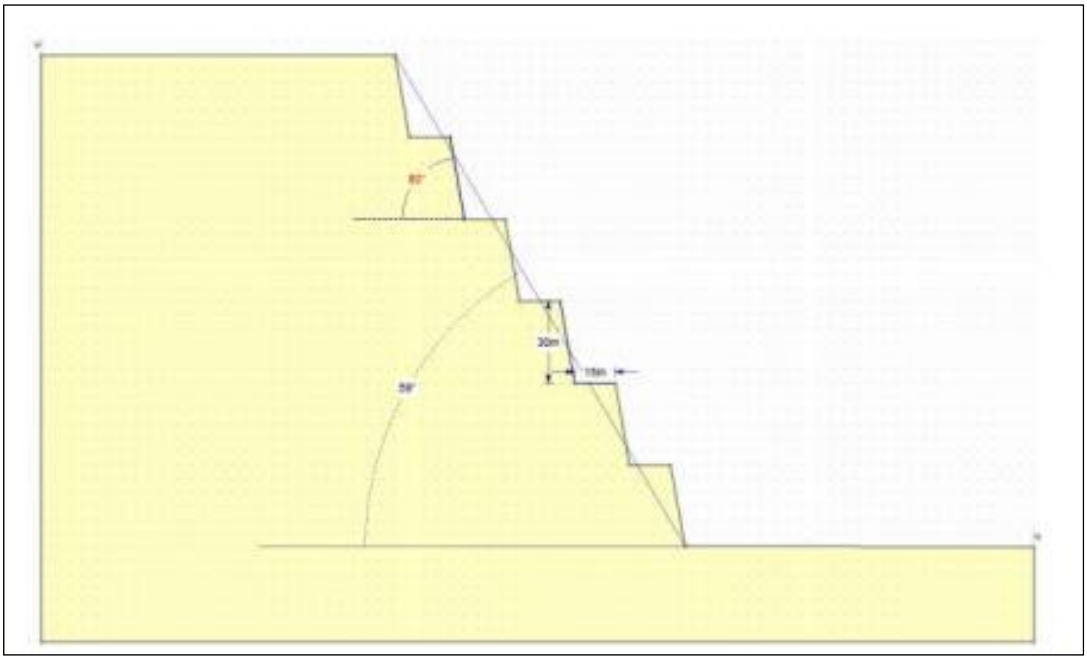


Figure 5 – Highwall Design Criteria for Glendell Mine (after AECOM 2018)

For safety and wall-stability both final highwalls have undergone pre-split blasting, this provides smooth highwall conditions and ensures long term stability of the pit walls. The same pre-splitting technique to achieve smooth final wall conditions will be employed for the proposed Project. Also, as the Project progresses in a northerly direction, the void in the south and central parts of the pit (adjacent to the Bowmans Creek Study Areas 1 and 2) will be backfilled using overburden material. This backfilling of the void area adjacent to areas close to Bowmans Creek will provide long term support for the highwall which reduces (and ultimately avoids) erosive effects and the potential for highwall failure which could increase fracturing in strata between the pit and Bowmans Creek.

In general, the inspection revealed some erosion impact in the top part of the top bench of the highwall. This is due to the presence of soft strata material in this section, including soil and other weathered strata layers. The lower highwall sections showed stable rock strata conditions (i.e. no significant wall stability issue nor any significant highwall damage due to blasting).

The inspection of the western highwall and adjacent surface area revealed the absence of any major slope stability issues. There is a minor impact of the local geology on the wall quality i.e. the jointing is almost parallel to the western wall face, hence occasional minor toppling failure exposing the joint surface can be observed. The final western walls are in the order of approximately 150 - 180 metres deep and provide stable highwall conditions. The surface strata inspection for the top of the western wall along the exposed wall revealed a lack of any surface cracking, see **Figures 6A-B**. There is some ongoing water erosion damage at the top of the slope (limited to the soft strata layers), which is typical for open cut pits and is of no consequence in terms of developing adjacent surface strata cracking.

Figure 6A – View of the Western Wall Condition of the Barrett Pit (Sept. 2018)

Figure 6B – View of Top Surface Strata Adjacent to the Western Wall of the Barrett Pit (Sept. 2018)

The inspection of the southern wall determined similar rock strata behaviour as for the western wall. There is a soft upper strata layer which undergoes erosion process. The lower sections revealed relatively stable wall conditions, without any visible toppling or wedge failure effect which could potentially extend beyond the original wall face, see **Figures 7A-B**.

In some sections a noticeable effect of the local geology on the final wall condition can be observed. The inspection revealed that the joints direction is unfavourable (i.e. almost perpendicular to the wall face), which ultimately manifests as jagged edge wall condition.

The top surface strata inspection along the southern highwall did not reveal any visible cracks / fissures / strata movement on the surface, which could potentially impact on the ongoing strata deterioration and propagate the damage further away from the edge of the southern highwall.

In summary, both inspected highwalls are classified as stable and did not reveal any obvious signs of blast impacts such as back break or ongoing rock strata damage, which could impact on the long term highwall condition. There is a minor surface erosion for the top (soft) strata layer (inferred to be Bettys Creek alluvium) however this is expected given the general weathered nature of this material prior to mining. The inspection did not reveal any obvious signs of surface cracking behind the inspected highwalls, which could affect adjacent rock strata beyond the highwall area. As such blasting impacts from Glendell Mine blasts do not seem to have a significant impact on the condition of the adjacent strata (including the softer weathered strata).

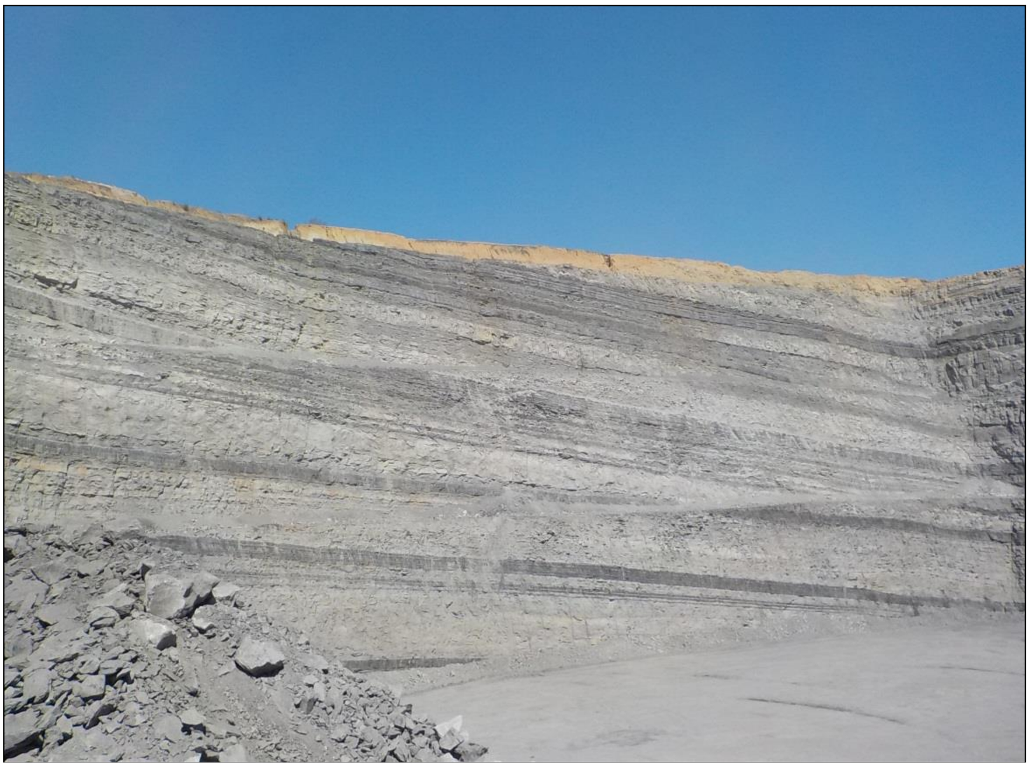


Figure 7A – View of the Southern Wall Condition of the Barrett Pit (Sept. 2018)

Figure 7B – View of Top Surface Strata Adjacent to the Southern Wall of the Barrett Pit (Sept. 2018)

2.2 Bowmans Creek Soils and Inspection Summary

Bowmans Creek Soils

Geologically, the Project Area is subdivided by the Camberwell Anticline (centrally located and trending North-South), which separates the Project into western and eastern sections which are structurally different. The presence of the anticline highly influences the dipping of the strata layers.

Based on the geological model developed for the Project, see **Figure 8** (i.e. cross-section for East-West directions for the Glendell Pit Extension) the strata is dipping to the west, away from the Glendell Pit Extension towards Bowmans Creek. This is a favourable condition as collected water from Bowmans Creek aquifer would not be drained away towards the Glendell Pit Extension i.e. against gravity.

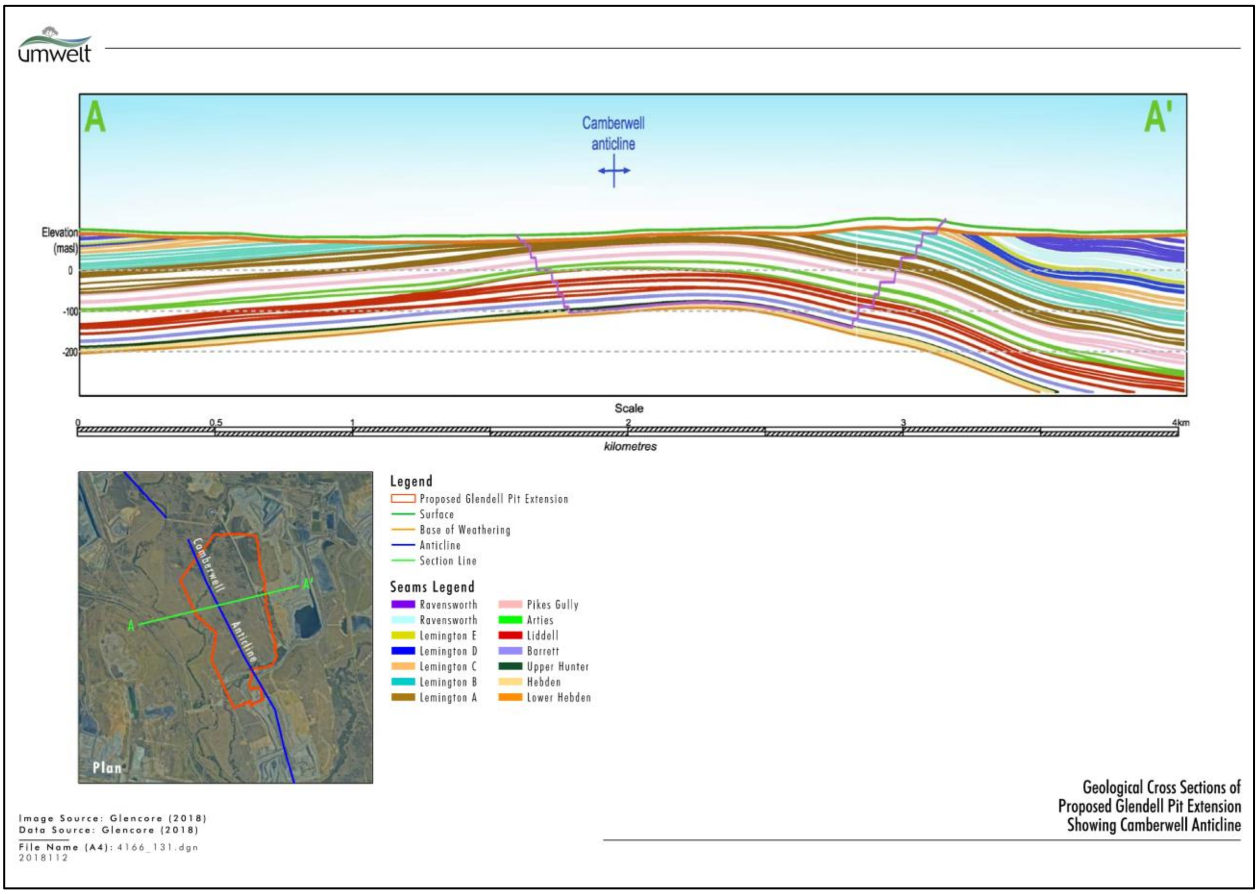


Figure 8 - Geological Cross Section (East-West) for Glendell Pit Extension

To assess Bowmans Creek geology, data from three paired piezometers (six in total) installed along the length of Bowmans Creek was analysed (i.e. based on piezometers installed by Jacobs Engineering Consultants); for the location of piezometers see **Figure 9**. The bore logs obtained during piezometer installation, which targeted the alluvium and weathered bedrock, are considered fully representative of the strata conditions for the Bowmans Creek study.

The depth of the bore holes ranged from 5 to 16 m. Generally, the top section of the bore logs revealed soft formations (such as sandy clay / gravel / sandy gravel or similar) i.e. representing alluvium material of the creek. This was followed by stronger formations such as coal, sandstone or siltstone. The coal layer was found at around 8 metre depth. It is inferred that the creek bed is located on these stronger bedrock formations (i.e. sandstone / siltstone layers), with softer material being washed away.

The borehole logs revealed detailed stratigraphy for the creek banks and creek river bed. All borehole logs presented multiple layered rock strata, see **Appendices 2A-B**.

An outline of the stratification for the examined borehole logs is summarised as follows:

GNP09D – (14.4 m deep) – 0.7 m of sandy clay, 1 m clayey sand, 1.7 m of sandy gravel, 3 m of gravel, 1.2 m of sandy clay, 2.3 m coal, 5 m sandstone.

GNP09S – (6.6 m deep) – 0.7 m of sandy clay, 1.2 m of clayey sand, 1.7 m of sandy gravel, 3.1 m of gravel.

GNP10D – (16 m deep) 0.3 m of topsoil, 3.7 m of gravelly sand, 2 m of clayey gravel, 1.4 m of gravel, 0.3 m of residual sandy clay, 0.7 m of weathered sandstone, 3.2 m of sandstone, 0.2 m of coal, 2 m of sandstone, 0.2 m of coal/tuff, 2 m of sandstone.

GNP10S – (7.1 m deep) 0.3 m of topsoil, 3.7 m of gravelly sand, 2 m of clayey gravel, 1.1 m of gravel.

GNP11D – (11.1m deep) 0.9 m of topsoil, 0.4 m of gravelly sand, 0.5 m of sandy gravel, 3.2 m of clayey gravelly sand, 0.6 m of sandy clay, 2 m of weathered sandstone/siltstone, 1.2 m of coal, 2 m weathered siltstone, 0.3 m of sandstone.

GNP11S – (5.4 m deep) 0.9 m of topsoil, 0.4 m of gravelly sand, 0.5 m of sandy gravel, 3.2 m of clayey gravelly sand, 0.4 m of sandy clay.

The provided logs demonstrate that the sequence is generally well bedded. The dominant strata layers for Bowmans Creek area (within the first 16 m of drilled depth) in this region generally consist of the following:

- Creek embankment (typically)
    - a top layer of soil,
    - either clayey sand / or sandy clay / or gravelly sand (i.e. few different layers present)
    - either sandy gravel / or clayey gravel (i.e. gravelly material present)
- Creek bed (typically)
    - weathered sandstone or siltstone
    - coal
    - sandstone or siltstone

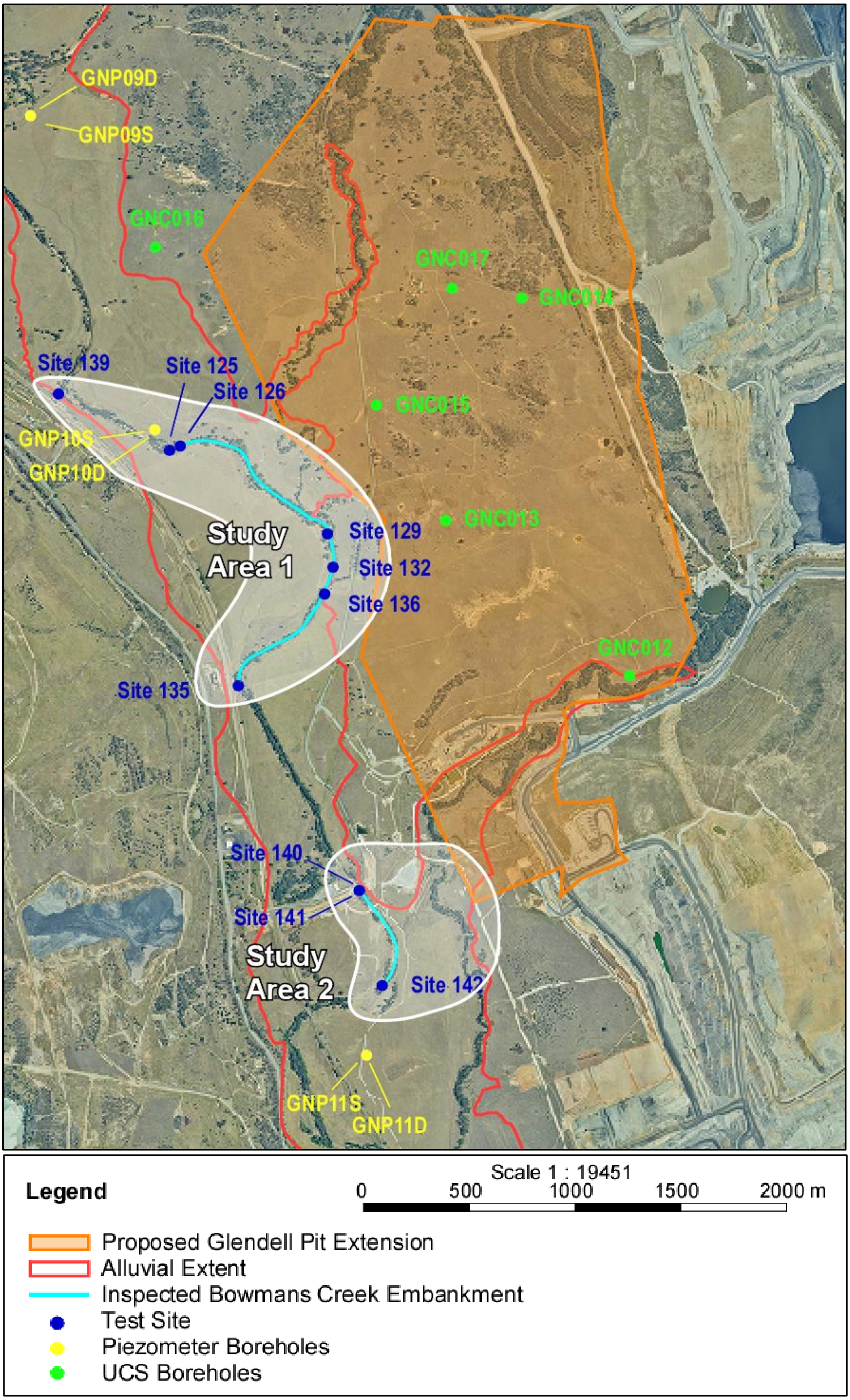


Figure 9 – Project Boundary, Piezometer Locations, UCS Boreholes and Tested Sections

Inspection Summary

A general site inspection of the Bowmans Creek area was carried out by ESC's Principal Consultant on 26 September 2018. The site inspection included an overview of creek bed conditions, creek banks and the area located between Bowmans Creek and the proposed Glendell Pit Extension; see **Appendices 3A-P** for Study Area 1 and **Appendices 4A-D** for Study Area 2.

In addition to a visual assessment a non-destructive type of testing was undertaken using a Schmidt Hammer (operating range 10 – 60 MPA) and a penetrometer (operating range 0 - 5 MPa), see **Appendices 5A-B**. The results of the non-destructive tests using the above specified instruments are summarised in **Table 1**. The sites where the testing was undertaken are marked in **Figure 9**.

<u>Creek Bed Conditions</u>

The inspection of the creek bed (within the Study Areas) was undertaken during drought conditions. The creek bed was mostly dry with a few small remaining pools of water (i.e. ponds) scattered occasionally. The inspected sections of the creek bed generally were covered with vegetation. The creek bed was laced with a high number of fist size cobbles (typically ranging between 5 and 20 cm in diameter), see **Figure 10A**.

In sections, it was observed that besides the overlying silt the creek bed rock included typically sandstone and siltstone bedrock layers, see **Figure 10B** to **10C**. Whenever possible the creek bedrock was tested using Schmidt Hammer to obtain an indicative rock strength values for the creek bed. In places the sandstone strata extended into the embankment walls. This allowed for rock strength testing. The results of rock strength testing are summarised in **Table 2**, while the tested locations are marked in **Figure 9**. The table indicates rock strength values for the creek bedrock being in the order of 7 – 10 MPa. This is sufficient to sustain moderate/high vibration exposure without negative impact on the rock strata conditions.

Figure 10A – View of Bowmans Creek Bed (Sept. 2018)

Figure 10B – View of Bowmans Creek Bed Showing Sandstone/Siltstone Layer (Sept. 2018)

Figure 10C – View of Bowmans Creek Bed Showing Sandstone Layer (Sept. 2018)

Table 2: Summary Results of Non-destructive Testing

Site	Penetrometer Rock Strength (MPa)	Schmidt Hammer		Average Rock Strength (MPa)
		(Rebound Number)	Rock Strength (MPa)	
Study Area 1 – Site 125 (316883; 6411227) (Creek bank)				
ID 125	5, 5, 5	(Not engaged, <10), (Not engaged, <10), (Not engaged, <10)	< 10, < 10, < 10	5
Study Area 1 – Site 126 (316934; 6411247) (Creek bank)				
ID 126	5, 5, 5	(Not engaged, <10), (Not engaged, <10), (Not engaged, <10)	< 10, < 10, < 10	5
Study Area 1 – Site 129 (317629; 6410832) Siltstone / sandstone band (Creek bed)				
ID 129	5, 5, 5, 5, 5	16, 10, 10, 14, 10, (Not engaged, <10), 24, 22, 16, 30, 26	< 10, < 10, < 10, < 10, < 10, < 10, 10, < 10, < 10, 22, 15	Approx. 8 – 10
Study Area 1 – Site 132 (317655; 6410675) Sandstone band (Creek bed)				
ID 132	5, 5, 5, 5	(Not engaged, <10) (Not engaged, <10) 18, 25, 10, 10, 10, 26, 24, 12	< 10, < 10, < 10, 12, < 10, < 10 < 10, 15, 10, < 10	Approx. 7 - 9
Study Area 1 – Site 135 (312208; 6410115) (Creek bed)				
ID 135	5, 5, 5, 5	24, 24, 25, 23, 22, 18, 21, 22, 20, 25, 24, 30	10, 10, 12, <10, <10, <10, <10, <10, <10, 12, 10, 22	Approx. 8 - 10
Study Area 1 – Site 136 (317615; 6410548) (Creek bank)				
ID 136	5, 5, 5, 5, 5			5
Site 139 (316359; 6411493), Sandstone band (yellow/orange colour)				
ID 139		28, 35, 25, 28, 20, 37, 33, 18, 38, 29, 32, 30, 28	18, 30, 12, 18, <10*, 34, 28, <10*, 36, 19, 26, 22, 18	21
Study Area 2 (near the bridge) (317779; 6409148), Concrete Pillar (for comparison)				
ID 140		40, 40, 39, 39, 53, 48, 45, 42, 43, 43	40, 40, 38, 38, 60**, 54, 49, 43, 45, 45	45
Study Area 2 (near the bridge) (317779; 6409148), (Creek bank)				
ID 141	5, 1.8, 4, 3.5, 4.2			3.7
Study Area 2 (317887; 6408699), (Surface Strata)				
ID 142	5, 5, 5, 5, 5			5

**- assumes value of 5 MPa for calculations (10 MPa is the lower limit of the instrument range)*
*** - assumes value of 60 MPa for calculations (60 MPa is the upper limit of the instrument range)*

<u>Creek Embankment</u>

The site assessment included site inspection along the whole marked corridor of Bowmans Creek's Study Area 1 and Study Area 2. The inspection focused on the following:

- assessment of the state of the creek bed condition, including an assessment of the composition of the creek bed strata layers i.e. identification of strata layer composition and material cohesion supported by limited strata testing using penetrometer
- assessment of the creek bed conditions including identification of rock strata layers and rock strata testing using a non-destructive rock testing method. This was achieved through the use of a Schmidt Hammer and penetrometer.

The inspection of the Study Areas revealed substantial variability in the creek embankment heights ranging from 0.5 up to 4 metres in the highest places (with 1 m high being the most common) (See **Appendices 3A-P** for Study Area 1 and **Appendices 4A-D** for Study Area 2).

Based on the site inspection a typical cross-section through the creek embankment generally consists of at least three different layers of material, as marked in **Figure 11**. The observed stratification included top soil (top section), either clayey sand / or sandy clay / or gravelly sand (middle section), and either sandy gravel / or clayey gravel (bottom section). The base below these three layers was formed from either sandstone or siltstone strata (creek bedrock - typically sandstone / siltstone, coal, sandstone)

It was also noted that the level of compaction, material cementation and strength increase for deeper strata layers in comparison to the shallower layers. Also, larger gravel size material was observed for deeper layers than to shallower layers. Occasionally, well compacted conglomerate sections were also observed.

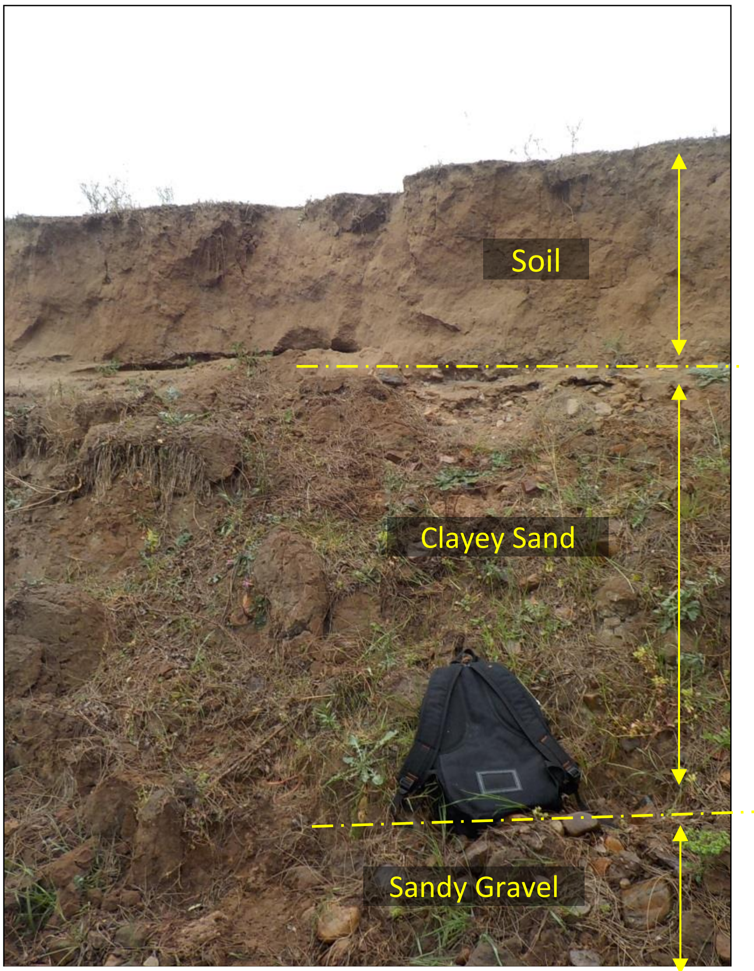


Figure 11 – Typical Cross-section through the Creek Bank (Sept. 2018)

Area between Bowmans Creek and Glendell Pit Extension

The inspection of surface strata between the Glendell Pit Extension and Bowmans Creek did not reveal any obvious signs of faulting, the presence of joints, unusual rock outcroppings or other obvious signs of potential weaknesses. The surface vegetation precluded a more detailed assessment.

The available hazard risk map (after Pre-feasibility Report (2018)), includes identified geological features in the vicinity of the Project Area and is shown in **Figure 12**. There are two known geological features (i.e. the dyke and block fault zone) intersecting Bowmans Creek. These features intersect Bowmans Creek in the sections substantially distant from the Glendell Pit Extension (i.e. 470 and 620 m for the dyke and block fault zone respectively).

The site inspection of the area between the Glendell Pit Extension and Bowmans Creek revealed surface strata consisting of heavy compacted soil / clay material (in the top section) with an indicative strength in the order of 5 MPa. Therefore, no damage due to blast vibration on such compacted surface strata and associated alluvium is to be expected.

Note that during the inspection (September 2018) the NSW state was experiencing drought, highly impacting on soil densification and compaction, particularly applicable to soils with a clay component.

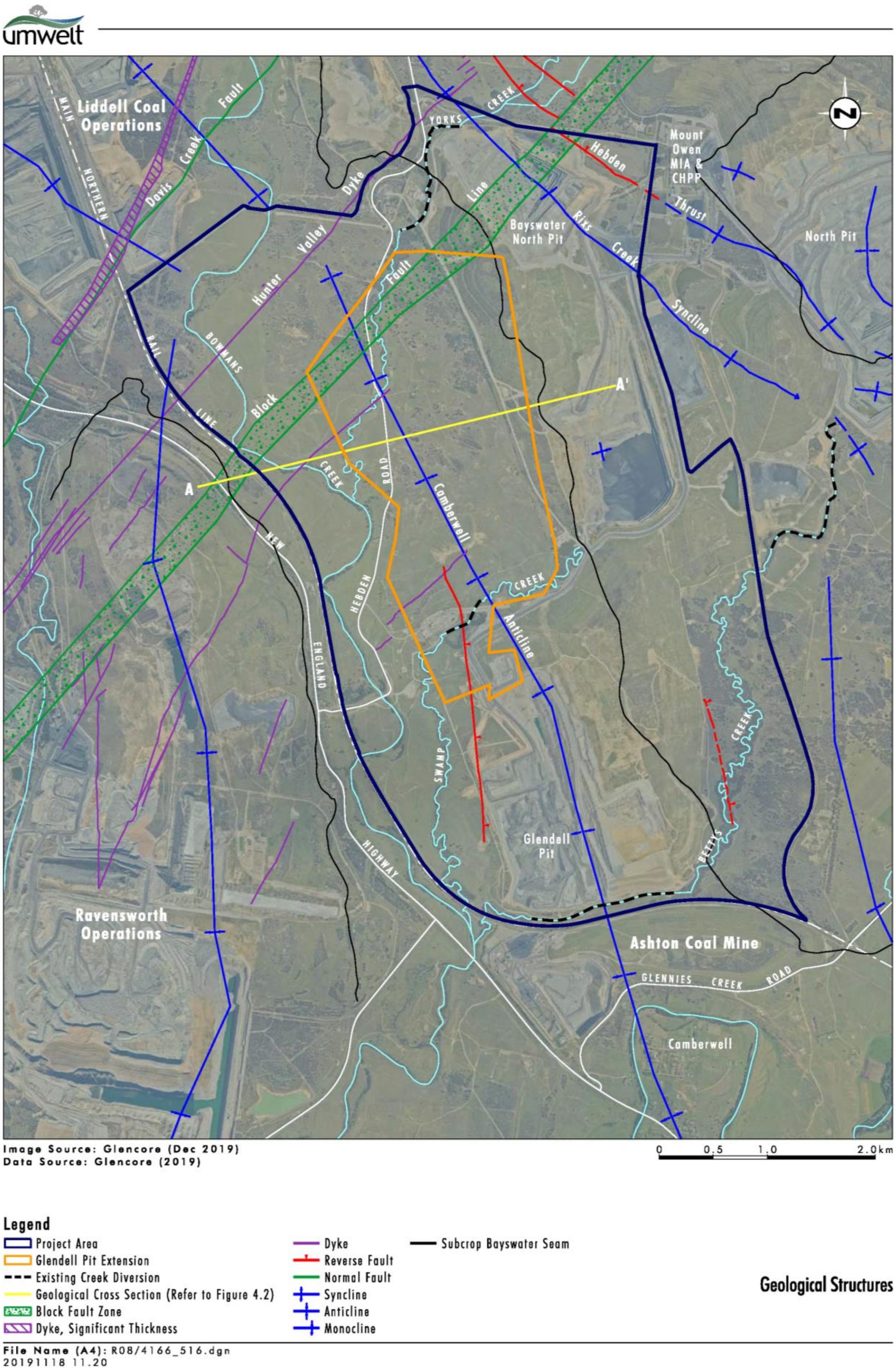


Figure 12 – Hazard Risk Map Showing Identified Geological Features (after Umwelt (2019))

3. REVIEW OF PAST STUDIES

The literature review presented below aims to provide evidence related to:

- the impacts on rock strata conditions and strata fracturing related to close range blasting in the vicinity of sensitive areas (i.e. adjacent benches, roads and underground tunnels),
- indication of vibration limits when blasting in the vicinity of creeks / rivers and the impacts on embankments and nearby infrastructure (including bridges and dams).

The presented review aims to provide an indication of potential strata behaviour when subject to blasting from the adjacent open cut operation and consequently the effect on Bowmans Creek and associated alluvium.

3.1 Assessment of Close Range Blast Impacts on Potential Bulk Displacement and Strata Fracturing for a 110 m Wide Strata Pillar (South Africa)

Rorke and Thabethe (2004) described large scale open cut blasting in South Africa immediately adjacent to the main national road. The road was positioned between two open cut voids (forming a road bearing pillar of 110 m in width) creating a risk of potential bulk displacement (i.e. rock strata displacement and related rock strata fracturing) due to a lack of confinement on both sides of the road. **Figure 13** presents a simplified section showing the risk of bulk displacement of the pillar (bearing the road) as a result of the reaction forces from the blast. The large-scale blast was undertaken immediately adjacent to the pillar. The risks were identified and included flyrock, vibration damage and bulk displacement. Each risk was dealt with appropriately.

As a result of these blast design control measures the blast produced a low vibration impact, well below the specified limit of 150 mm/s. The back damage (behind the blast) was very limited and there was no evidence of bulk ground displacement. No damage to the road was detected.

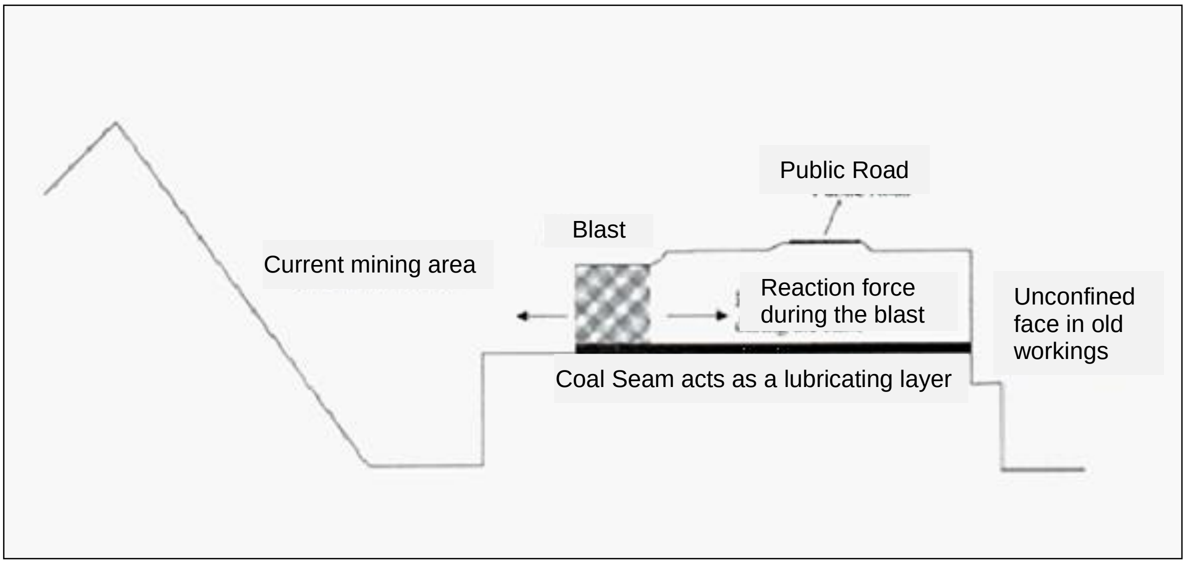


Figure 13 – A Simplified Cross-section Showing the Risk of Bulk Displacement of the Road Bearing Pillar as a Result of Reaction Forces from the Blast on the West Side (left) of the Road (after Rorke and Thabethe, 2004)

3.2 General Guidelines on Vibration Limits – ACARP Project C14057

ACARP Project C14057 is a research project sponsored by the coal mining industry. The publications from ACARP Projects are recognised as reference materials. This type of study provides an independent opinion on various technical subjects.

Project C14057 produced general guidelines on allowable vibration limits for various infrastructure facilities, see **Table 3**. The report recommends a limit of 100 mm/s for most infrastructure including bridges. Since bridges are installed on or close to river embankments, it can be reasoned that this level of vibration exposure is safe for river / creek banks and hence the same limit of 100 mm/s could potentially be applicable.

As indicated in the ACARP report, the values in **Table 3** are only an initial recommended limit. The report indicates that higher vibration limits can be considered following a more detailed assessment of the vibration tolerances of specific structures by a qualified expert. Therefore, one can infer a significant factor of safety in the recommendations provided by the ACARP report.

Table 3: Recommended 'Safe' Vibration Limits without more Detailed Analysis (after ACARP 2008)

Item		Previous Limit[5] (mm/s)	PPV Limit (mm/s)	Observation From (mm/s)	Possible Upper Limit (A) (mm/s)
Public roads		-	100		Block movement
Rail way lines		-	100*		Block movement
Concrete bridges		25	100≠[6]		200
Conveyor structures		25	100[6]		200
Power lines	Timber poles	-	100		200
	Concrete poles	25	100[6]		200
	Steel towers	25	100[6]		200
Electrical substations (Buckholz switches)			10-50	10	100[7]
Fixed mine plant and buildings		25	100		200
Underground workings		-	100[6]	10**/25	150[9]
Surface pipelines		-	100	25	150
Buried communication cables and pipelines		-	100	100	Block movement
Dams		-	100	50	200[10]
Heritage structures		-	BS7385 to 50mm[6]/s	20[x]	50
Mine offices, houses		10	BS7385 to 50mm[6]/s		200[8]

1* With track monitoring protocols and inspections
2** If men are present
3≠ Without traffic loads
4x In maintained condition
5(*) AS2187.2-1993
6(**) AS2187.2-2006
7 With reed switches
8 With minor repairs
9 Adequate ground support
10 Fell et al
(A) Only after a detailed investigation to determine frequency response and strain measurements

3.3 Close Range Blasting and Assessment of Rock Strata Fracturing – CSIRO Report

A CSIRO study presented by O'Regan et al (1983) produced a detailed assessment of rock strata behaviour immediately adjacent to a major open cut blasting area. The study was undertaken by the CSIRO with various monitoring equipment placed strategically behind the blasting area at Blackwater Open Cut Mine, see **Figures 14A** to **14C**. The study utilised accurate surface and sub-surface instrumentation (including extensometers and piezometers) as well as conventional ground survey techniques and cross hole seismic surveys.

The study can be summarised as follows:

- The damage to the adjacent highwall is a function of both geology and blast design.
- The extent of damage, including back-break cracking, which developed on the surface (vertical cracks or semi vertical), was limited to 23 m from the highwall (based on extensometer results). Based on a seismic survey the extent of the damage is limited to approximately 30 m showing a reduction in the seismic velocity.
- The extent of the horizontal cracks (along the weak strata layer) was estimated to be 50 m horizontally from the blasting area (based on extensometer results). The mechanism of rock damage was described in detail and was driven by gas penetration of the blasting product through the rock strata.

The presented study provides an extreme example of potential damage to the soft rock strata from the adjacent open cut surface blasting. By today's standard; it is apparent that the assessed blast was poorly executed, that is, ineffective timing and blast chocking (including inadequate face movement). Nevertheless, the study highlighted an extreme scenario of rock strata damage behind the open cut surface blast, as well as the potential maximum distance of rock strata damage behind the blasting area.

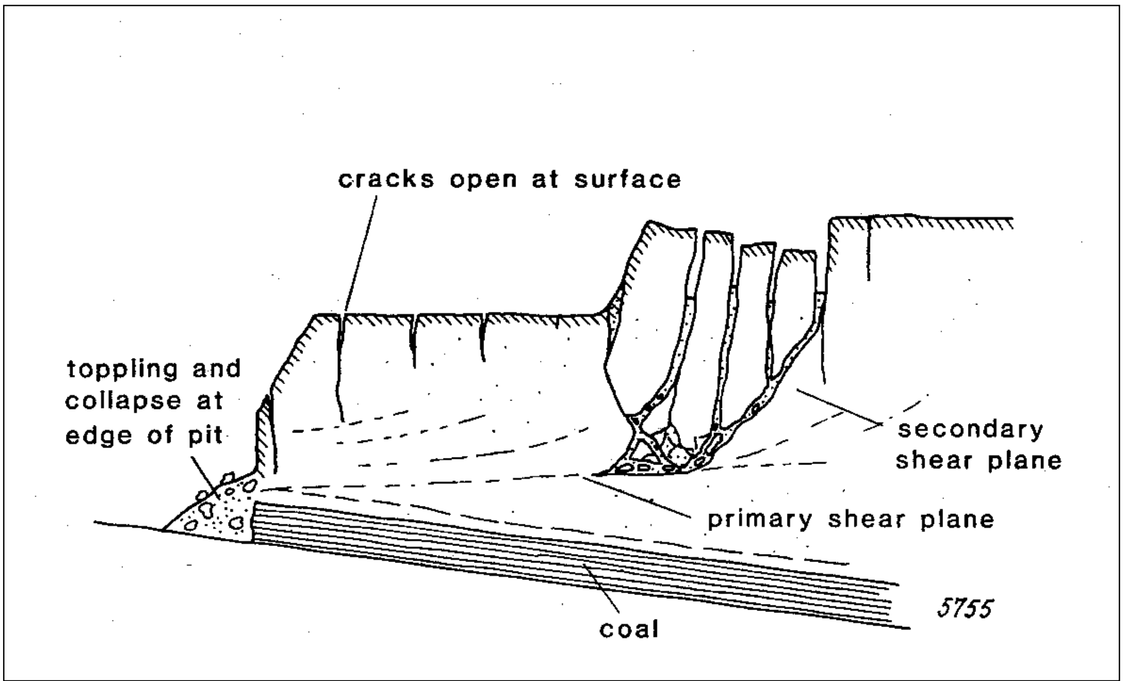


Figure 14A – Highwall Damage Due to Adjacent Blasting (after CSIRO 1983 Report)

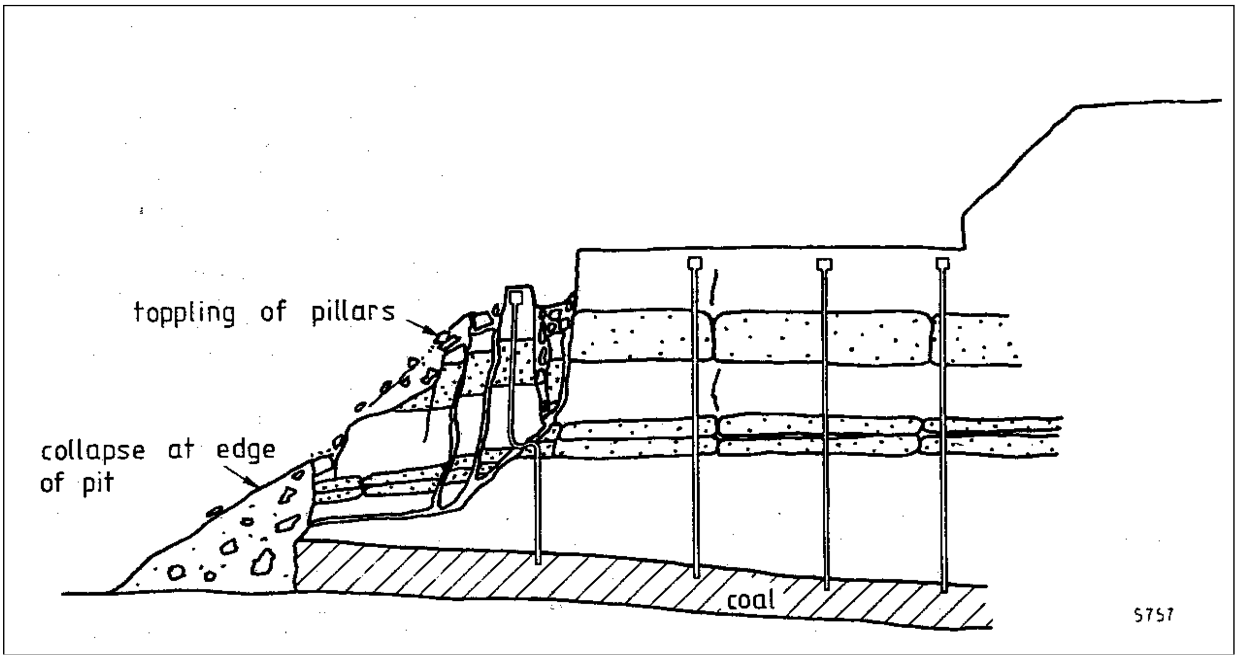


Figure 14B – Damage Showing Vertical and Horizontal Cracks (after CSIRO 1983 Report)

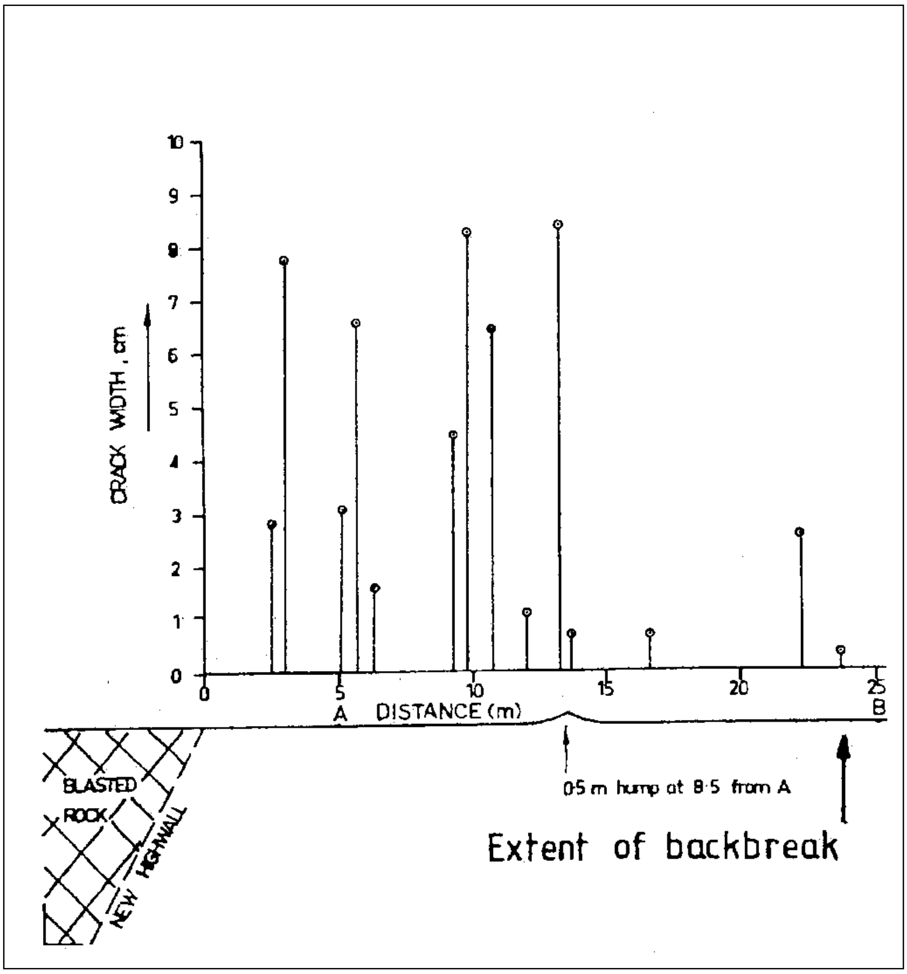


Figure 14C – Estimation of Back-break Cracking (after CSIRO 1983 report)

3.4 Close Range Blasting – Blast Impacts Study (Lewandowski and Cope 2009)

The study undertaken by Lewandowski and Cope (2009) dealt with the impacts of close range blasting on adjacent infrastructure at Bulga Open Cut Mine. The study also included a blast impact assessment on the local strata, specifically addressing damage from close range blasting. The surface strata included predominantly sandstone, mudstone, siltstone and coal bands.

The blasts of interest included pre-split blasts with an MIC of 530 kg. For these particular geological conditions, the extent of damage was relatively limited and was in line with other open cut mine experiences in the Hunter Valley, i.e. up to approximately 20 m behind the blast. The detected damage (manifested as a number of surface cracks and some surface layer displacement) was estimated to be in the order of up to 17 m from the edge of the blast, see **Figure 15.**

Figure 15 – Impact of Blasting – Showing Surface Rock Strata Damage to Blasted Pre-Split Line; Extending up to 17 m from the Edge of the Blast (after Lewandowski and Cope 2009),

3.5 Close Range Blasting and Rock Strata Fracturing Assessment – ESC (2007)

To demonstrate in detail typical rock strata behaviour when exposed to surface blasting ESC undertook an in-depth close range rock strata assessment study in a Hunter Valley mine in 2007. The mine of interest blasted through interburden material composed of sandstone and shale rock strata layers. This is considered comparable to the proposed Project conditions. The explosive charges were in the order of 600 kg, which is also considered comparable to blast design details of the proposed Project.

The main aims of the study were specified as follows:

- to establish a ground vibration decay curve for the mine's conditions and

- to establish the extent of the damage zones behind the open cut blast.

The work included a detailed assessment of vibration levels and rock strata conditions (including logging of rock strata fractures) for the bench located behind the blasted bench.

For the purpose of the assessment a total of seven vibration monitors were placed behind the blasting area. The study was supplemented by detailed rock strata assessment including photography and a scanline survey of the rock strata. The main aim was to precisely delineate and describe the zones of actual rock strata damage caused by the adjacent open cut surface blasting. The vibration monitors were utilised to collect vibration monitoring data, which could assist in the development of an accurate vibration predictive model for these particular blasting conditions.

The findings of this study were summarised as follows:

- The extent of rock strata damage for the adjacent bench to the blasting area, including back break, was limited to approximately 11.5 m from the edge of the blasted bench.
- The damage zone, including back break, was exposed to vibration levels well in excess of 400 mm/s (i.e. beyond instrument capability, see **Figure 16**), confirming that extremely high vibration levels are required to induce rock strata damage.

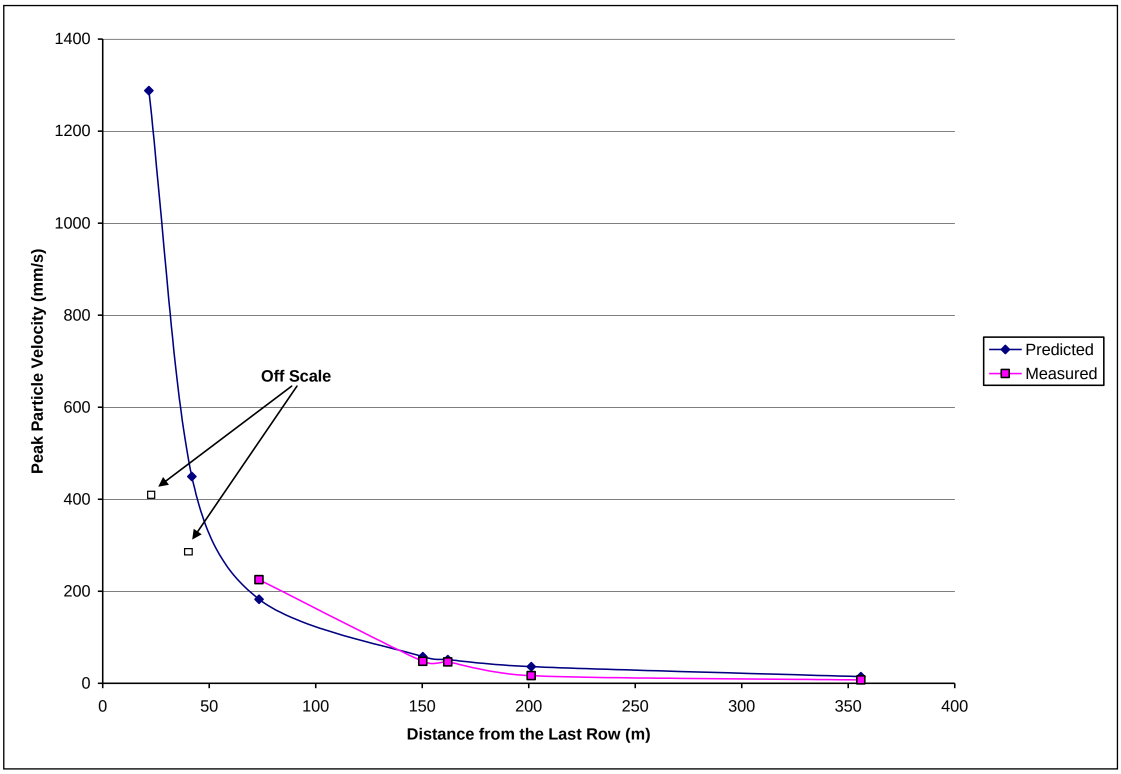


Figure 16 – Measured versus Predicted Vibration Behaviour

3.6 Underground Rock Tunnel off the Highwall – Assessment of the Rock Strata Damage from Blasting – (after ESC 2008)

The study undertaken by ESC in 2008 included an assessment of the impact of blasting on an underground mine tunnel located immediately off the highwall area. The highwall was originally formed by open cut blasting with an MIC in excess of 1,000 kg. Construction of the tunnel followed, which was located behind the previously fired blast and hence in the zone of highly fractured ground.

The study included an assessment of ground fracturing and rock wall damage within the underground tunnel, see **Figures 17A-C**. The assessment included a detailed inspection of the rock strata conditions for the underground tunnel, with the main aim to assess the level and extent of damage to the rock strata. The study was also supported by analysis of roof dilation data using roof extensometer measurements. This would provide evidence of horizontal crack formation caused by the adjacent strata blasting, see **Figure 17C**.

The rock strength data was also collated and included a review of the UCS values for the immediate roof strata. The moderately strong UCS values were measured for the immediate roof strata, ranging between 47 and 103 MPa. The UCS data was collated from a total of 16 borehole logs.

The study concluded that, in this particular case, the damage behind the highwall face (i.e. behind the blast) was limited to 12 m from the highwall entry. In this case both the horizontal and vertical cracks were limited to the quoted 12 m only. To combat the damage the underground mine had to substantially increase the bolting density (i.e. to mitigate the blasting damage effect of the rock strata), see **Figure 17B**. Note that beyond 12 m there was no apparent damage to the rock strata. Therefore, the impact of blasting was relatively limited for these particular rock strata conditions which included predominantly mudstone, siltstone, sandstone and coal bands.

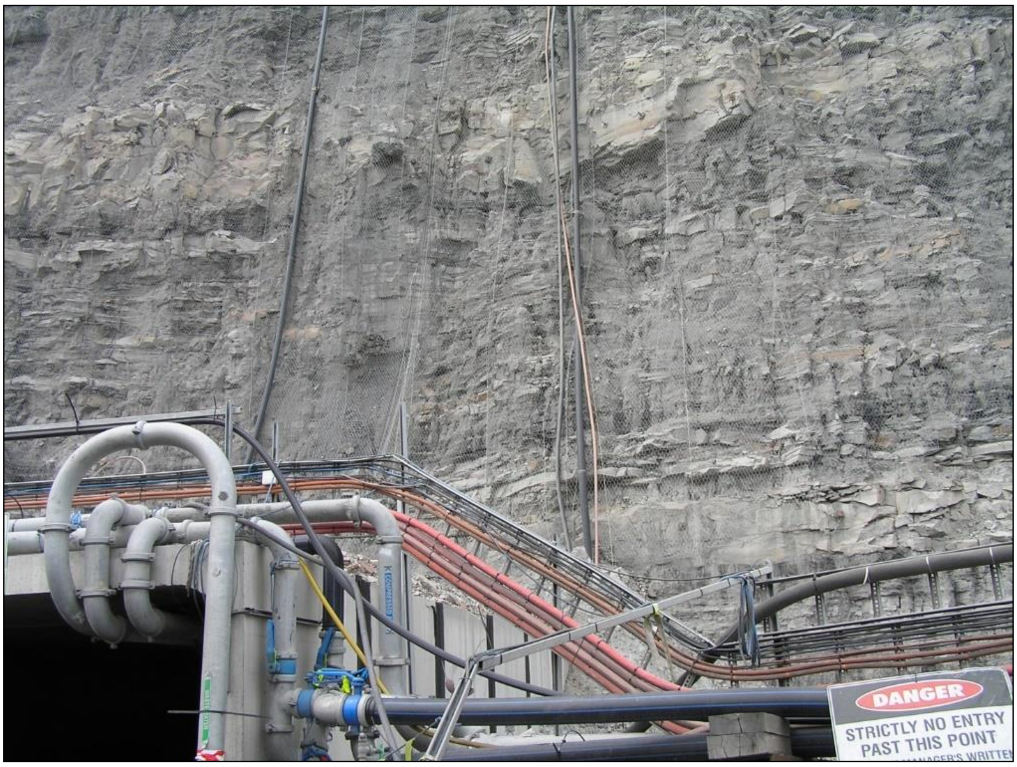


Figure 17A – Underground Mine Entry and Highwall Conditions after Blasting (after ESC Study 2008)

Figure 17B – Underground Strata Conditions and Induced Damage due to Previous Surface Blasting (after ESC Study 2008)

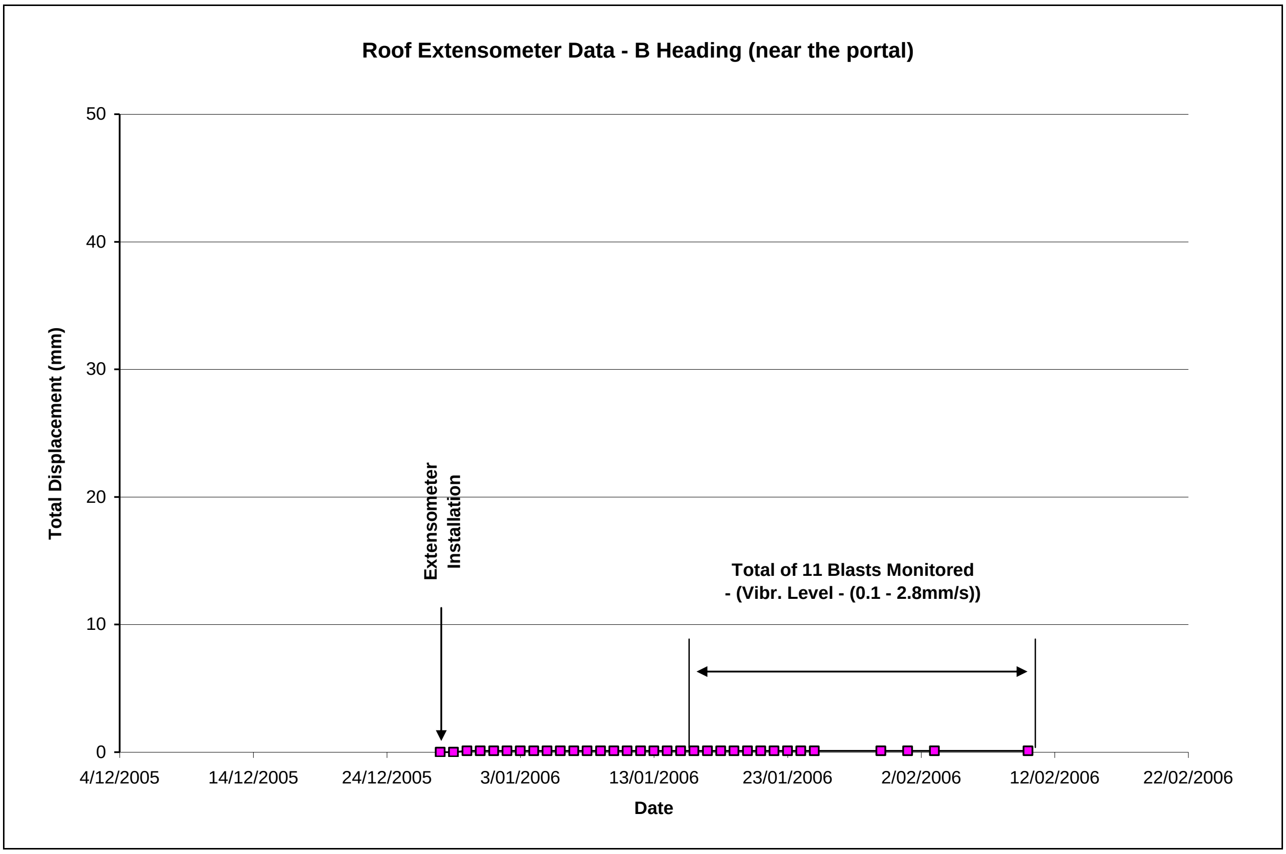


Figure 17C – Roof Extensometer Data near the Portal Entry

3.7 Blasting and Gas Monitoring through Fractured Rock Strata and Permeability Implications – McKenzie (1999)

Gas penetration, which occurs during the blasting process, assists in crack formation and subsequent crack progression within rock strata. The study undertaken by McKenzie (1999) provided a detailed summary of various research groups on gas flow into the adjacent rock strata. The gas monitoring in that case would provide strong evidence of the extent of rock strata fracturing behind the blasted bench and the induced increase in permeability of the rock strata (i.e. increased fracturing causes an increase in permeability of the rock strata). The elevated gas level is an indicator of the penetration of gases into the rock strata. As shown in **Figure 18,** with increased distance the pressure generated by gases (during the blasting process) decreases gradually. As such, the transmitted gas pressure causes less damage to rock strata and cases a lesser impact on strata permeability (with increased distance). At some point away from the blast the gasses are dissipated to such an extent that there is no sufficient pressure to cause any further damage to the strata, nor cause any impact on strata permeability. Also, one can conclude that the extent of damage and impact on permeability from the blasting area will be very much dependent on rock strength characteristics and the actual blast impact (i.e. controlled/affected by MIC and the type of blast / energy relief).

From all these studies, McKenzie provided a concise summary of the relationship between gas pressure data and distance, see **Figure 19**.

The monitoring showed high gas levels measured within 5 m of the blast and a decrease in gas pressure with an increased distance from the blasting area. The study indicates that low pressure has been measured at 15 – 16 m from the blasting bench, which is equivalent to approximately two burden distances from the blasted hole. McKenzie concluded that the gas flow has been observed for distances up to 20 m behind the blasthole patterns, related directly to potential increase in rock strata permeability.

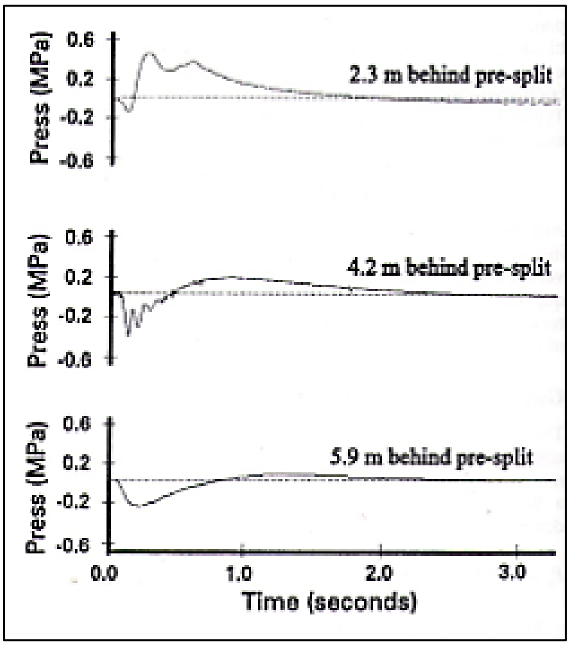


Figure 18 – Example of Gas Pressure Waveforms Measured at Various Distances Behind Pre-split Charges (after McKenzie 1999)

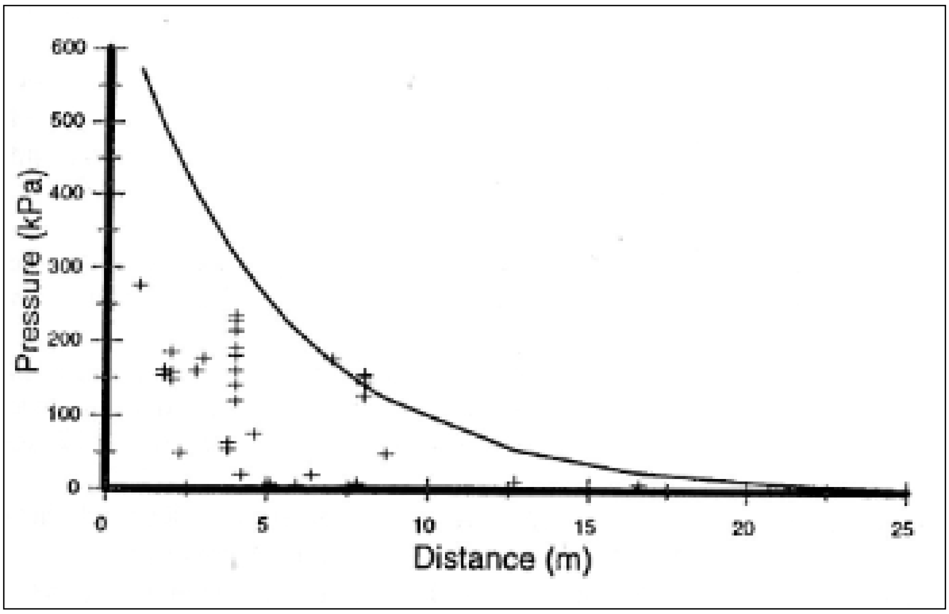


Figure 19 – **Gas Pressure Measured versus Distance – Obtained from Literature Review (after McKenzie 1999)**

3.8 Bench Dilation Measurements for Large Hole Blasting – LeJuge et al (1994)

The study was undertaken by LeJuge et al (1994) in the Rossing Mine in Namibia. The study concentrated on assessing the impact of blasting from large diameter hole blasts, including a 381 mm hole diameter. For the blast impact assessment, the study utilised an extensometer measuring technique. This was to assess the impact of blasting on the adjacent area. The study concentrated on the measurement of ground heave and ground dilation. The study revealed that the dilation of the ground was limited to 20 m from the blasting area, indicating a relatively limited distance of rock strata fracturing. The study showed the highest ground heave adjacent to the blasted hole with a gradual decrease in the ground heave with increased distance. The effect faded away after 20 m.

3.9 Crack Dilation and Gas Pressure Measurements behind Blasting Area and Permeability Implications – Brent and Smith (1996)

The study was undertaken in a Hunter Valley mine in NSW (Brent and Smith 1996). The impacts of blasting (including crack formation) have been measured behind the blasting area. The study covered confined and unconfined type blasts (as used in Hunter Valley mines) with a 200 mm hole diameter with burden and spacing of (7 x 8) m. The explosives used included ANFO and heavy ANFO product placed at the toe of the blast.

The study included a comparison of strata behaviour for confined and unconfined type blasts. The observation concluded the absence of any visible structures and discontinuities before the blast.

Unconfined Type Blast

After the blast (for the unconfined type of blast) the authors observed a large number of open cracks and no flow of gas from pressure transducers located in the sealed holes behind the blast.

Confined Type Blast

After the blast (for the confined type of blast) the authors observed a large amount of open cracks and significant gas flow over the full range of monitoring distances pointing to an increased permeability of the broken strata (caused by the blast explosion effect and adjacent surface strata damage / response) resulting in gas penetration up to 62 times the charge diameter i.e. measured by the transducers located in the sealed holes behind the blast.

Brent and Smith 1996 study concluded an exponential gas decay function for the confined type blasts

$$\text{Press} = 445.6\, e^{(-0.535d)}$$

Press – pressure measured in kPA
d – distance from blasthole (m) for coupled charges

In summary, the study included the assessment of cracks in the test holes (located behind the blasting area) as well as the measurement of negative gas pressure (generated as a result of gas incursion into the strata and induced changes in the rock strata permeability). The results of the highest blasting impact (the worst-case scenario) are summarised in **Figure 20**, showing a potential maximum impact up to 30 metres away from the blast (for confined type blast).

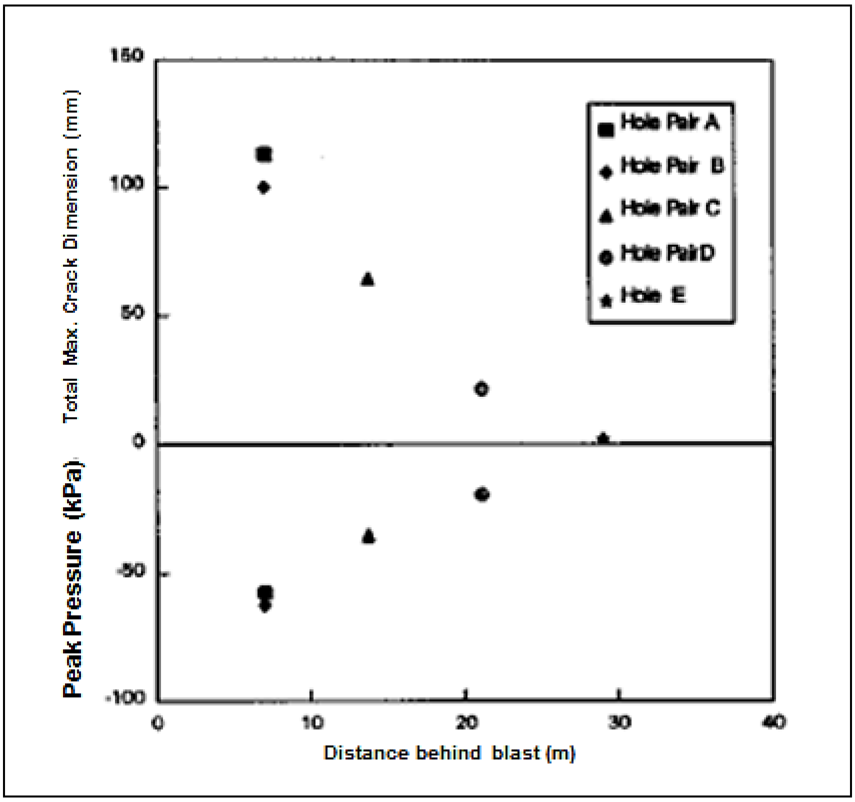


Figure 20 – Correlation of Negative Pressures and Visible Fractures (after Brent and Smith 1996)

The study revealed that there is a gradual decrease in crack dilation from approximately 60 mm at a distance of 15 m and approximately 20 mm at 20 m. The study concluded that at a distance of 30 m the impact of blasting dissipates, i.e. no measured negative gas pressure and marginal crack dilation. Therefore, the potential impact was limited to approximately 30 m.

3.10 Liquefaction – Laefer et al (2008) and Oriard (2002)

The liquefaction process involves transition of soil from solid to liquid state, which is a process assisted by earthquake shaking / or other rapid loading (such as high vibration exposure) in certain conditions. However, for liquefaction to take place there are three necessary components that need to occur simultaneously including:

- presence of sandy conditions i.e. sandy strata layer
- high water saturation of the local strata such as flooding condition
- high vibration exposure

Based on the reviewed studies, the vibration exposure needs to be at least in the order of 150 mm/s or above (i.e. Laefer et al (2008) indicated that high vibration levels at least in the order of 149 mm/s are required for liquefaction to take place. Similarly, the study summarised by Oriard (2002), (i.e. undertaken for Kootenay Canal in Canada) which utilised a nominal 100 mm/s limit for a soil slope susceptible to liquefaction, showed that blasting up to this level did not induce any adverse response in the soil slopes, confirming that higher vibration level is required for liquefaction to take place.

4. DISCUSSION OF POTENTIAL IMPACTS

The summary of various blasting studies and related strata fracturing were presented in detail in the above sections and are also summarised in **Table 4**. As shown, the damage is dependent upon the rock strength characteristics and blast parameters.

A typical fracture damage zone (behind the blasted bench) is in the order of 5 to 20 m, with the most extreme cases extending possibly up to 30 m from the edge of the blasting area. There was only one study identified which indicated the potential for vertical cracking of up to 23 m and horizontal cracking up to 50 m. This, however, applied to a soft strata band and poorly executed blast (blast chocking conditions). Therefore, it is reasonable to conclude that there is a potential blast impact limit of 30 m (i.e. worst-case scenario) where strata can undergo fracturing and potentially induce some changes into the rock strata permeability.

The rock strength data from the Project Area indicates moderately strong rock strata conditions (i.e. UCS range of 6 - 85 MPa, with majority of the results above 30 MPa and two thin softer formations locked between strong strata layers). From a blasting perspective such a moderately strong rock strata is not susceptible to long distance crack propagation from a blasting area.

A comparison of rock strata conditions revealed that the most likely potential damage zone for the proposed Project will be limited to a distance of approximately 12 m from the blasting area. This is concluded considering blasting impacts from other projects with a comparable rock strength conditions and comparable blasting parameters (analogous to the case in Section 3.6; study – ESC (2008)).

Table 4: Summary of Rock Strata Damage / Gas Flow / Permeability Implication from Blasting Studies

Study	Rock Strata Strength (MPa)	Extent of Fracturing (m)	Vibration Exposure (mm/s)	Comments / Blast design
Rorke and Thabethe (2004) - South Africa	Inter-bedded shales and sandstone	No impact on stability of the 110 m pillar. Very little back damage – not quantified. No movement / damage for roadway.	150 mm/s – limit for roadway Measured vibrations below vibration limit	110 m bench/pillar not affected by adjacent blasting 200 mm – hole diameter 15 m benches Max MIC – 215 kg per deck
ACARP C14057	n/a	n/a	100 mm/s – bridges 100 mm/s – water dam	Recommended 100 mm/s vibration limits applicable to bridge / river embankments and dam embankments, comparable for creek conditions
O'Regan et al (1983) CSIRO study - QLD study	Well bedded strata consisting of claystone, sandstone, siltstone and coal bands	23 m – vertical cracks detected 50 m – horizontal cracks along weak strata	n/a	Detailed study of an adjacent bench to the blasted area using piezometers, seismic assessment and extensometer measurements Blast assessed as inadequate, i.e. chocking
Lewandowski and Cope (2009) Bulga – Hunter Valley Conditions	Sandstone (UCS: 30 MPa) / mudstone and siltstone (UCS: <10 MPa)	17 m – surface cracks identified	unknown	MIC – 530 kg Utilised detailed surface survey
ESC (2007) Wambo – Hunter Valley Conditions	n/a Sandstone / shale	11.5 m – from the edge of the blasted bench	>400 mm/s	MIC – 600 kg Investigation of rock strata damage due to close range surface blasting. Extremely high vibrations are required to induce damage to the assessed rock strata.
ESC (2008) North Wambo - Hunter Valley Conditions	UCS: 47 – 103 MPa Sandstone / mudstone / Siltstone /Conglomerate	12 m – assessed as underground (u/g) damage zone (including vertical and horizontal cracks)	inferred as >500 mm/s)	Assessed through u/g evaluation of u/g tunnel conditions – adjacent to previously blasted area. Underground surveys including extensometers.

Study	Rock Strata Strength (MPa)	Extent of Fracturing (m)	Vibration Exposure (mm/s)	Comments / Blast design
McKenzie (1999) Concise summary of various gas monitoring studies related to increased rock strata permeability	Various rock strata from a number of different studies	20 m – concluded as gas penetration limit and increased rock strata permeability into adjacent strata	Unknown	Gas monitoring utilised to establish the extent of gas penetration related to increased strata permeability into the rock strata and inferred potential strata cracking /changed strata permeability.
LeJuge et al (1994) Namibia	Unknown	20 m – extent of damage Extensometer and ground heave measurements	n/a	Large hole diameter – 381 mm used
Brent and Smith (1996) Hunter Valley Conditions	Hunter Valley rock strata conditions	Crack dilation and gas flow measurements (i.e. permeability) in tested holes (behind the blast) showing impact up to a distance of 30 m (for confined type blast)	n/a	200 mm - hole diameter, (7 x 8) m blasting pattern Accurate correlation of negative pressure and crack dilation / increased permeability in tested holes behind the blast using gas pressure measurement technique.
Laefer et al (2008)	Sandy soils susceptible to liquefaction	Liquefaction process	149	Indicative vibration level limit required for liquefaction to take place
Oriard (2002) Cootenay Canal in Canada British Columbia	Natural soil slopes susceptible to liquefaction (not free draining) Strength unknown	Blasting up to a 100 mm/s level did not induce any liquefaction to the slope prone to liquefaction conditions.	100	No adverse response to blasting observed in the soil slopes. Pore pressure remained at acceptable levels. No slope movements took place

Water Flow and Permeability Implications

The study identified that due to the presence of the Camberwell Anticline, the strata is dipping to the west which is away from the Glendell Pit Extension towards Bowmans Creek. This is a favourable condition as collected water from Bowmans Creek's aquifer could not be drained away towards the Glendell Pit Extension i.e. against gravity.

Also, the reviewed studies indicated a possible maximum change in the rock strata permeability (due to blasting) to be in the order of 20 – 30 metres distance from the blasting area. This is using a gas pressure measurement technique.

Identified Geological Features

The study identified two geological features intercepting Bowmans Creek, a dyke and block fault zone. However, as these features intersect Bowmans Creek in the sections substantially distant from the Glendell Pit Extension (i.e. 470 and 620 m for the dyke and block fault zone respectively) the vibration impact should not present significant concerns. The estimated vibration impact using an MIC of 600 kg (typical MIC for the Project will be in the order of 450 - 600 kg) will be in the order of 16 mm/s for 470 m and in the order of 9 mm/s for a 670 m distance respectively. Therefore, even accounting for a potential magnification effect (times 2 or times 3 i.e. after Lewandowski et al 2009 study) due to free vibration transmission along these features, such impact is considered low/moderate, as it would not be sufficient to cause damage for the considered rock strata.

Liquefaction

The inspection of the creek banks indicated the presence of a sandy layer, which may be prone to a liquefaction process. However, for liquefaction to take place there are three necessary components that need to occur simultaneously including:

The first component (i.e. sandy strata conditions) is not completely satisfied as the observed sandy strata layers and present alluvium material are very well compacted showing high cohesion. The liquefaction is more likely to occur in loose sandy conditions, which were not identified during the site inspection.

The second component (i.e. high-water saturation) can potentially occur during an occasional major flooding event.

Similarly, the third component (high vibration exposure) to be in the order of 149 mm/s or above at the creek bank will not be reached as a result of blasting from the Project; this is due to a substantial distance of at least 200 metres to the Glendell Pit Extension. The estimated highest vibration impact using an MIC of 600 kg (typical MIC for the Project will be in the order of 450 - 600 kg) will be in the order of 62 mm/s for a 200 m distance. Also, it is unlikely that the mine will undertake blasting during a major flooding event as mines are usually shut down during such an event i.e. due to the operational restrictions of the equipment.

Therefore, there is no significant risk of liquefaction and damage to the creek's high bank area.

200 m Buffer Zone

The minimum distance from the Glendell Pit Extension to the top of the high bank of Bowmans Creek is approximately 200 m. Based on the results from the reviewed blasting studies, this distance is sufficient to provide an adequate buffer. In addition, the Additional Disturbance Area extends at minimum 175 m from the Glendell Pit Extension towards the creek, which would also adequately capture areas where cracking may occur from the adjacent blasted benches.

As a precautionary measure it is recommended to continue with regular site inspections along the western highwall of the Glendell Pit Extension to identify and monitor blast induced surface impacts such as surface cracking. This would allow for an accurate assessment of rock strata response when blasting in the vicinity of Bowmans Creek.

Glendell's Pit Wall Damage Experience and Implications

The study included a review of the rock strata behaviour behind the blasted final pit wall of the current Glendell Mine pit.

The site inspection did not reveal any obvious signs related to adjacent surface strata blasting, such as cracks, fissures or displaced strata layers. There is only limited soft strata material erosion in the top section of the pit restricted to a few metres from the pit edge i.e. typical natural erosion mechanism.

Therefore, no risk from blasting from the proposed Project for the adjacent Bowmans Creek and associated alluvium has been identified. This is assuming similar geological conditions for the proposed Project area, which is supported by a review of geological data collected for the Project.

Vibration Limit

Upon the review of the various studies presented above it is concluded that the 100 mm/s vibration limit for the Bowmans Creek Area is considered to be an appropriate limit. The limit is justified according to the geology of the area, permitting high vibration exposure.

A supporting argument for the postulated 100 mm/s vibration limit was provided by the various published studies and substantiated by the author’s experience in the area of strata fracturing due to blasting. In addition, some recommendations have been provided and presented in ACARP Project No. 14057 (2008). The ACARP authors postulated an indicative vibration limit of 100 mm/s for bridges and therefore also applicable to river banks.

The alluvium material associated with Bowmans Creek does not present any specific, distinct feature on the ground that could be affected by ground vibrations, therefore there is no need to establish a vibration limit for alluvium.

5. CONCLUSIONS AND RECOMMENDATIONS

At the request of Umwelt an investigation into the potential impacts of blasting from the proposed Glendell Continued Operations Project on the integrity of rock strata between Bowmans Creek area and the Glendell Pit Extension was conducted.

Blasting will be undertaken at variable distances from Bowmans Creek with the closest section located approximately 200 metres to the top of the high bank of the creek. The Project, will also mine through the alluvium in Swamp Creek and Yorks Creek.

The results of the undertaken assessment are summarised as follows:

- CREEK BED ASSESSMENT

  The identified rock strata layers including sandstone / siltstone / coal are considered to form an adequate creek base and are not prone to surface cracking at moderate / high vibration exposure. The non-destructive testing in the study areas indicated creek bed rock strength of 7 to 10 MPa, confirming an adequate strength to resist moderate / high vibration impacts from the Project.

- CREEK BANK ASSESSMENT

  Overall, the creek banks present stable escarpments resistant to moderate / high ground vibration exposure from the Project.

  The possibility of creek bank area damage due to liquefaction process has been assessed and no significant risk has been identified.

  It needs to be recognised that creek bank will still be prone to natural erosion processes (physical force of water action and moisture intake into the clay / soil material) and ongoing degradation. However, the water erosion will not have any effect on the underlying strata and its propensity to be impacted by adjacent blasting practices.

- ALLUVIUM ASSESSMENT

  The alluvium material associated with Bowmans Creek does not present any specific, distinct feature on the ground that could be affected by ground vibrations; therefore, there is no potential risk to alluvium damage.

- AREA BETWEEN BOWMANS CREEK AND THE GLENDELL PIT EXTENSION ASSESSMENT

  The study identified that due to the presence of the Camberwell Anticline, the strata is dipping to the west which is away from the Glendell Pit Extension towards Bowmans Creek. This is a favourable condition as collected water from Bowmans Creek's aquifer would not be drained away towards the Glendell Pit Extension.

  The area within the assessed Study Area 1 and 2 was determined to be free of any known significant geological features.
  The identified geological features (i.e. a dyke and wide block fault zone) intersect Bowmans Creek at substantial distances from the Glendell Pit Extension (470 and 620 m respectively, thus they do not represent a significant risk, i.e. no significant risk related to connective cracking or increased permeability).

- EXTENT OF BLASTING DAMAGE

  The study shows that the rock strata fracturing is dependent upon the rock strength characteristics and blasting parameters.

  The geotechnical assessment of the rock strata revealed moderately strong strata conditions (i.e. UCS of 6 – 85 MPa, with majority above 30 MPa), which can sustain substantial blast impacts and prevent any significant damage propagation. The identified two weaker bands are only 0.3 m in thickness and are embedded between strong formations, preventing any extensive damage to this strata layer due to blasting. It is estimated that strata fracturing due to the impact of blasting from the Glendell Pit Extension is potentially limited to a distance of 12 m.

  The assessment of blast impacts from the existing Glendell open cut pit confirmed that Glendell Mine blasting does not have any significant observable impact on the adjacent rock strata (i.e. no damage beyond pit walls observed). There is some limited soft strata erosion within soil and the top soft strata layer limited to few metres from the pit edge only. As the Project will utilise similar blasting parameters and is within a similar geological domain, similar blast impacts on the adjacent strata are to be expected. Therefore, no significant risks for the adjacent Bowmans Creek and associated alluvium have been identified.

  In view of the assessment a distance of 200 m as a buffer zone between the Bowmans Creek's high banks and the boundary of the Glendell Pit Extension is considered adequate.

- VIBRATION LIMIT

  The 100 mm/s vibration limit for the Bowmans Creek high bank is considered to be appropriate for the management of vibration impacts on the creek and creek bed.

To conclude based on the distances considered in the assessment for Bowmans Creek, the risk of damage to rock strata and subsequent damage / crack formation and related increased permeability between the blasting area and Bowmans Creek, and damage to the creek bed / creek bank or increased permeability is low / negligible beyond the concluded 12 m distance (potential rock strata damage zone). Additionally, any rock fracturing and subsequent increased permeability that results from blasting will not extend far enough to the west to intercept the Bowmans Creek alluvium and result in leakage into the pit.

RECOMMENDATIONS

When blasting within 300 m of the high bank of Bowmans Creek, as a precautionary measure, it is recommended to undertake regular site inspections along the western highwall of the Glendell Pit Extension and the closest section of Bowmans Creek for any damage to identify and monitor blast induced surface impacts such as surface cracking. This would allow an accurate and ongoing assessment of rock strata response when blasting in the vicinity of Bowmans Creek. A review of the blast design processes should be undertaken if surface cracking beyond 12 metres is observed.

The 100 mm/s vibration limit, together with the recommended inspection regime when commencing blasting within 300 m, should provide an adequate measure to alert / prevent surface damage, including surface cracking taking place between the blasting area and Bowmans Creek.

Thomas Lewandowski
Enviro Strata Consulting
25th November 2019

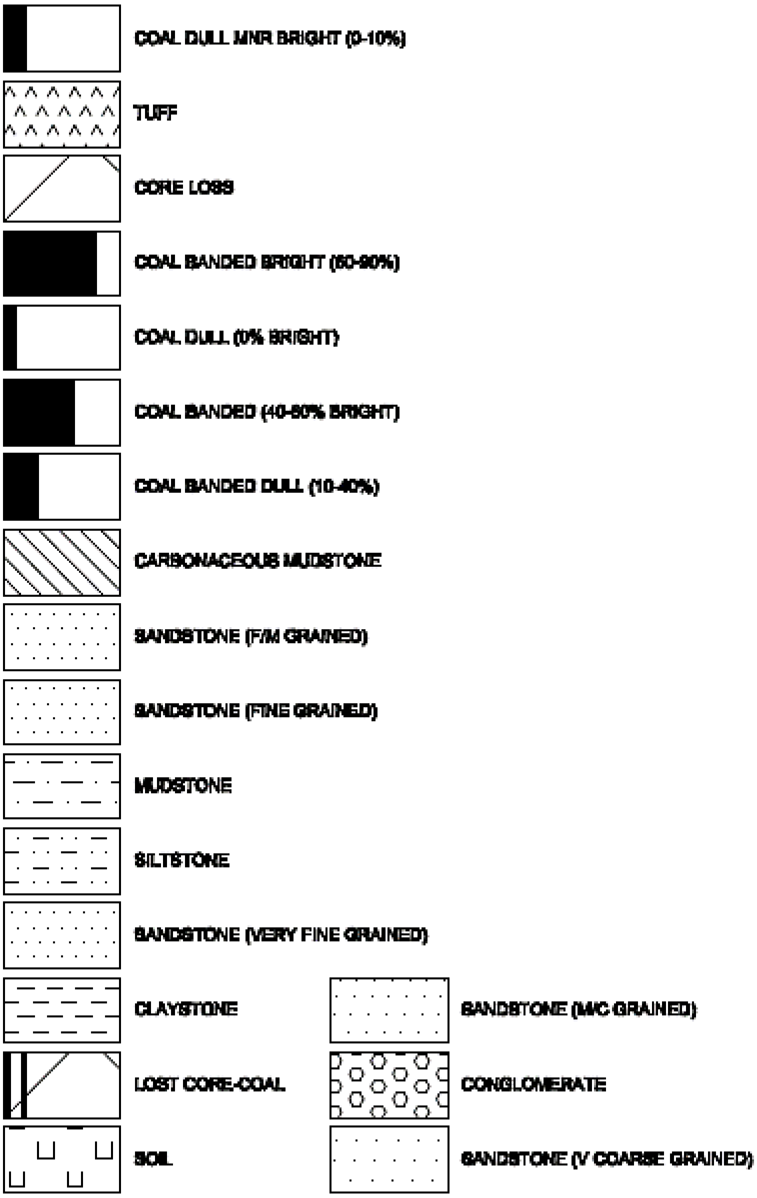
REFERENCES

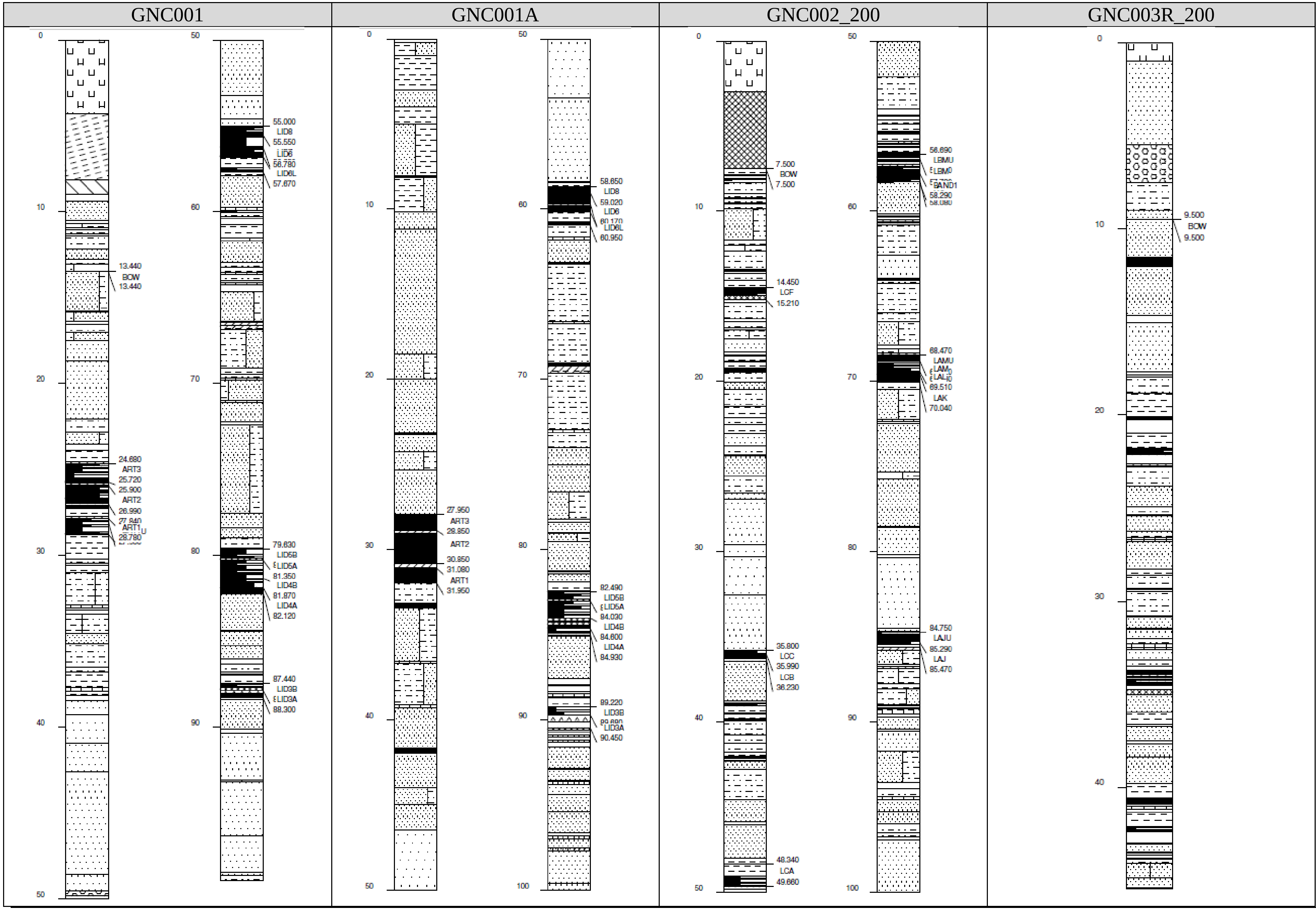
1. ACARP Project no.C14057, (2008). “Effect of Blasting on Infrastructure”, Richards, A., and Moore, A.
2. AECOM (2018). Geotechnical Characterisation Report – Glendell Mine. Internal Report AECOM Australia 04.05.2018.
3. Brent, G.F., and Smith, G.E., (1996). “Borehole pressure measurements behind blast limits as an aid to determining the extent of rock damage” Fragblast 5 – Conf. of the Int. Soc. Of Rock Mechanics Commission on Rock Fragmentation by Blasting, Mohanty (Ed), Montreal, Canada
4. Enviro Strata Consulting Pty Ltd (ESC), (2008). “Initial Assessment of Proposed North Wambo Underground Development and Open Cut Interaction”, Report No. NW-0803-090109.
5. Jacobs (2018). Mt Owen Piezometers Installations. “Drilling and Piezometers Installation Report. Report no. 158901-003b. May 4, 2018
6. LeJuge, G.E., Lubber, E., D.A., Sandy, D.A, McKenzie, C.K. (1994). “Blast damage mechanisms in open cut mining”. Open Pit Blasting Workshop ’94, Curtin University of Technology, Perth, Australia, pp. 96-103.
7. Laefer, D. F., Loughlin, B., Hickey, S., O’Farrell, S., O’Mahony, G. (2008). ” Unexplained Blasting Vulnerabilities in a Historic Town”. In the proceeding of the 6th International Conference on Structural Analysis of Historic Construction, SAHC08., pp. 1207-1215.
8. Lewandowski, T., and Cope, G. (2009). “Impact of Close Range Blasting on Infrastructure and Associated Vibration Management”. In proc. of the 5th Int. Conference Budapest 2009. European Federation of Explosives Engineers, pp 125 – 134.
9. Lewandowski, T., Richards., L., Hamson, L, Merchant, M. Spargo., A. (2009). “The Impact of Geological Features on Level of Ground Vibrations”. In proc. of the 9th Rock Fragmentation by Blasting – Fragblast 9, Granada Spain, pp 535 - 544.
10. McKenzie, C.K., (1999), “A review of the influence of gas pressure on block stability during rock blasting”. EXPLO 99 – A conference on rock breaking, AusIMM, 7-11 November, Kalgoorlie WA, Australia.
11. O’Regan, G.J., Boyd, G., Cox, R.H.T., Nguyen, V.V. (1983). “A study of the Effects of an Overburden Blast on the Structure of a Newly Formed Highwall at Blackwater Strip Coal Mine”, Queensland. Report no. 47 CSIRO 1983.
12. Oriard, L.L. 2002. Explosive Engineering, Construction Vibrations and Geotechnology. Int. Soc. Of Explosives Engineers, Cleveland, Ohio., pp 162–163.
13. Pells Sullivan Meynink (2018). Nominated Locations for VWP Installations and Geotech Drilling. Internal Correspondence.
14. Pre-feasibility Report (2018). Pre-feasibility Report for Glendell Continued Operations (GCO) Project, Chapter 8 Geology and Mineral Resources. February 2018.
15. Rorke, T., Thabethe, S. (2004) “Blasting next to an unsupported road using electronic detonators” Published in the Journal of Explosives Engineering. Volume 21 Number 6, November / December 2004.
16. Strata Testing Services (2018). “Geotechnical Laboratory Test Reports” Lab Report L3278 Report dated 23.02.18.
17. Strata Testing Services (2018). “Geotechnical Laboratory Test Reports” Lab Report L3335 Report dated 13.04.18.

18. Strata Testing Services (2018). “Geotechnical Laboratory Test Reports” Lab Report L3279 Report dated 23.02.18.
19. Strata Testing Services (2018). “Geotechnical Laboratory Test Reports” Lab Report L3336 Report dated 13.04.18.

APPENDICES

Appendix 1 – Borehole Logs for Project Area Showing First 30 m

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LID6
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BOW
13.440
24.680
ART3
25.720
25.900
ART2
26.990
27.840
ART1
28.780
79.630
LID5B
LID5A
81.350
LID4B
81.870
LID4A
82.120
87.440
LID3B
LID3A
88.300
58.650
LID8
59.020
LID6
60.170
LID6L
60.950
27.950
ART3
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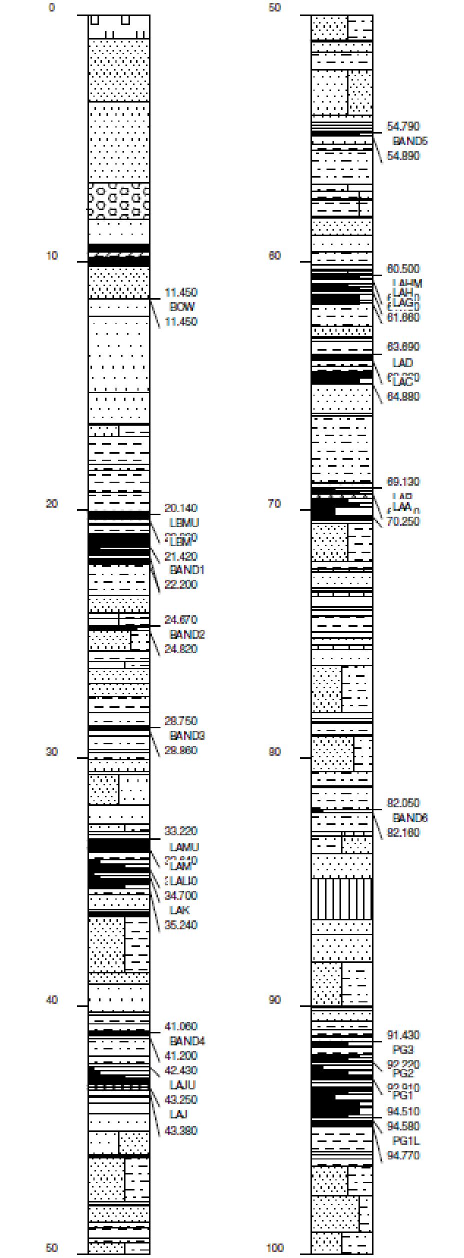
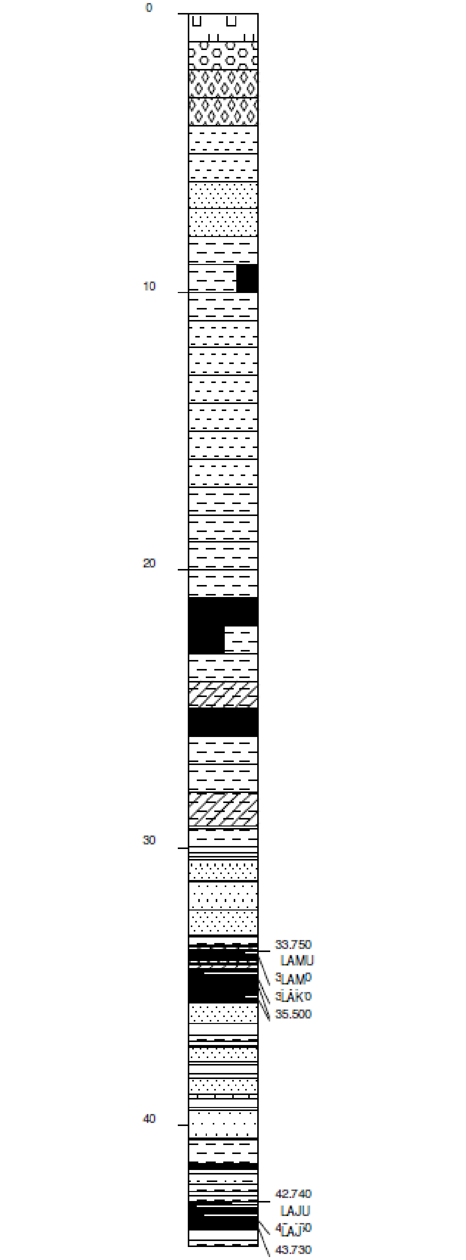
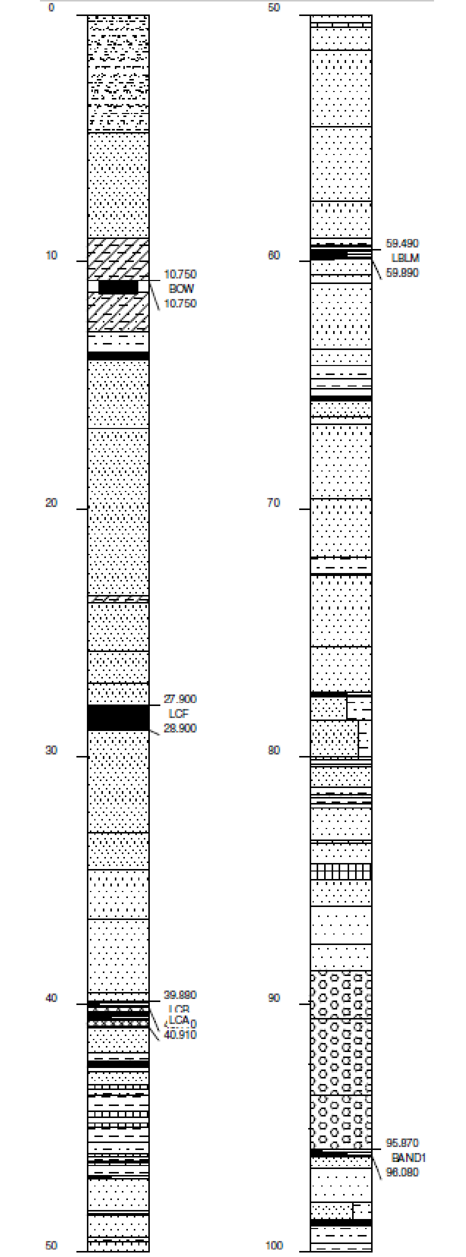
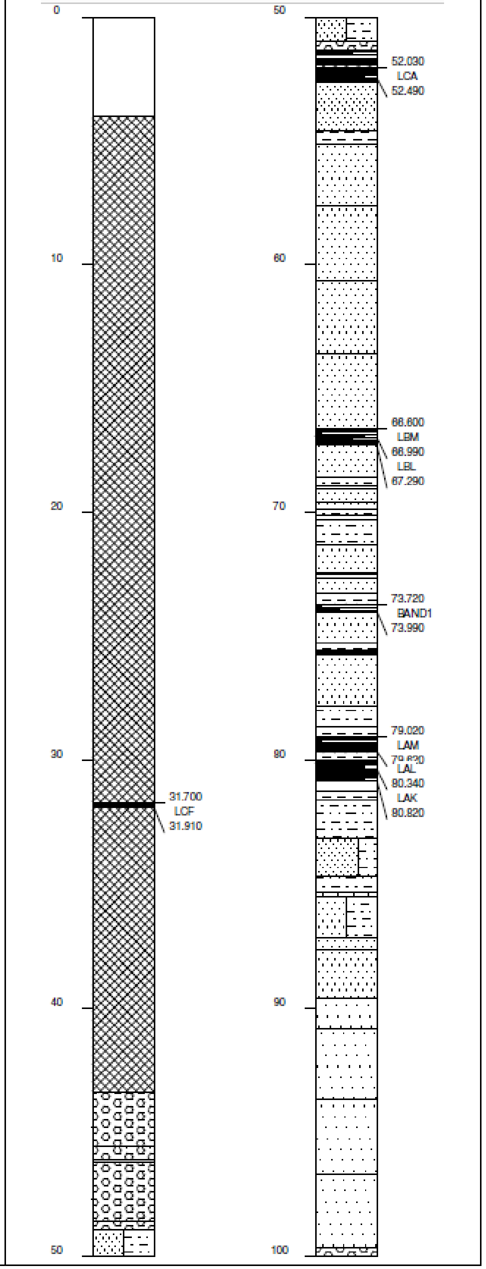
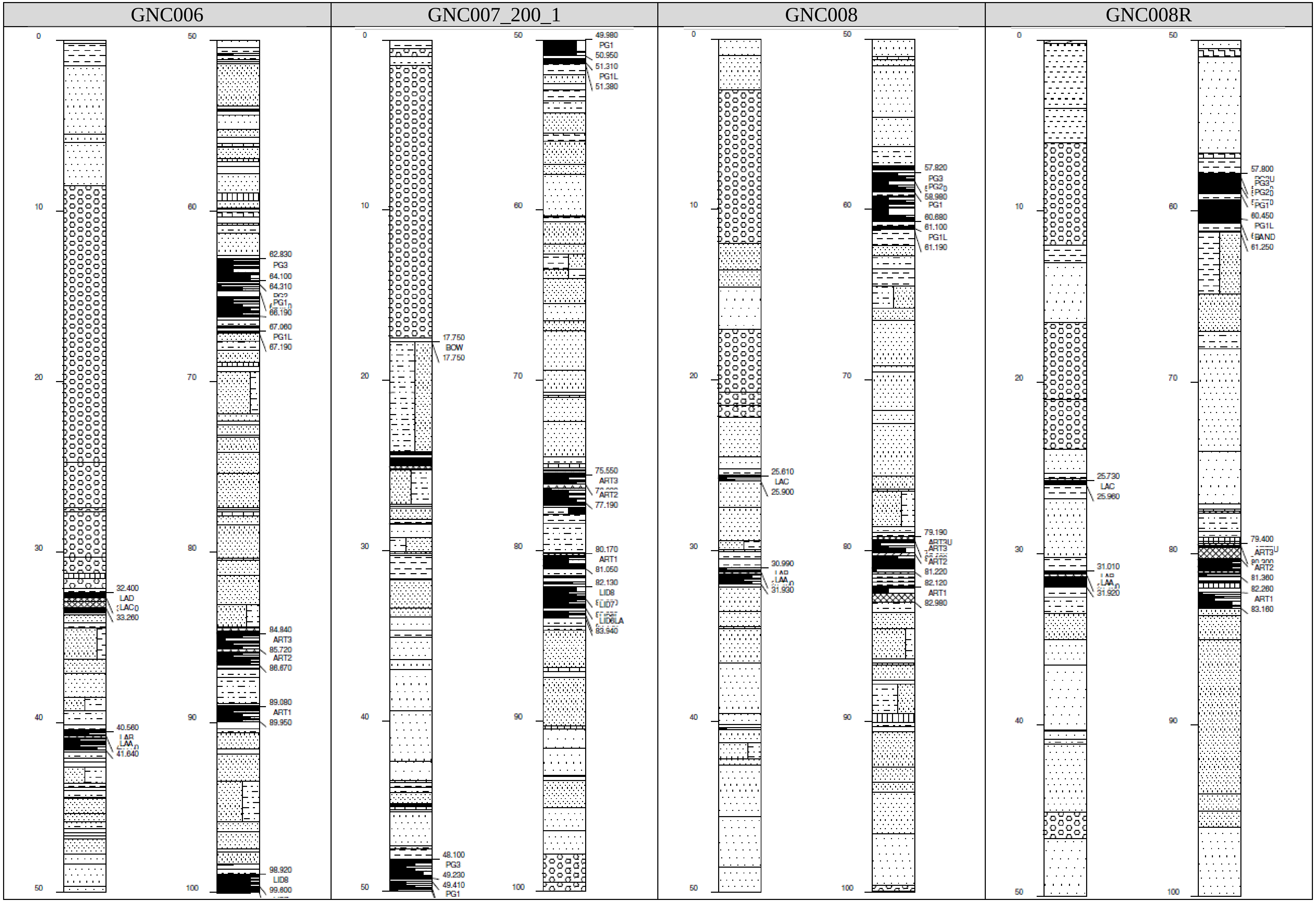
ART2
30.850
31.080
ART1
31.950
82.490
LID5B
LID5A
84.030
LID4B
84.600
LID4A
84.930
89.220
LID3B
LID3A
90.450
7.500
BOW
7.500
14.450
LCF
15.210
35.800
LCC
35.990
LCB
36.230
48.340
LCA
49.660
56.690
LBMU
LBMO
BAND1
58.290
68.470
LAMU
LAM
LAL
69.510
LAK
70.040
84.750
LAJU
85.290
LAJ
85.470
9.500
BOW
9.500

GNC003RR Graphics_200	GNC003RRR Graphics_200	GNC004	GNC005
			



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64.310
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67.060
PG1L
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84.840
ART3
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ART2
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ART1
89.950
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BOW
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PG1
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PG1
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PG1L
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LAC
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PG1L
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ART2
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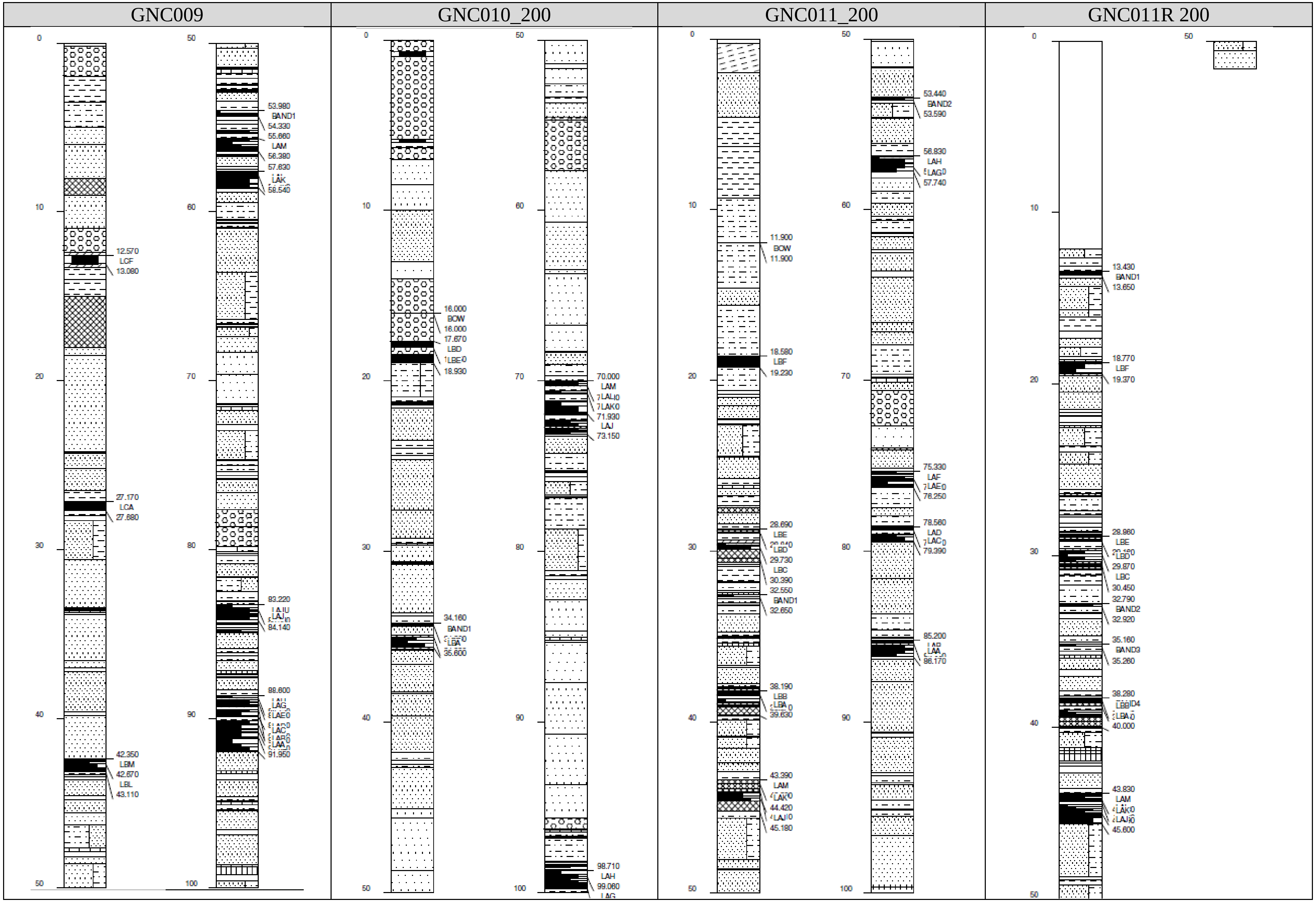
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LAM
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BOW
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17.670
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LAM
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BOW
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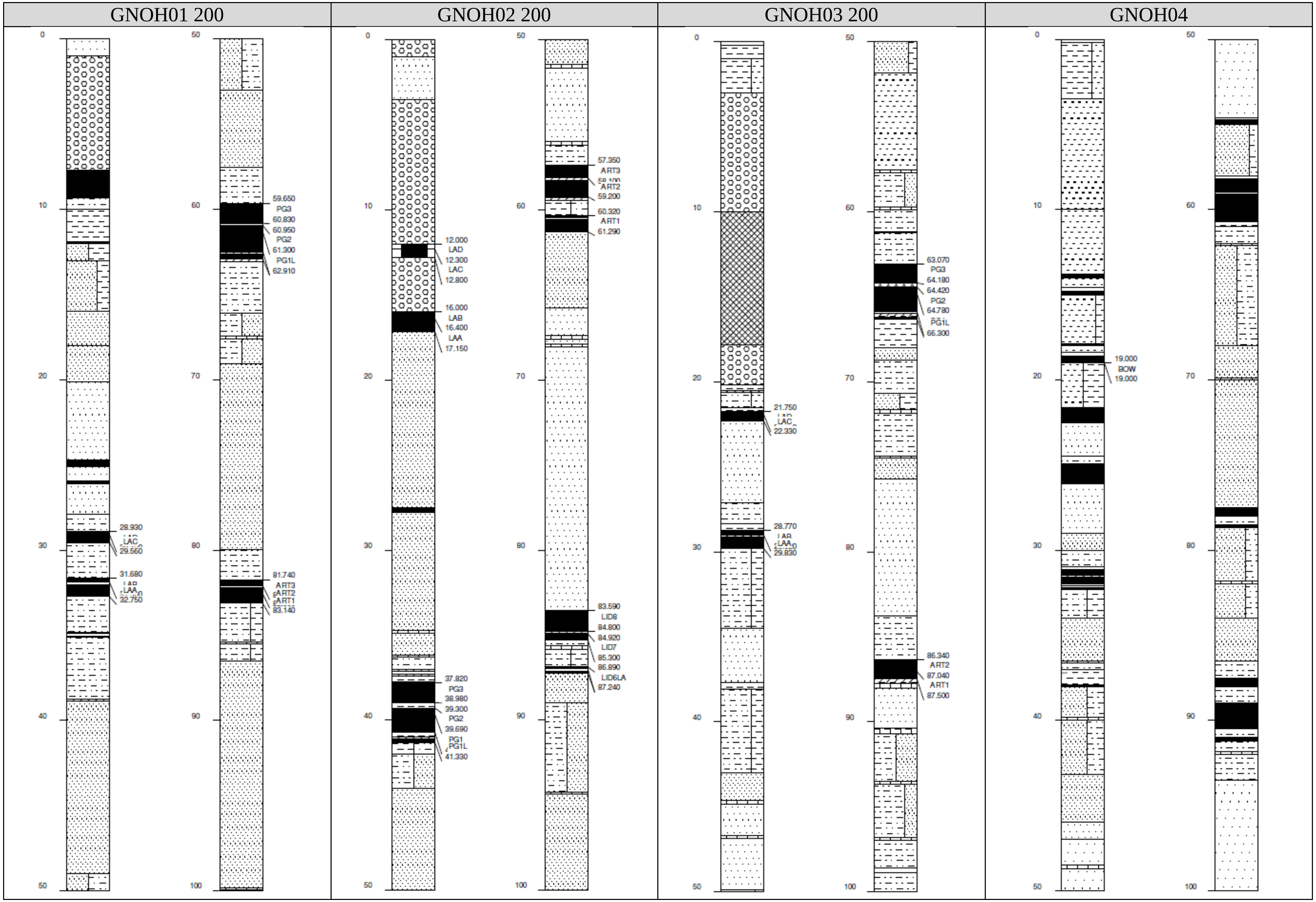
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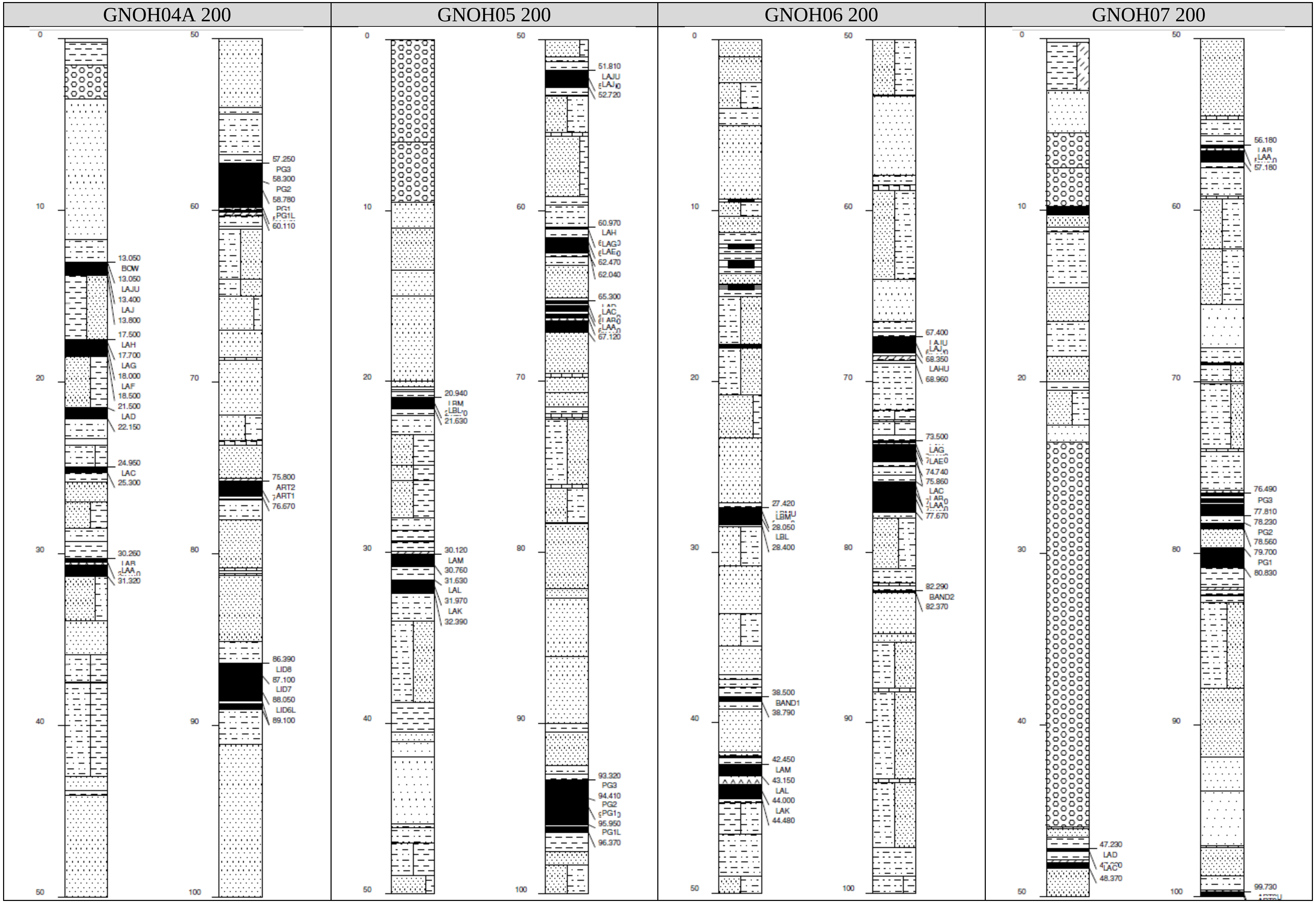
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76.490
PG3
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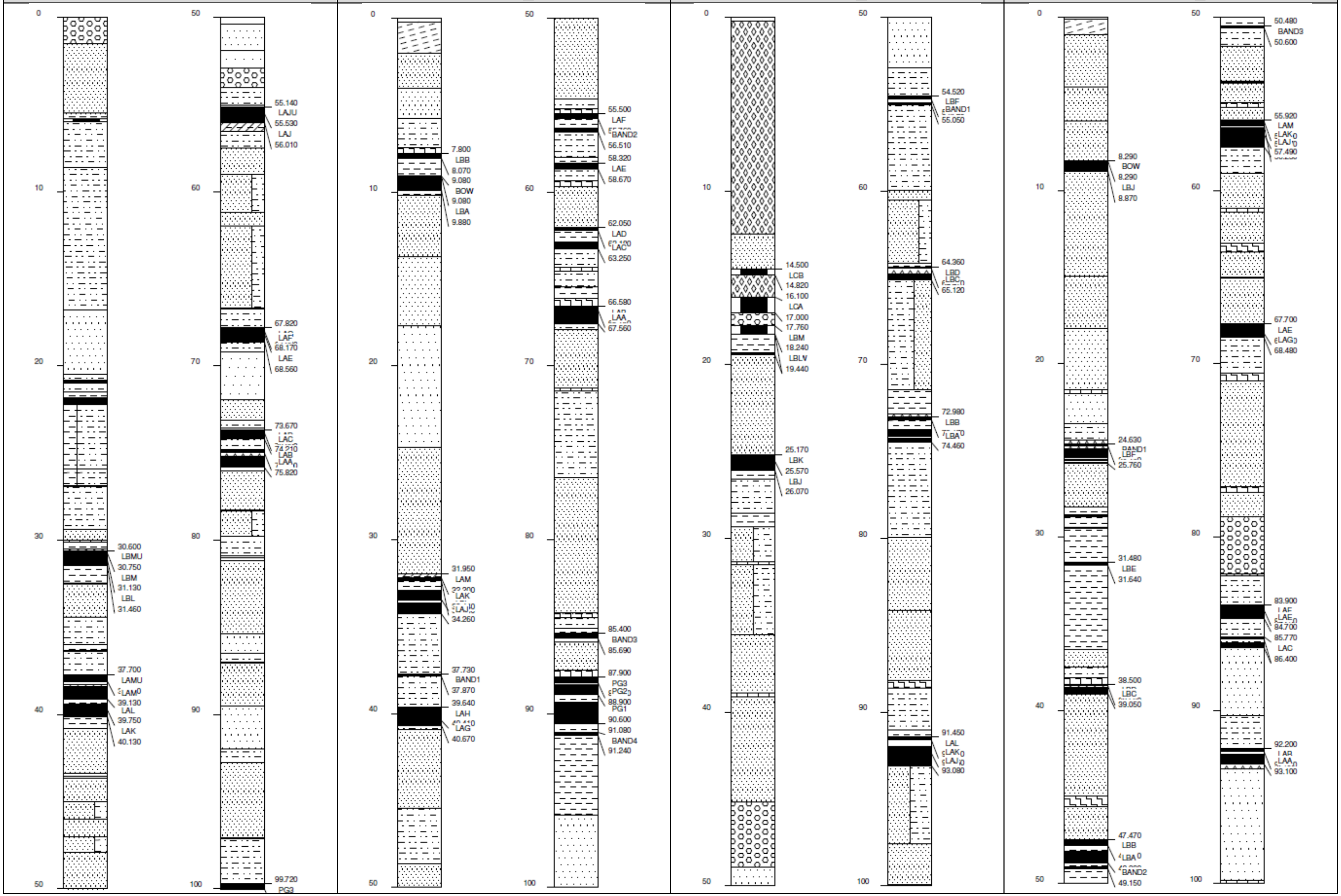

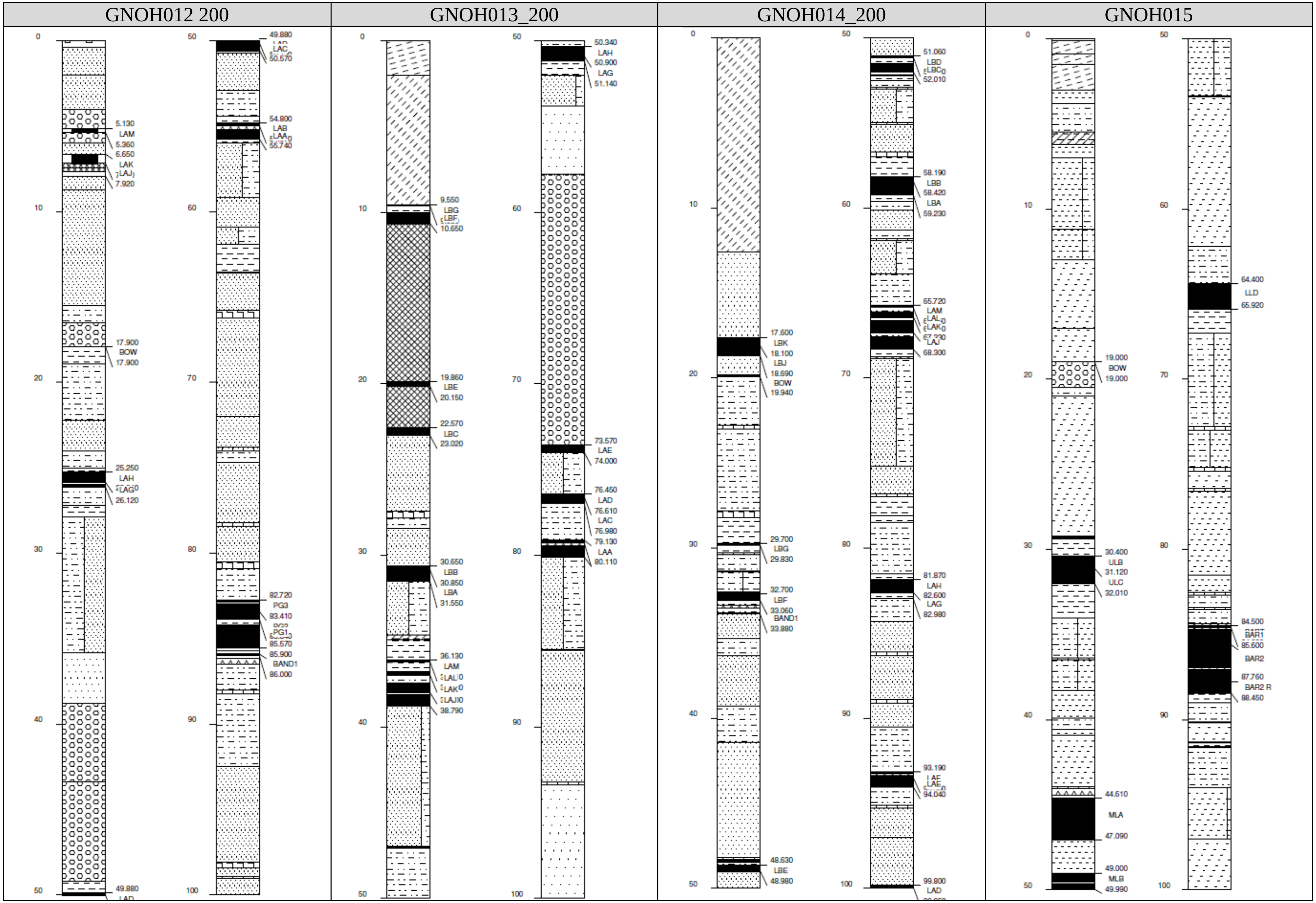
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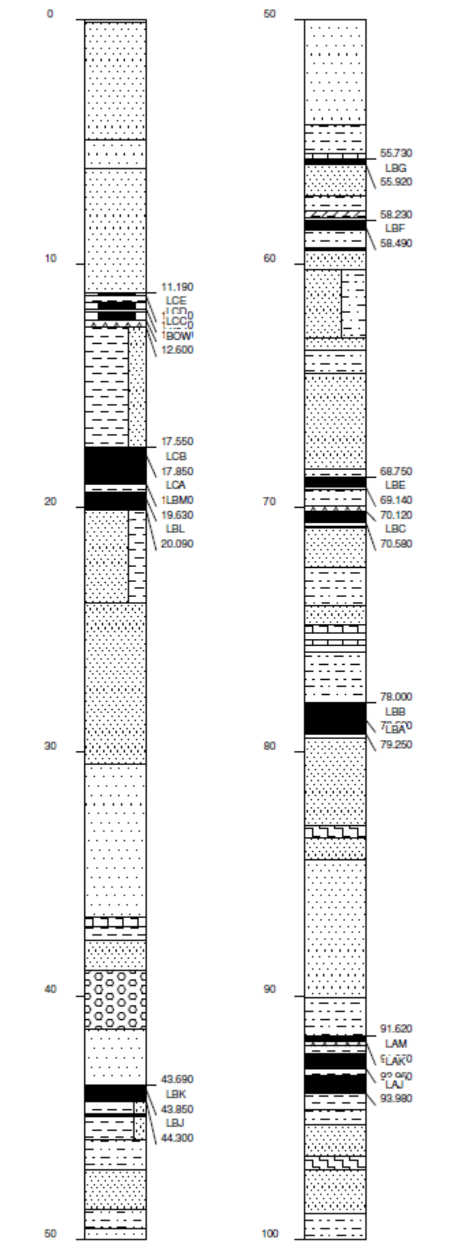	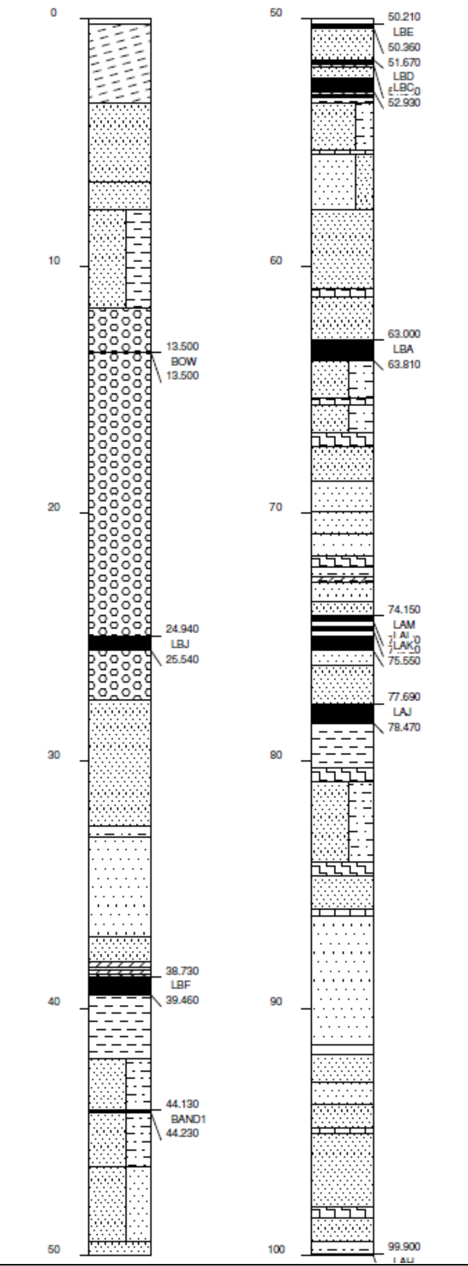	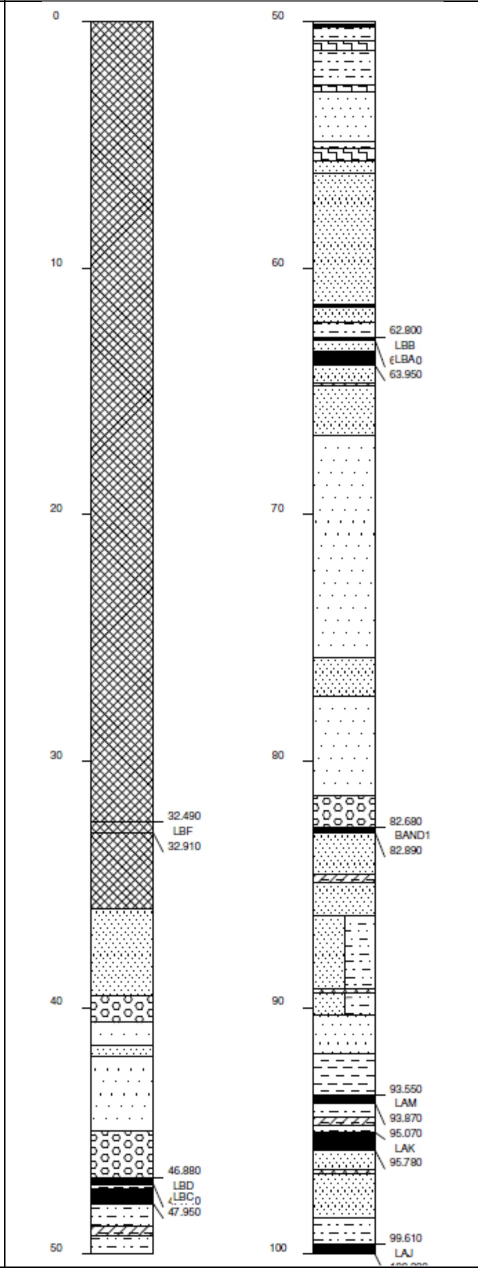	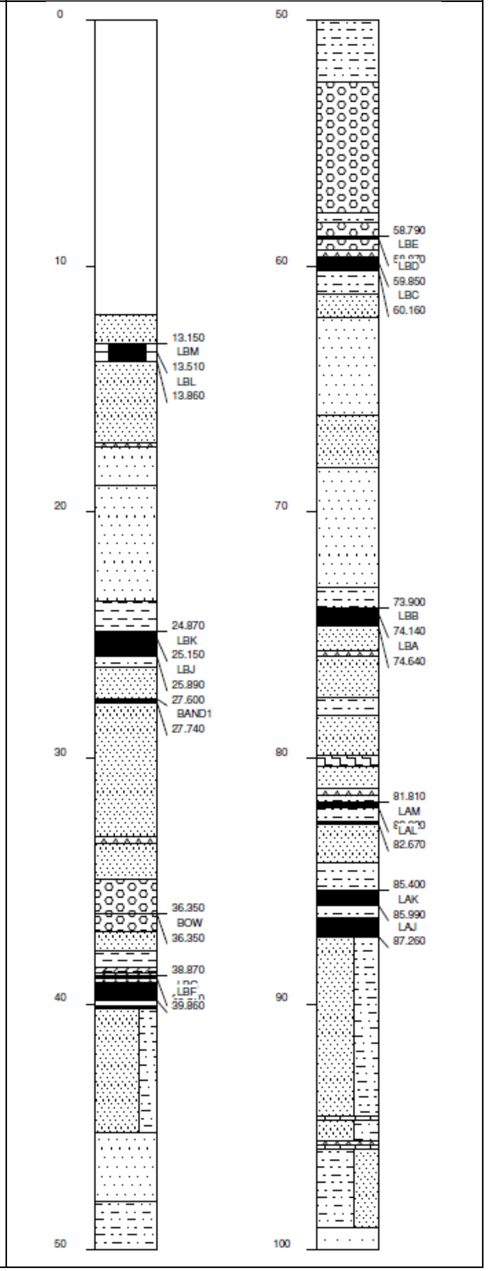

Appendix 2A – Piezometer Borehole Logs after Jacobs (2018)

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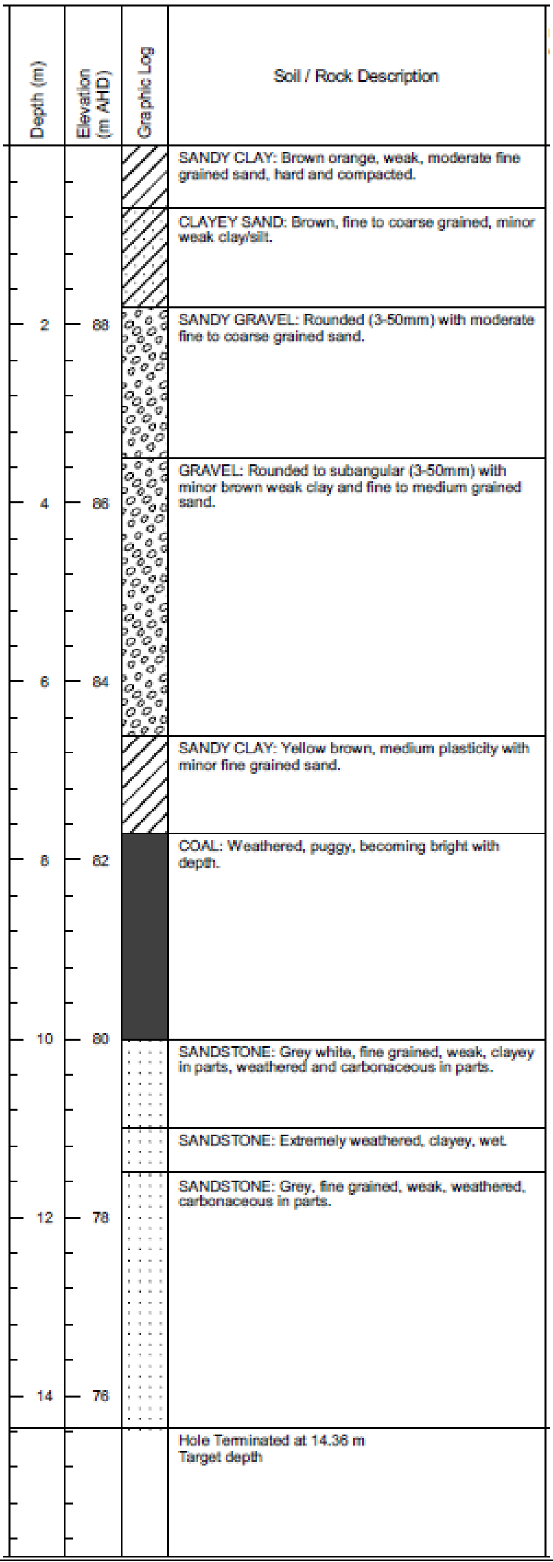	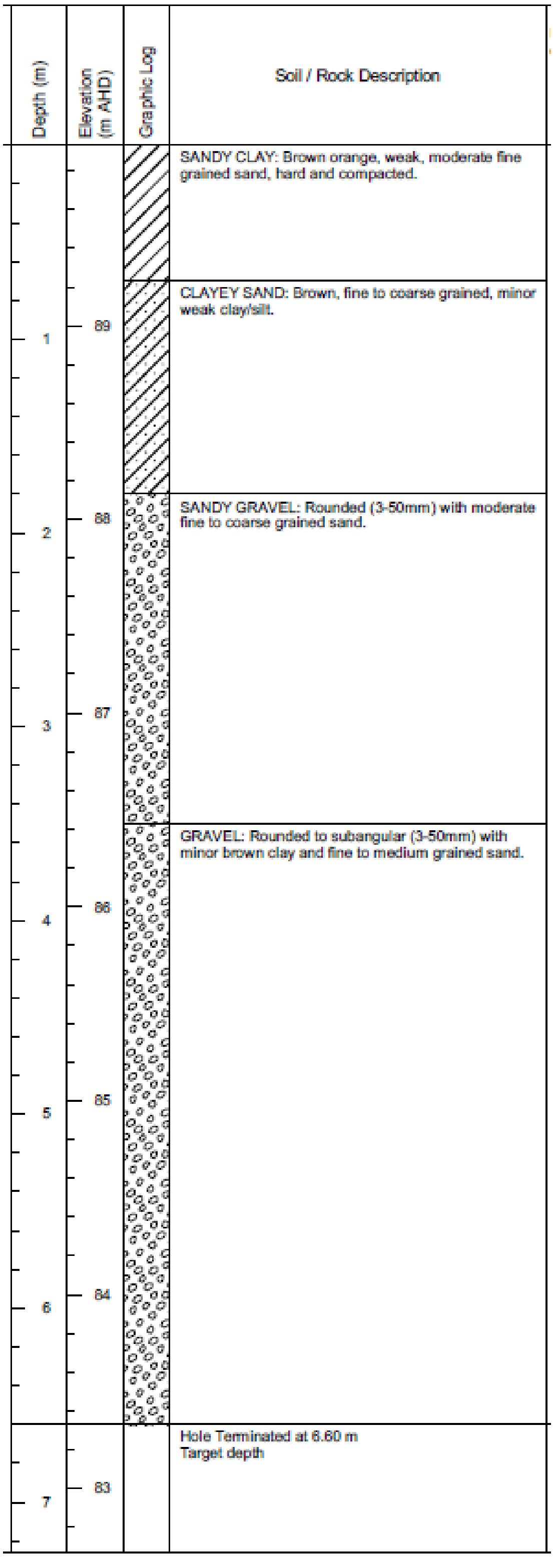

Appendix 2B – Piezometer Borehole Logs after Jacobs (2018)

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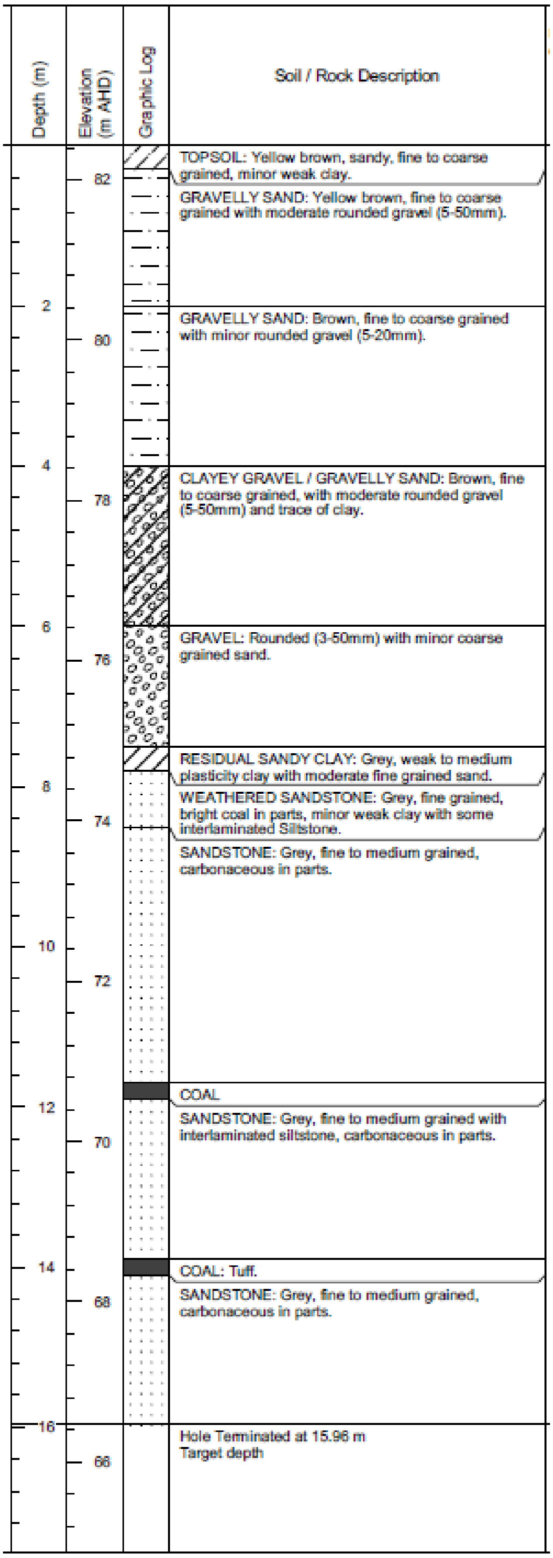	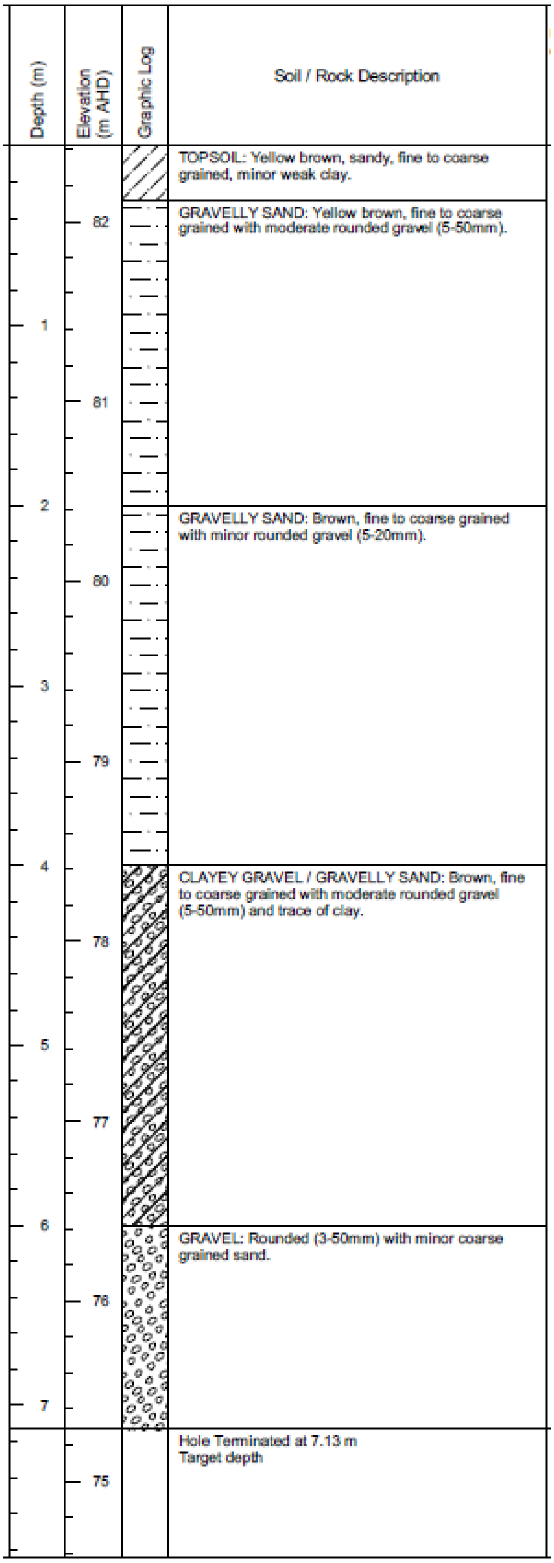

Appendix 2C – Piezometer Borehole Logs after Jacobs (2018)

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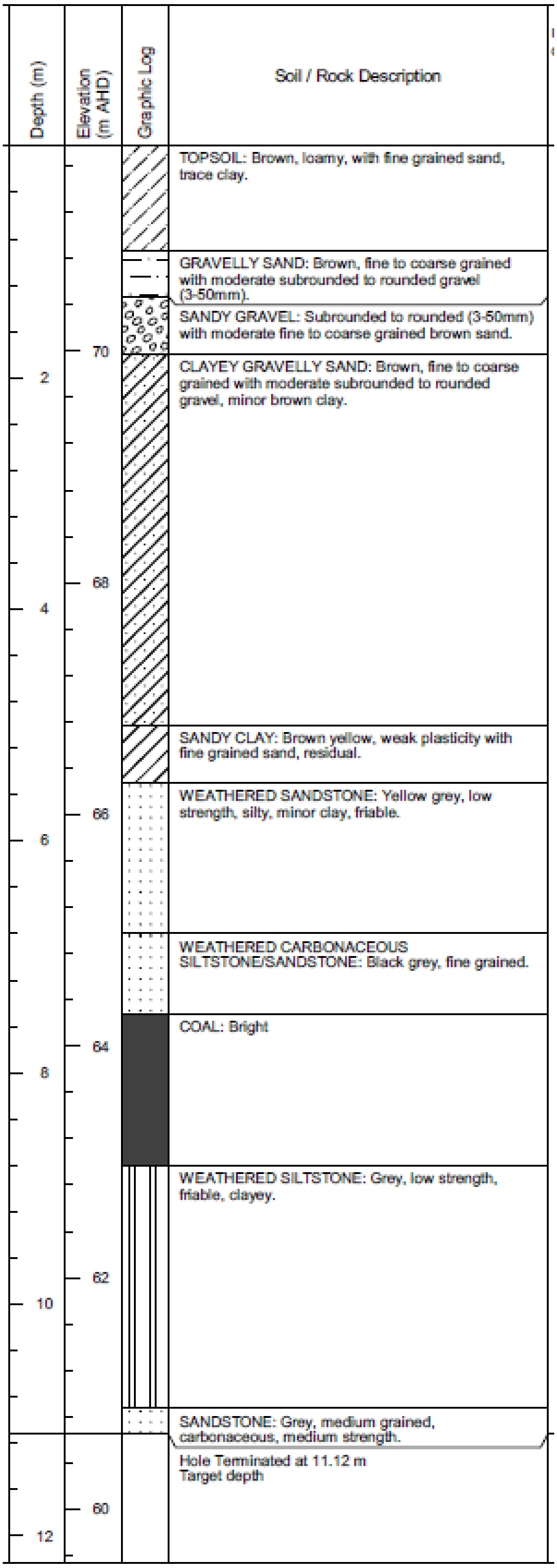	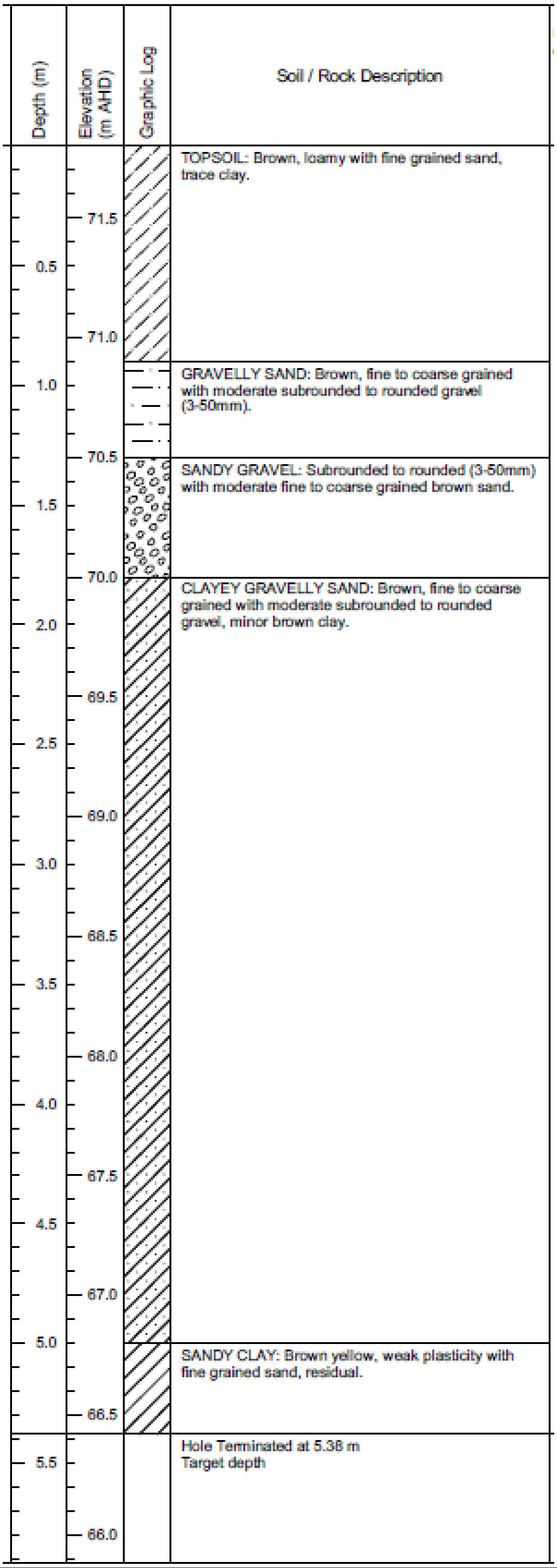

Appendix 3A – Study Area 1 - View of Bowmans Creek

Appendix 3B – Study Area 1 - View of Creek Embankment Conditions (High bank in background)

Appendix 3C – Study Area 1 - Cross Section of Strata through Creek Embankment

Appendix 3D – Study Area 1 - View of High Embankment

Appendix 3E – Study Area 1 - View of High Embankment (Gravelly Conditions)

Appendix 3F – Study Area 1 - View of High Embankment (Gravelly Conditions)

Appendix 3G – Study Area 1 - View of Creek and Embankment's Vegetation

Appendix 3H – Study Area 1 - View of Trapped Water in Ponds

Appendix 3I – Study Area 1 – Creek River Bed Showing Sandstone Layer

Appendix 3J – Study Area 1 – Creek River Bed Showing Sandstone/Siltstone Layer

Appendix 3K – Study Area 1 – Creek River Bed Showing Sandstone Layer

Appendix 3L – Study Area 1 – Creek Embankment Showing Sandstone Layer

Appendix 3M – Study Area 1 – Creek Embankment Showing Sandstone Layer

Appendix 3N – Study Area 1 – Creek Embankment Showing Sandstone Layer

Appendix 3O – Study Area 1 – Creek Embankment Showing Vegetation

Appendix 3P – Study Area 1 – Creek Bend Showing Sandstone Layer

Appendix 4A – Study Area 2 - View of Surface Strata near the Bridge

Appendix 4B - Study Area 2 - View of Surface Creek bed and Embankment

Appendix 4C – Study Area 2 - View of Surface Creek Embankment

Appendix 4D – Study Area 2 - View of Surface Creek Embankment

Appendix 5A - View of Schmidt Hammer

Appendix 5B – View of Penetrometer