APPENDIX 7

Hunter Water Infrastructure – Blasting

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REVIEW OF RISKS AND ASSESSMENT OF POTENTIAL BLAST IMPACTS FROM THE PROPOSED STONE RIDGE QUARRY ON HUNTER WATER INFRASTRUCTURE

Report prepared for Umwelt (Australia) Pty Ltd on behalf of Australian Resource Development Group Pty Ltd

FINAL

Report No. SR-2205-150523

Thomas Lewandowski
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1. INTRODUCTION

Australian Resource Development Group (ARDG) Pty Limited is seeking to develop a new hard rock quarry, known as Stone Ridge Quarry (the Project), located within Wallaroo State Forest at Balickera NSW, approximately 25 kilometres (km) north of Newcastle within the Port Stephens Local Government Area (LGA).

Enviro Strata Consulting Pty Limited (ESC) was engaged by Umwelt Australia Pty Ltd (Umwelt) on behalf of ARDG to undertake a detailed assessment of potential blasting impacts and risks associated with the Project on adjacent Hunter Water infrastructure including the Balickera Tunnel, Balickera Channel and associated infrastructure (see **Figure 1)**.

This report has been prepared in accordance with the Secretaries Environmental Assessment Requirements (SEARs). The report provides an overview and assessment of the existing conditions and integrity of the adjacent Hunter Water infrastructure in addition to a detailed assessment of the potential blasting impacts (including associated risks) and implications for infrastructure as a result of the Project.

Figure 1 – Location of the Project and Hunter Water Infrastructure

2. OVERVIEW OF INFRASTRUCTURE FACILITIES

The Balickera Tunnel, Balickera Channel and associated infrastructure form a part of the Hydro Scheme along with Grahamstown Dam, which was originally constructed between 1955 and 1965.

The primary purpose of the existing Hunter Water infrastructure is to assist with transporting water from the Williams River to Grahamstown Dam in order to supply drinking water for Newcastle and the surrounding region. It is noted that the Balickera Tunnel, along with the Balickera Channel, is considered a critical asset of Hunter Water Australia Pty Ltd.

The assessed infrastructure system comprises of the following elements / items:

- Balickera Channel
- Balickera Tunnel
- Water pumping station
- Electrical sub-station with powerlines
- Bridge
- Main pipelines

Balickera Channel

The Balickera Channel is primarily an open canal divided into two primary sections' (lower and upper). The channel was constructed by digging, drilling and/or blasting into the surrounding land. The leg of the channel that is located north of the Balickera Tunnel and closest to the Project is approximately 1,500 metres (m) long.

The lower section of the Balickera Channel is formed by an excavated section of ground that provides a channel from the Williams River to the water pumping station (located in Balickera, NSW). Generally, the lower section of the channel and the channel edges/sides include exposed and/or non-reinforced rock strata sections with high overgrown vegetation in places.

However, for the upper section of the Balickera Channel (from the pumping station onwards), the channel edges have been reinforced with a concrete lining (approximately 150 millimetres (mm) in thickness). This is to prevent ongoing water erosion in view of the high-water flow (see **Appendix 2A)**.

Balickera Tunnel

Part of the Balickera Channel that runs underground is referred to as Balickera Tunnel. A section of the Balickera Channel that runs underground i.e., Balickera Tunnel, partly runs under Italia Road. The Balickera Tunnel was constructed by a drill and blasting method in 1962 and is approximately 1,219 m in length. The Balickera Tunnel has an arch formation with a minimum width and height designed to be 4.3 m; however, within the concrete lined section of the tunnel, the width decreases to a span of 3.7 m.

As reported from previous studies (including site inspections), there is substantial variation in the Tunnel's condition throughout its length because of the local geology or change in the local geology. These are discussed in more detail in Sections 3.1 to 3.4.

The original schematic drawings through the channel (including design plans), other dimensions and geological information are presented in **Appendix 1**.

Water Pumping Station

The water pumping station and adjacent pipelines (connecting the pumping station to the upper channel) transfers water from the lower section to the higher section of the channel. Water is then pumped approximately 15 m vertically upwards (via main pipelines) into a second, upper channel, which then directly transfers water to the Grahamstown Dam.

The water pumping station building is constructed of materials that include concrete, steel, and corrugated iron (see **Appendix 2B)**. The pumping station itself is erected on a concrete slab.

Because of the nature of its operations, some level of vibration is continuously generated and experienced by the pumping station. Therefore, construction of the pumping station is designed to sustain ongoing vibrational exposure.

Electrical Sub-Station with Powerlines

The electrical substation is located adjacent to the water pumping station. The electrical substation consists of power lines, power poles, transformers, and switches which are located on a concrete slab. The substation supplies electricity directly to the water pumping station (see **Appendix 2C)**.

Bridge

There is a small concrete bridge located in close proximity to the water pumping station spanning over the Balickera Channel, the bridge provides access across the channel (see **Appendix 2D)**.

Main Pipelines

There are several main directing pipelines between the pumping station and the upper Balickera Channel that are used for an upward transport of water (refer to **Figure 2**).

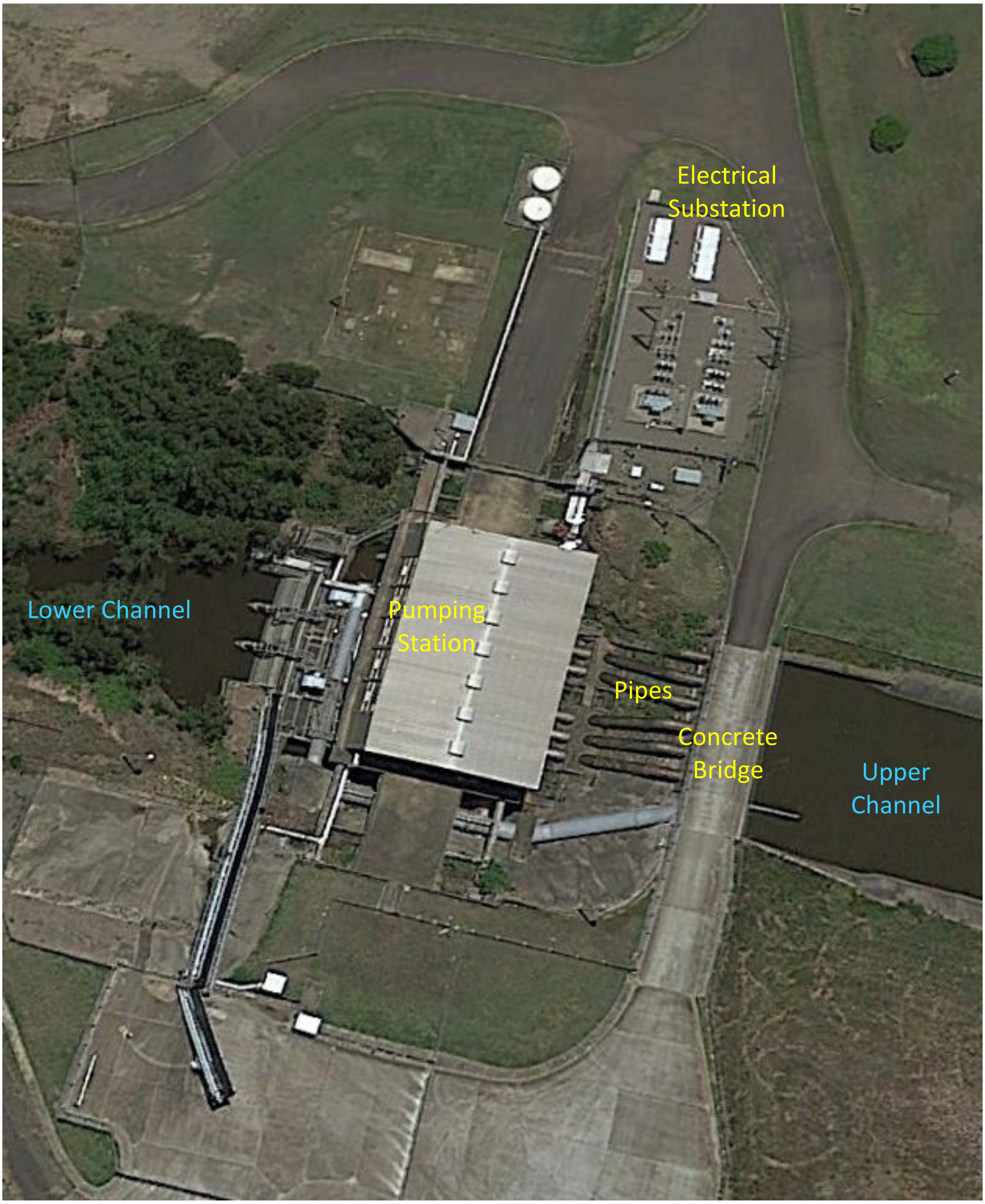

Figure 2 – Hunter Water Infrastructure

3. BALICKERA TUNNEL - ASSESSMENTS AND REMEDIATION WORKS

The Balickera Tunnel represents the closest Hunter Water infrastructure in relation to the location of the Project.

A summary of various assessments, inspection findings, and remediation measures undertaken on the tunnel is presented below. This provides an indication of the current condition of the tunnel and the implications for blasting associated with the Project.

3.1 Assessment by Douglas Partners (2007)

In 2007, Douglas Partners completed a detailed geological assessment on the condition of the Balickera Tunnel. This assessment also provided a list of recommendations for remediation works and additional support requirements to be undertaken to improve its condition.

As stated, there is substantial variation in geological conditions within the Balickera Tunnel. For instance, the lithology identified includes carboniferous rocks belonging to two stages (volcanic and glacial stages for the western and eastern sections, respectively) as highlighted in **Table 1**.

Table 1: Summary of the Local Geology of the Tunnel (based on Douglas Partners (2007))

Parameter	Description
Tunnel Length	1,219 m
Western Portal (upstream)	Volcanic Stage: Toscanite, Rhyolitic lavas, Tuff
Eastern End (downstream)	Glacial Stage: Tillitic conglomerates, Shale, Toscanite sandstone, Tuff
Regional Dip	south easterly; up to 50 degrees

The assessment comprised of visual inspection as well as a sounding inspection of the tunnel arch (including roof and rib sections, whenever accessible). The process of sounding of the roof is an indicative method which can alert and/or inform of potential rock strata stability issues whenever drummy sound is detected. Their investigation also involved: an assessment of tunnel conditions (including concrete lined and non-lined sections), as well as geologically and/or geotechnically affected areas and loose rock sections. In addition, it allowed for identification of potential areas with increased risks (requiring remediation works). Photographs were also taken of any detected geological features or structural abnormalities of concern. The results of Douglas Partners' investigation are summarised in **Table 2**.

The report notes there is a 50 m error in chainage measurements; most likely due to the stretching of the measuring string. Nonetheless, the study highlights the low risk (assessed as "good roof") and potential higher risk areas (negatively affected tunnel areas) and where some remediation works needed to be undertaken.

To better visualise the state of the tunnel (based on this study), the sections have been categorised and marked in different colours to highlight the urgency of the remediation works. Colours and their meaning are shown below:

- **'Red'** identifies high risk areas requiring immediate attention indicating areas where the potential for a roof fall is high.
- **'Orange'** indicates tunnel areas with an existing increased risk where either the bolts of the roof supporting system are highly corroded or there are some geological issues potentially impacting on long term stability of the tunnel.
- **'Yellow'** indicate potential remediation work is to be undertaken (only in certain sections).
- **'Green'** indicate there is no need to undertake any remediation work.

Note: 'Red' colour coding has not been used in the table as no 'high risk' areas were identified within the assessment (where the potential for a roof fall is high).

Table 2: Summary of Douglas Partners Investigation (based on inspection by Douglas Partners (2007))

Chainage *	Observations / Findings	Classification / Risks
0 – 5 Concrete lined section	No issues identified.	Generally **good condition**
5 – 131 Massive conglomerate with occasional jointing	No evidence of recent rock falls. Steps on the wall – due to fanning effect of drilled perimeter holes. Generally good conditions observed. Some drummy areas identified.	Conditions classified as **moderate** (may need attention where drummy areas identified)
131 – 140 Concrete lined section	Calcite and manganese staining. Hairline joints.	Generally **good condition**
140 – 199 Massive conglomerate with few joints & intermediate volcanics with numerous joints	Volcanics contains numerous joints. Areas of possible past falls identified. Tetrahedral overbreak observed - potential for further block falls.	Tunnel section **requiring attention** – especially for volcanics section Expected. Badly corroded bolts - near the end of lifespan (need replacement) – expected rock falls
195 – 250 Concrete lined section	Thickness of concrete – (130 -200) mm. Some voids observed above crown. Hairline cracks and calcite and limonite deposits detected. One corroded steel bar in the crown.	Generally **good condition**
250 – 385 Mainly conglomerate with bedded volcanics rock	Observed bedding plane shears. Occasional joints in conglomerate and volcanics. Shear separating conglomerate and volcanics.	Generally **good** condition Occasional drummy areas Some joint blocks are present
385 – 431 Predominantly volcanic rock	Presence of joints observed. Absence of major rock falls. Small joint blocks have fallen.	Conditions classified as **moderate** (may need attention); At 408 unstable rock supported by one (1) bolt.
431 – 440 Concrete lined section	Minor hairline cracks. Roots observed in the cored holes in the crown.	Generally **good** condition
440 – 485 Generally massive conglomerate with few bedding planes	Generally good condition.	Generally **good** condition

Chainage *	**Observations / Findings**	**Classification / Risks**
483 – 500 Basalitic dyke section of the tunnel	Dyke associated with parallel shear zone. High joint density. Substantial overbreak near the dyke. Dyke systematically rock bolted.	Tunnel section **requiring attention.** Many nuts and plate corroded
500 – 540 Predominantly conglomerate with some boulders up to 0.6m	Massive rock and restricted jointing. Possibly one recent 250mm rock fall detected.	Generally **good** condition
540 – 565 Concrete-lined section	Hairline cracks observed.	Generally **good condition**
565 – 612 Volcanic with high angle shears	Area affected by joints. Area bolted with variable pattern. Recent wedge failure observed.	Tunnel section **requiring attention**. Observed nuts and plates corrosion Potential for further wedge failure
612 – 695 Concrete-lined section	Calcite and limonite deposit due to large inflow in the central part.	Generally **good condition**
695 – 874 Excavation through volcanics	Number of joint sets varies from 3 to 5 from widely to closely space. Loose rock plates observed. Cantilevered blocks with joint separation. Tight jointing observed.	Conditions classified as **moderate** (may need attention) This section requires scaling to remove loosened rocks. Spot bolting will be required to address potential OH&S issue
874 – 890 Concrete lined section	No issues detected.	Generally **good condition**
890 -1001 Volcanics and include dyke and shears	Jointed sections detected (intensity spacing varies 0.2m to 2m). Recent fall visible, extensive overbreak above tunnel profile. Pattern and spot bolting observed. Some corroded bolts observed.	Tunnel section **requiring attention** - affected by geology and support system corrosion
1001 – 1169 Concrete lined section	Concrete visually sound. Minor defects detected.	Generally **good condition**

* *NOTE – Study discusses the error of 50m in identified locations, i.e., most likely due to stretching of the measuring string*.

The report findings are summarised as follows:

- The report highlights variations in geological conditions for western and eastern sections of the Balickera Tunnel. As identified by the study, a number of intersected geological features or changes in geology impacted on the quality of the tunnel arches. As summarised in **Table 2**, the inspection allowed identification of tunnel deficiencies and areas of increased risk.
- The observed ongoing bolt corrosion provides potential risk for future tunnel stability. There is a potential risk of falls, which could compromise tunnel operation e.g. a substantial fall size may either stop or significantly restrict the flow of the water.
- Various options for remediation work were considered, including:
  - A method involving the use of shotcrete lining (150 mm in thickness). It was proposed that the lining be reinforced with plastic fibre instead of steel to control shrinkage and provide structural reinforcement.
  - The report concludes that 150 mm thick complete fibrecrete (closed ring) forms would be sufficient to provide long term support. In the case of incomplete fibrecrete forms, the edges of fibrecrete are to be anchored by the rock bolts.
  - For bolt installation (recommended to support fibrecrete or on bare rock), additional recommendations were made to prevent corrosion i.e. when installing bolts, the the bolts are to be cement grouted with plastic sleeve CT Bolts.
  - A partial tunnel support option (excluding shotcrete lining) has also been discussed with appropriate recommendations made. Other alternative options of fibrecrete lining were also discussed.

3.2 Assessment of Remediation Work Options by Douglas Partners (2010)

Following a Hunter Water inquiry into the available options for remediation works for the Balickera Tunnel, an additional report was provided by Douglas Partners (2010), which included a detailed review of remediation works to be undertaken. It discussed the available options for maintenance of the tunnel in detail.

Minimum Work Requirements

The report considered minimum work to be undertaken on the tunnel including scaling of all loosened rock and strata bolting. In addition, it recommended an inspection and replacement of all corroded bolts with new bolts and for some tunnel sections, installation of shotcrete, fibrecrete, along with mesh installation should also be considered.

Alternative Methods

Alternative methods proposed included either a cast in place concrete lining, pre-cast concrete, or steel lining which requires grouting between the lining and the existing tunnel. As noted, these are more expensive methods than the minimum work method (i.e., bolting method).

Recommendations

The report recommended a detailed Rock Mass Classification study, which would help determine the necessity of remediation work (i.e., information on timing schedule).

Another option considered was the preparation of a sonar survey to estimate the quantity of the fallen rocks debris. This would provide a more in-depth study on identifying at risk areas of the tunnel (i.e., identification of areas prone to rock falls).

3.3 Rock Mass Classification Study by Douglas Partners (2011)

A subsequent, detailed assessment on Balickera Tunnel conditions was undertaken by Douglas Partners in 2011, which included a Rock Mass Classification study. This study served as a further filtration mechanism to assess tunnel areas of increased risk where potential rock falls may be encountered. It allowed improved identification of areas for further remediation work to be undertaken by Hunter Water. Findings were provided in a tabulated format that identified potential risk areas using chainage measurement.

The study concluded that the main risks were associated with potential slab and block falls. However, this was of relatively limited size. It also stressed that there is a possibility of larger scale falls, although this is dependent on the failure of the existing bolts that are in place. Failure of bolts will most likely be driven by age and external factors such as the presence of water and high humidity in the tunnel, which highly impacts corrosion of these bolts.

Douglas Partners (2011) also attempted estimation of the potential impact of the rock fall on the water flow in the tunnel. As indicated, this type of assessment is extremely difficult to conduct even if detailed joint data is available. Nonetheless, accounting for the geology of the site, the report indicated that rock fall height within the tunnel (if any) will most likely be limited. In the case of large-scale rock fall, it was indicated that the height of rubble on the floor most likely will not exceed 2 m; signifying only partial tunnel blockage.

The rock mass classification report provided commentary on the practical aspects of tunnel management when dealing with rock fall and remedial works. This includes safety considerations for personnel.

3.4 Inspection Findings by Abyss Solutions (2018)

Abyss Solutions (on behalf of GHD) undertook a detailed inspection of the Balickera Tunnel ((GHD (2018)) employing an above water inspection method. For that purpose, Abyss Solutions utilised a Tunnel Inspection Platform (TIP), which included a high-fidelity video recording of the tunnel crown with data analysis. This allowed identification of any fauna presence and the identification of potential defects present within the tunnel area.

Besides the fauna findings, a total of 36 potential structural defects and/or deficiencies were identified using this method. These are summarised in **Table 3**.

Summary

In summary, the number of identified defects within the Balickera Tunnel is considered limited taking into consideration its age (erected in 1962) and the length (approximately 1,219 m). For the tunnel's considered age, this inspection confirmed no immediate (significant) structural issues that would potentially impact on the tunnel operation or have immediate consequences such as completely (100%) blocking water flow or blocking 50% of water flow.

The observed limited damage is due to favourable lithology of the area where the tunnel was excavated through, as well as the original roof support system installed in the identified geologically/ geotechnically affected areas.

Table 3: Summary of Inspection Findings by Abyss Solutions (Abyss Solutions (2018))

Defect Type	Number Identified
Root penetration through the tunnel	4
Concrete ruptures	13
Seeping ruptures and joints	12
Cavity formation in the natural rock arch	1
Deteriorated rock anchors	6

3.5 Balickera Tunnel Remediation Works (2021 - 2022)

Based on the outcomes of the assessments undertaken, Hunter Water undertook a series of remediation works on the Balickera Tunnel in 2021 – 2022 with the aim of improving the long term structural stability of the infrastructure.

Remediation work undertaken on the tunnel, included removal of loose rocks from the floor and walls, and reinforcement of the tunnel walls. This remediation work was completed in 2022.

To improve long term stability, basically two methods were employed that included rock bolting and shotcrete / concrete lining of the tunnel walls (see **Appendices 3A-B** for more details).

Rock bolting is an effective method in any underground operation including tunnel works to achieve long term stability of the roof and rib strata. It is also an effective method for rock strata reinforcement as it provides long term structural gains by bonding any loose rock strata layers (or potentially delaminated strata) using chemically-anchored steel bolts installed in pre-drilled holes.

Another effective method of improving structural integrity of the tunnel walls is the application of shotcrete and/or concrete lining to the wall surface. By improving the tunnel's skin layer, long term cohesion is provided and any further delamination of the adjacent rock strata is limited.

Note: Some sections of the Balickera Tunnel had been previously concrete lined. This was primarily undertaken for geotechnically affected sections of the tunnel, Table **2** highlights concrete lined sections of the Tunnel.

It is noted that rock bolting had already been used during the initial construction phase of the Balickera in 1962, when the tunnel was excavated. The spot bolts and occasional sectional pattern bolting were installed in critical sections of the tunnel where weak geology or geological-structurally affected areas were detected at that time. Spot bolting is a simple and effective method for controlling roof in underground mines and tunnels excavated through hard rock strata material, where occasional geotechnical issues arise.

Pattern bolting is a more advanced method where a whole section of the roof strata is bolted up using the same pattern, for example repeating a design of 3 bolts per 1.5 m. Therefore, as the whole section of the roof strata undergoes reinforcement, improved solidity is provided for a large section of the roof.

A downside of such method is the potential for degradation and/or corrosion over time of the installed rock bolts. Corrosion is mainly driven by the presence of water and/or high humidity while it is noted that some of the geotechnical reports indicated corrosion of bolts and plates detected in the tunnel on some previously installed bolts.

Nevertheless, the described defects of potential roof bolt corrosion were identified and rectified with the remediation tunnel works. This included installation of roof bolts replacing corroded bolts with new bolts and installing additional bolts in highly affected areas. In addition, any suspected and/or potential unstable rock strata areas identified were scaled and bolted up (see **Appendices 3A-B** showing the process of rock strata bolting).

Another remediation method employed involved concrete lining of the tunnel. This would provide a firmer and/or smother arch tunnel support and therefore, lower resistance for water flow.

Both remediation methods described highly improve the tunnel's quality and minimise any potential risks over the long term, including risks of fall and blocking of the tunnel.

4. ASSESSMENT OF BLAST IMPACTS ON INFRASTRUCTURE

To complete this assessment, the following methodology was followed:

- Assessment of potential ground vibration, airblast overpressure, and flyrock impacts from blasting associated with the Project, for each infrastructure facility in view of applicable criteria or damage levels.
- Assessment of risks in view of the infrastructure type, state and condition, and implications for each infrastructure facility.

4.1 Site Law Model and Ground Vibration Estimation

This assessment utilised a ground vibration predictive model specifically developed for Stone Ridge quarry (ESC (2020)). A series of single hole test blasts were executed within the Project area. The blasts relied on controlled explosion of variable charge masses using explosives in pre-drilled holes. The method mimics (simulates) the future blasting practice associated with the Project, with varying charge masses applied. The blast induced ground vibrations were recorded using a number of vibration monitors. The data collected was utilised to develop a ground vibration predictive model (i.e., site law model) representative of the Project.

Site Law Model

The site law analysis is presented using a standard log-log scale, where monitored Peak Particle Velocity (PPV) values are plotted against the scaled distance (see **Figure 2)**.

Two lines apply to the assessment. The first line represents a median line (i.e., 50% level line), which indicates that 50% of vibration responses are located above the line and 50% are below the line.

The second line is a 95% level line where 95% of vibration responses are located below this line. The 95% level, advocated by the Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines (1990), allows for an inherent variation in emission levels. This allows for a 5% exceedance of the general blast criterion.

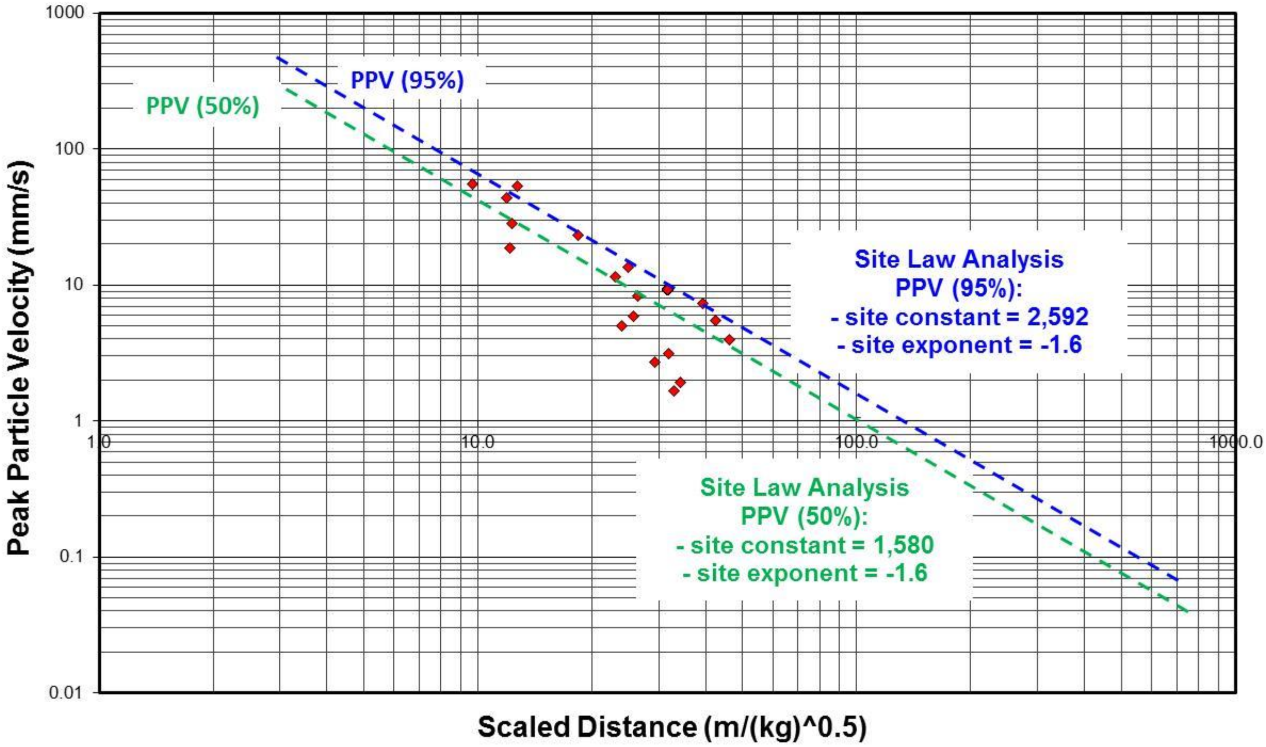

Figure 2 – Site Law Analysis for the Balickera Area (after ESC (2020))

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

- site exponent a = -1.6
- site constant *k* = 2,592

Therefore, the formula for vibration modelling for the Balickera area is:

$$\boldsymbol{PPV} = 2{,}592\left(\frac{D}{\sqrt{m}}\right)^{-1.6}$$

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)

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

- site exponent a = -1.6
- site constant *k* = 1,580

Ground Vibration Estimations

Vibration modelling has been performed according to the formulas specified above (i.e., using 50 and 95% level models, which allows for the estimation of a potential range of vibrations).

Note: A wide range of charge masses have been used for modelling purposes as no final decision has been made yet on the Project charge masses (related to proposed blasting bench heights). Most likely the Project will utilise charge masses in the order of 120 – 180 kg, equivalent to 15 m and 20 m benches respectively.

The results of the vibration modelling are summarised in **Table 4**. These are compared to available criteria and/or limits whenever applicable.

Table 4: Results of Ground Vibration Modelling for Hunter Water Infrastructure

Vibration Estimate* (mm/s)						
Receptor	**Min. Dist. (m)**	**MIC (kg)**				**Assessment / Limits / Comments**
		60	**120**	**180**	**240**	
Balickera Tunnel	270	5 – 9	9 – 15	13 – 21	16 – 27	Vibration estimates below the damage criteria for underground rock strata and concrete material being in the order of few hundreds mm/s (Siskind (2005), Lewandowski *et al*. (1999), (2006). For the underground tunnel the airblast and flyrock risks are not applicable.
Upper Channel	340	4 – 6	6 – 11	9 – 15	11 – 19	Vibration estimates below the damage criteria for concrete material being in the order of few hundreds mm/s. Flyrock** risk is low; Airblast risk – n/a
Lower Channel	840	1 – 1.4	1 - 3	2 – 4	3 – 4	As above.
Pumping station	800	1 – 2	2 – 3	2 – 4	3 – 5	Vibration estimates below the 25 mm/s limit for occupied non-sensitive sites (AS 2187.2-2006). Flyrock** risk is low; Airblast risk is low; any airblast requirements will be met by the application of limit criteria for private residences located in the area.
Bridge	770	1 - 2	2 – 3	2 – 4	3 – 5	Vibration estimates below the 100 mm/s limit for concrete bridges (ACARP Report No. C14057). Flyrock** risk is low; Airblast risk – n/a
Electrical Substation	800	1 – 2	2 – 3	2 – 4	3 – 5	Vibration estimates below the 25 mm/s limit for occupied non-sensitive sites (AS 2187.2-2006). Flyrock** risk is low; Airblast risk – n/a
Timber Power Poles	770	1 – 2	2 – 3	2 – 4	3 – 5	Vibration estimates below the 100 mm/s limit for timber power poles (ACARP Report No. C14057). Flyrock** risk is low; Airblast risk – n/a
Pipelines	780	1 – 2	2 – 3	2 – 4	3 – 5	Vibration estimates below the 100 mm/s limit for buried cables and pipelines (ACARP Report No. C14057). Flyrock** risk is low; Airblast risk – n/a

**- Vibration predictions based on both site law model for 50% and 95% levels.*

***- Flyrock risk - the risk of flyrock damage is low being located beyond the exclusion zone for plant and equipment (i.e., 300 m from the blast, which is typically applied in the open cut mining environment).*

The results of the blast impact analysis are summarised below:

- The vibration modelling shows that the impact of ground vibrations on critical infrastructure (including the Balickera Tunnel and Balickera Channel) is well below the damage criteria for the infrastructure items; hence the risk is concluded as low. This is taking into consideration the vibration level exposure, type, and state of the infrastructure facilities (see Section 4.3 below). The risk of damage from flyrock and airblast overpressure is considered not applicable (i.e. being an underground facility) or low for Balickera Channel (located beyond the exclusion zone area).
- The vibration modelling for other infrastructure facilities (i.e. located further away from the Project area) are also well below the damage criteria. This is taking into consideration the type and state of the infrastructure items (see Section 4.3 below). The risks of damage from flyrock and airblast overpressure are considered either low and/or negligible (being well behind the blasting exclusion zone), or not applicable.

4.2 Airblast Overpressure

Usually, infrastructure sites with no specific airblast criteria are not assessed in terms of airblast overpressure impacts. This is due to the fact that the levels required to inflict damage on infrastructure are not applicable and / or not reached during blasting operations.

4.3 State of the Infrastructure and Assessment of Risks

The state of infrastructure facilities is of principal importance when assessing infrastructure response to blast impacts i.e., infrastructure in a dilapidated state can easily be damaged or even destroyed (Lewandowski *et al*. (2011)). Conversely, infrastructure in a "sound / good condition" can be exposed to substantial vibration impacts without negative effects.

Infrastructure can be exposed to low, moderate or high levels of vibration. Detailed assessment is required when infrastructure is exposed to moderate or high vibration impacts. However, when dealing with low level vibration a detailed analysis is not essential. This is because at low vibration levels the blast impact is usually minimal in terms of generated stresses and strains, and subsequently the risk of infrastructure damage, is low or even negligible.

State of Balickera Tunnel and Assessed Risks

As presented in Section 3, majority of the tunnel is classified as being in sound / good condition.

Initial assessments, however, identified that some sections, presented potential issues; these were identified and recommended for further remediation work to be attended by Hunter Water. The issues were classified as being of moderate in nature e.g., potential localised falls, which may restrict the tunnel area. It is noted that potential issues were only limited to certain sections of the tunnel i.e., where either unfavourable geology was intersected or where the roof support system was affected by corrosion.

Following these findings, Hunter Water conducted remediation works in 2021 – 2022. The rehabilitation work on the tunnel area included re-supporting tunnel sections and realigning the tunnel walls. Based on this work, it can be concluded that some sections of the tunnel now have significant improvement in condition (through increased strata support). Overall, sound / good strata conditions and good tunnel conditions can be concluded as a result of the findings from the past assessments and remediation works carried out in 2021 – 2022.

Another point of note is the underground rock strata response to blast vibrations. To gauge the underground rock strata behaviour when exposed to ground vibrations indicative responses from underground coal mines are included in **Appendix 4.** This is based on the author study (Lewandowski et al. (2006), which includes vibration measurement and observation of underground rock strata behaviour at coal mines (approximate coal strength 7 – 15 MPA, roof strength 15 – 40 MPa) when exposed to adjacent surface open cut blasting. The reference material indicates that the levels of vibration need to be of substantial magnitude (i.e., few hundred mm/s to induce damage to underground rock strata). This is similar to that reported by Siskind (2005) and Lewandowski *et al*. (1999). By comparison, the modelling of vibration impacts for the tunnel revealed low vibration impacts (i.e., no higher than 27 mm/s – see **Table 4**). Based on the table Impact of Vibrations in **Appendix 4** which summarises indicative strata behaviour when exposed to a range of blast vibrations it is inferred that the arches of the tunnel would respond in elastic manner to blast vibrations. The expected impact even at the highest predicted level (i.e., 27 mm/s) would most likely induce falling of the accumulated dust to the floor and potentially displace small loose pieces (unattached / trapped pieces in cervices) to the floor. Therefore, the predicted level of vibration exposure is considered to be relatively low and should not provide any major risks for infrastructure such as the Balickera Tunnel.

The tunnel also includes a section of concrete lining material. Concrete (i.e., typically 20 – 30 MPa in strength is similar to rock strata material) is extremely hard material and resistant to impacts of blasting, where vibration levels in the order of few hundred mm/s are required to induce any impacts (Oriard (1998), Siskind (2005) and Lewandowski et al. (2011)). There is no risk of damage for concrete material at the predicted levels of up to 27 mm/s.

Using **Table 5** for risk classification and considering sound/good infrastructure condition (i.e., following the remediation work) and low vibration exposure (i.e., based on **Table 4**) for the Balickera Tunnel, the risks are classified as low.

State of Balickera Channel and Assessed Risks

As previously identified, the banks of the Balickera Channel are constructed of concrete material approximately 150 mm in thickness. Concrete represents extremely hard material (i.e., typical strength in the order of 20 – 30 MPa) and resistant to impacts of blasting. Vibration levels in the order of few hundred mm/s need to be induced for any sign of impact to be observed (Oriard (1998), Siskind (2005) and Lewandowski *et al*. (2011)).

There is no risk of damage as a result of blasting associated with the Project, for concrete material at the predicted levels of vibration exposure (i.e., no higher than 19 mm/s for Balickera Channel).

The considered Balickera Channel is inferred to be of sound / good condition. Any deterioration of the channel would be detected and rectified on ongoing basis by the infrastructure operator during operational processes.

Using **Table 5** for risk classification and considering good infrastructure condition and low vibration exposure (i.e., based on **Table 4**) for the Balickera Channel, the risks are classified as low.

State of Other Infrastructure and Assessed Risks

The state of other infrastructure facilities (including the pumping station, electrical substation and the bridge) is inferred to be in sound and/or good condition. These facilities are in continuous operation and management by Hunter Water; sound / good conditions constitute an elementary requirement for the hydro management system operation. It is assumed that any deterioration of these facilities would be detected and rectified by the infrastructure operator during associated operational processes.

Using **Table 5** for risk classification and considering good infrastructure condition, and low vibration exposure (i.e., see **Table 4**) for these facilities, the risks from blasting are classified as low.

Table 5: Risk Assessment for Infrastructure Facilities and the Balickera Tunnel

Infrastructure Condition / Geotechnical Condition	RISK LEVEL		
	Low Vibration	**Moderate Vibration**	**High Vibration**
Poor	Low Risk	Moderate / High Risk	High Risk
Moderate	Low Risk	Moderate Risk	Moderate / High Risk
Sound / Good	Low Risk	Low Risk	Moderate Risk

5. CONCLUSIONS

In response to the SEARs requirements (SEARs (2020)), ESC have conducted a detailed assessment of blasting impacts and related risks associated with the Project on the adjacent Hunter Water infrastructure. The investigation included identification of infrastructure facilities, ground vibration modelling, and assessment of potential risks for each infrastructure item. The investigation relied on the review of available assessment studies, the latest remediation works on the Balickera Tunnel, and literature findings on blasting impacts on underground roads and tunnels as well as the applicable limits for infrastructure. The following conclusions have been made:

- The relevant infrastructure facilities were identified as follows: the Balickera Tunnel, Balickera Channel and associated infrastructure (including pumping station, electrical substation, pipelines and bridge). This infrastructure is considered critical infrastructure facilities to supply water to Grahamstown Dam.
- The Balickera Tunnel and Balickera Channel, represent the closest infrastructure facilities, located within 270 and 340 m of the Project area. The vibration modelling (using various blasting scenarios) predicted vibration levels to be well below the damage level criteria for the infrastructure. The assessment of risks from blasting for the Balickera Tunnel and the Balickera Channel concluded Low risk. This considered the assessed type, state, and other factors (such as geological/geotechnical conditions based on reviewed assessments) and the latest remediation work for the tunnel area undertaken in 2021 - 2022. The risk of damage from airblast and flyrock is considered low / negligible or not applicable.
- Vibration impacts for the remaining related infrastructure were estimated based on a range of various blasting scenarios. Modelling confirmed no significant blast vibration impacts (i.e., well below damage criteria) for the infrastructure. The risk of damage from blast vibration exposure is classified as low for the infrastructure i.e. no damage or deterioration is expected due to blasting. The risk of damage from airblast and flyrock is considered low / negligible or not applicable.

In summary, the study concluded an absence of any significant risks related to blasting activities associated with the Project on Hunter Water infrastructure.

Thomas Lewandowski
15th May 2023

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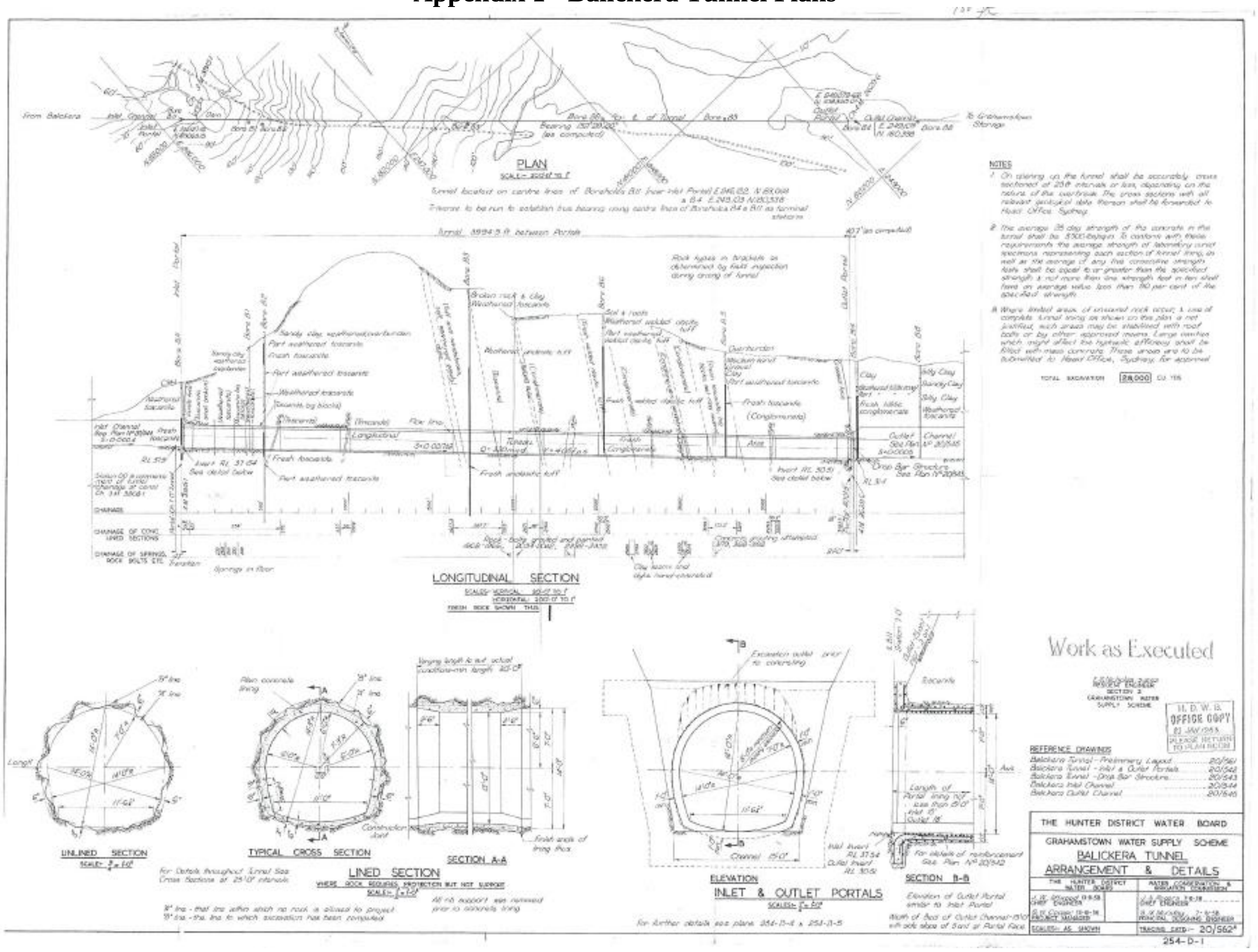
APPENDICES

Appendix 1 - Balickera Tunnel Plans



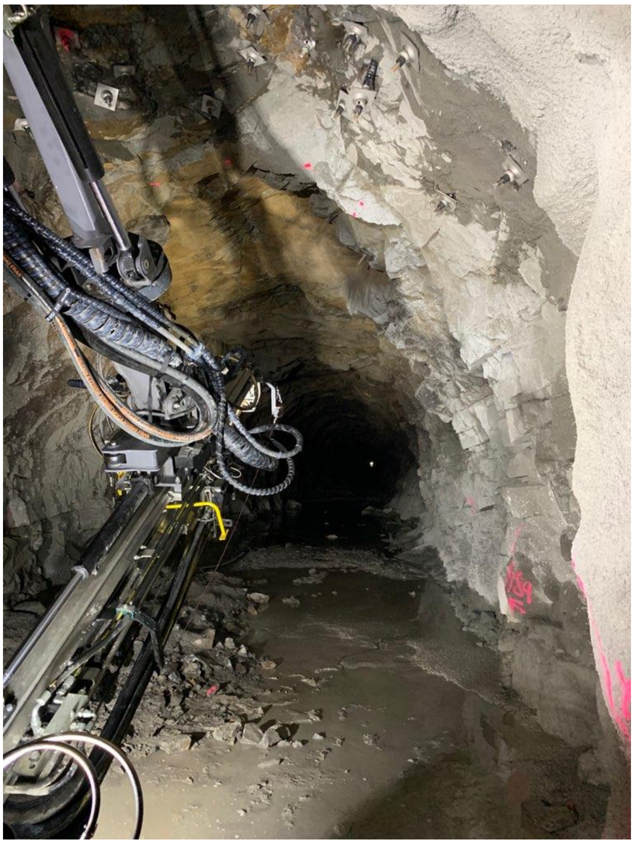
Appendix 2A – View of Balickera Channel Leading to Balickera Tunnel

Appendix 2B – View of Water Pumping Station

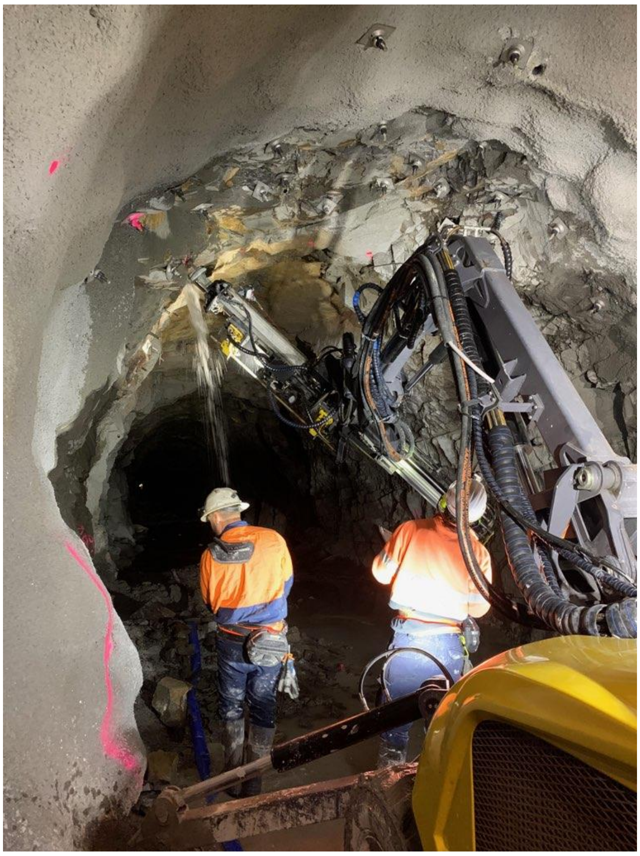
Appendix 2C – View of Electrical Substation

Appendix 2D – View of Concrete Bridge over Balickera Channel

APPENDIX 3A – Balickera Tunnel Remediation Work



APPENDIX 3B – Balickera Tunnel Remediation Work



Appendix 4 – Impact of Vibration – Indicative Roof and Rib Behaviour for Coal Mine (after Lewandowski et al. (2006))

Vibration Level (mm/s)	Description	Symptoms
0 – 20/30	- elastic roof behaviour - no impact on roof and ribs	- loose pieces of coal / rock can possibly fall due to vibration - acceptable vibration level by personnel
20/30 – 40	- elastic roof behaviour - no damage to the rock strata	- some pieces of coal dust fall on the floor - unpleasant/intolerable vibration level by personnel - loose pieces of coal / rock can possibly fall due to vibration
40 – 150/180	- elastic roof behaviour - no damage to the rock strata	- large amount of stone dust on the floor - loose pieces of coal / rock can possibly fall due to vibration
150/180 – 250	- minor damage stage	- minor roof fretting - minor damage to the roof corners - minor damage to the ribs - large amount of stone dust on the floor
250 – 350	- deteriorating stage (more pronounced damage stage)	- development of roof cracks - pronounced damage to the ribs - roof corner deterioration - possible damage in the vicinity of geological features
>350?????? level unknown	- failure stage (possible roof fall stage – this stage is highly dependent on roof and rib bolting density)	- substantial number of new cracks in the roof - possibility of joints opening - possibility of roof fall highly dependent on roof bolting density - possible delimitation of the roof - substantial damage to coal ribs