Impact Evaluation of Blasting
Prieska Zinc Copper Project
(Including the Vardocube Extension)

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2 SUMMARY

This evaluation is for blasting in the proposed opencast and underground mining operations for Prieska Zinc Copper Project.

The impacts related to blasting induced vibration, air blast, fly rock, dust, and fumes have been evaluated. Their impact on structures, people and animals are included.

The impact assessment was based on the operational phase of the project, and deals with blasting in surface and underground mining. Blasting in the surface operations is scheduled to be completed in one to two years and will be followed by underground mining 900 m below surface.

Mitigation measures will be needed for fly rock control during the open cast phase of mining.

With mitigating measures in place, as outlined in this report, all significance ratings will all be **Low** for blasting impact for both surface and underground mining. This includes an evaluation of negative impact on the following receptors that surround the proposed mine:

Management Offices and other proposed mine infrastructure
Magazines
Eskom Yard
Copperton Access Road
Closest borehole
The existing and planned solar power plants in the vicinity of the proposed mine
Copperton town
Proposed Copperton Wind Farm and Garob Wind Farm
Copperton Rail Station (out of use at present)
Farm Dam
Copperton airstrip
R357

This revision of the report includes a blasting risk assessment for the newly proposed Vardocube extension to the underground workings. The only environmental aspect from blasting will be blasting induced ground vibration. This will have a Low significance on the receptors that are closest to the blasting, these all being within 1300 m of the blasting. Receptors beyond this distance will be see Very Low to Zero impact significance. Although mitigation measures will not be required, a control measure has been described, should complaints be received from people who perceive a risk of damage.

3 Independence Declaration

The author of this report is independent. The work that has been done for this report has been performed in an objective manner and according to international standards, which mean the result and recommendations may not be positive to the client.

The author has the required expertise to conduct this study and report. A resume is provided in the Appendix 4 of this report.

4 INTRODUCTION

This report provides an impact evaluation for the blasting operations in the open pit and underground. The report is based on published methods for determining the impacts of ground vibration, air blast, dust, fumes and fly rock and on information provided in the ABS Africa Scoping Report March 2018.

Additional information is provided in Appendix 5 as an addendum for vibration calculations assuming multiple hole initiations for ground vibration risk assessment in an unmitigated situation using 171 mm holes for surface blasting and 102 mm holes for underground blasting. These represent worst-case scenarios regarding ground vibration impact.

Appendix 6 provides the assessed ground vibration risk assessment for underground blasting of the planned Vardocube extension

5 METHODOLOGY

The impact assessment for surface blasting is evaluated for the following potential effects:

1. Vibration impact on people, buildings and structures
2. Fly rock impact on safety of people and structures
3. Impact of dust and fumes on people, and sensitive structures near mining
4. Risk of water pollution caused by explosives dissolving into the ground water system
5. Risk of blast induced damage to water wells (boreholes) surrounding the mine

The impact assessment is based on international standards on limits for vibration and air blast and fly rock range. These are outlined in Appendices 1 and 2.

The blasting methods have been defined. These will have an influence on some of the impacts from blasting. The surface waste mining and the underground long-hole open stoping blasts will have the highest charge mass per hole and will therefore have a larger impact than the drift blasting or the open pit ore blasting. The drift blasts and open pit ore blasting will have a lower impact and because the impact significance is low based on the larger charge masses, these two are not assessed in this report.

6 PROJECT DESCRIPTION

6.1 Open pit blasting

The open pit mining will take place at the initial 12 to 24 months of the project while the underground workings are being refurbished.

Blasting of waste to final pit walls will be carried out on 10 m benches. Ore will be blasted on 5 m benches. Because of the taller benches for waste blasting, larger charges will be fired, and these will have a greater environmental impact. Therefore, ore blasting has been excluded from this study.

The impacts are based on 12 m deep holes to include sub-drill (Table 1).

The important variables for environmental impact control are the charge mass per hole and the stemming lengths applied. Standard stemming lengths have been applied based on hole diameters of 171 mm.

6.2 Underground Blasting

The long-hole open stope blasting (ring blasting) will have the highest impact on the vibration generated to the surrounding receptors. The other contributors (air blast, dust and fly rock) will have no significance for the receptors.

Table 1. Approximate designs that are planned for blasting of waste in the open pit and blasting of ore in the long-hole open stopes at the Prieska Zinc Copper Project. The information in this Table is only for risk evaluation purposes and <u>does not represent</u> a prescribed blast design methodology. The hole diameters that have been chosen for the assessment represent the largest likely diameter that might be used, and therefore, the largest likely charge mass.

	171 mm hole (Surface Waste)	**127 mm hole (Long-hole, underground)**
EXPLOSIVE		
Explosive Type	Emulsion	Emulsion
Charge Mass/Metre (kg/m)	27.17	15.24
Maximum Explosive Mass Per Hole (kg)	233.11	418.49
Effective Charge Diam (mm)	171.00	127.00
Average In-hole Density (g/cm3)	1.18	1.20
BLAST GEOMETRY		
Stemming Length (m)	3.42	2.54
Column Length (m)	8.58	27.46
Hole Depth (m)	12.00	30.00
Hole Diameter (mm)	171.00	127.00

Bulk emulsion explosives have been assumed for both mining methods in this design, because they have a higher in-hole bulk and are water-proof, thus limiting the impact of dissolution into the ground water.

The impact of blast design timing assumes that detonating cord will not be used on surface for initiating the holes and that holes will be timed to fire one-at-a-time. In other words, non-electric or electronic detonators will be applied for hole detonation sequencing in each blast, both surface and underground.

Presplit blasting design is not defined in this document except for the fact that presplitting is likely to be done by firing a line of holes at very short delay intervals and without stemming material in the presplit holes. The impact is based on this method.

7 DESCRIPTION OF RECEPTORS

7.1 Structures

The areas surrounding the mine are characterised by a small town (Copperton) and other structures including 3 operating and several proposed solar farms, two proposed wind farms (approximately 6 km from the mining area), roads, a dam and nearby Eskom buildings. The buildings and structures that are closer to the blasting will be negatively impacted by blasting more than those located further from blasting.

Isolated buildings closer to the mine have not been identified. The impact on these structures will depend on their distance and can be evaluated from the vibration curves given in Figure 1.

Most of the buildings are constructed of cemented concrete blocks or brick with corrugated iron or tiled roofs.

Table 2. Structures that have been identified within 10 km of the mining areas. The shortest distance (worst case) to the position in the mine where blasting will take place is given.

Receptor	Minimum Distance to Blasting (m)
Management Offices	550
Eskom Yard	1400
Copperton Access Road (by-passing the mine)	1500
Closest borehole	1800
Explosives Magazines	1800
Mulilo Solar PV	2100
HR Solar 1 to 3	>2200
Copperton Town	2300
Copperton Rail station (out of use at present)	2900
Farm Dam	3600
Copperton Airstrip	4800
Proposed Copperton and Garob Wind Farms	6200
14 Planned Solar Farms to the South of the mine	7000
R357	8400
Southern Solar Farm (Mulilo Sonnedex Prieska PV)	9500

Most of the buildings are not likely to be the same construction on which international vibration limits have been formulated. The limits applicable are likely to be less, and this study applies a limit of 5.0 mm/s, which is approximately half the USBM Standard provided in Appendix 1 at typical resonant frequencies of 4 to 20 Hz.

7.2 Solar Farms

There are several solar farms in the area surrounding the proposed mining. Where there are buildings in the solar farms, the vibration at these structures should not be allowed to exceed 5 mm/s (Building response to vibration is detailed on Page 25 (Appendix 1). The level of 5 mm/s provides for a very low probability of vibration induced damage from blasting.

7.3 Humans and animals

Humans are sensitive to vibration and react negatively to it especially when buildings or structures, in which they may be, respond and vibrate.

The levels at which human beings become alarmed or find vibration intolerable is between 2.5 and 7.5 mm/s. (Appendix 1, Page 25). For this assessment, a level of 5 mm/s has been applied so that complaints from neighbours are contained.

Generally, however, air-blast is confused for ground vibration (Chiappetta, 2000), and small noisy blasts, such as presplit blasting, can cause more distress to surrounding people than large well confined blasts where air-blast is contained, even when ground vibration is relatively high.

The response of animals to ground vibration and air blast from blasting is not well-known and no definitive studies have been done to determine the effect of blasting on livestock. However, the impact is likely to be similar or less sensitive compared to humans. Therefore, the limits applied for human beings will safely apply to animals. For a short time, animals may be alarmed by high air blast overpressures, but experience in other mining areas has shown that, within weeks, they begin to identify the air pressure waves as being non-threatening and ignore these completely.

7.4 Atmosphere

Blasting impacts the atmosphere in the form of carbon dioxide (CO2), which is a greenhouse gas. The level of negative impact will depend, however, on the control in blasting to limit the formation of nitrous oxide gases which are toxic and are a major greenhouse gas. Mitigation against the formation of nitrous oxides is provided in this document.

7.5 Water

Pollution of the ground water can occur through dissolved nitrates from the explosives. The dry conditions in this area will favour the use of explosives that are not water proof, such as ANFO. However, these types of product dissolve easily into the ground water releasing nitrates. Therefore, mitigation provides for the use of waterproof explosives.

7.6 Farm Dams

An earth dam with a small reservoir exists to the east of the planned mining that will be at risk from desegregation if the ground vibration exceeds 150 mm/s.

7.7 Buildings

The mine’s proposed management offices are 550 m from the edge of the proposed open pit. Although vibration will not present a risk, uncontrolled fly rock will place people working in the offices at risk.

7.8 Boreholes

There are several boreholes surrounding the mine, the closest one being some 1800 m from blasting activity. The predicted vibration result at this distance is less than 0.5 mm/s (Table 3). Reviewing the published information regarding vibration and damage to aquifers, the blasting pressure on the aquifer walls will be less than 4 KPa. This is much less than the pressure exerted on the walls by the water itself.

Therefore, regarding blasting, there will be no impact on the integrity of the borehole or aquifer walls.

8 ENVIRONMENTAL ASPECTS FROM BLASTING

8.1 Vibration

The estimated vibration levels presented in Table 3 are based on open cast waste blasting and underground long-hole open stope blasting. The likely peak vibration amplitude is referred to as Peak Particle Velocity (PPV) and is used as a basis for damage limiting criteria together with blasting frequency.

The PPV values presented in this Table are based on Equation 1 for the surface blasting and Equation 2 for the underground blasting (Appendix 1) as well as the charge mass per hole as defined in Table 1. The scaled distance equation (Equation 1/Equation 2) has been used because it is conservative and estimates the worst likely case. Table 3 presents estimated vibration amplitudes as a function of distance from blasting for the two opencast and underground blasting types and explosives having a density of 1.18 g/cm^3 and 1.20 g/cm^3 as outlined in Table 1.

Vibration amplitudes will depend on the initiation system used and the design applied by a blasting engineer. The latter will be able to control these variables so that the vibration amplitudes are lower than 5.0 mm/s at any building (limits are detailed in Appendix 1).

Table 3. Predicted vibration amplitudes from blasting based on the application hole diameters and charge mass per hole as per Table 1. Note: these values are based on a single hole firing per instance in time (mitigated). Vibration increases significantly if more than one hole is fired at a time.

Distance (m)	PPV (mm/s) 171 mm hole (Surface Waste)	PPV (mm/s) 127 mm hole (Long-hole, underground)
50	161.4	48.1
100	51.4	15.3
300	8.4	2.5
700	2.1	0.6
1000	1.2	0.3
1250	0.8	0.2
1500	0.6	0.2
1750	0.5	0.1
2000	0.4	0.1
2250	0.3	0.1
2500	0.3	0.1
3000	0.2	0.1
3250	0.2	0.0
3500	0.1	0.0

8.2 Graphical Estimate of Vibration Amplitudes

The vibration amplitudes presented in Figure 1 are based on the likely blast designs provided in Table 1 and on the scaled distance equations in Appendix 1.

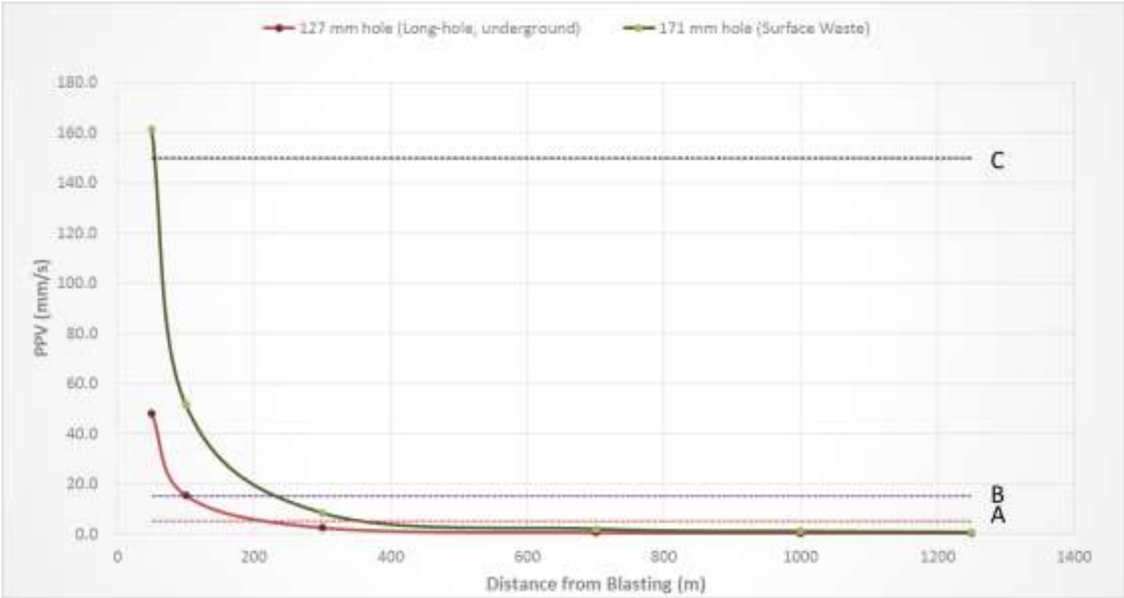

Figure 1. Vibration estimates from waste blasting (surface) and underground long-hole blasting. Estimates are made according to the scaled distance given in Appendix 1. Different levels represent the following: A = 5.0 mm/s is the amplitude level that is disturbing to human beings and complaints are likely to be received. B = 15 mm/s is the amplitude level where there is a 5% probability of cosmetic damage at building resonant frequencies. C= 150 mm/s at which point desegregation of earth walls becomes a risk.

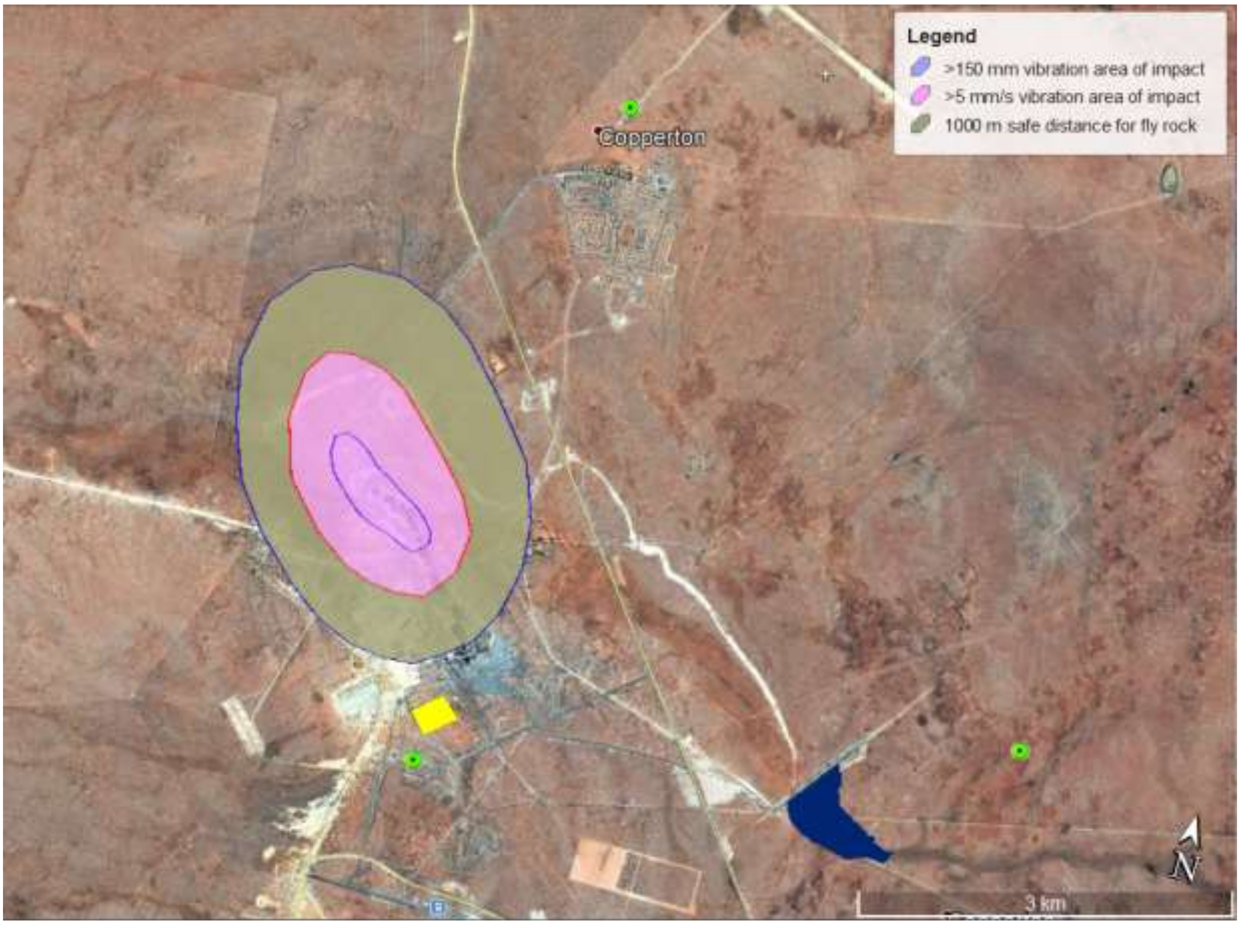

Figure 2. Google image with blasting impact areas overlain for vibration and fly rock.

To achieve low negative impact significance, vibration at any privately-owned structure must be maintained below 5 mm/s. From the distances presented in Table 2, it is unlikely that any privately-owned structures surrounding the mine will be negatively impacted by blasting vibration.

8.3 Air Blast (Opencast blasting only)

Over-charging of blastholes, poor stemming[1] performance or lack of stemming material and under-burdened holes contribute to high air blast levels. These levels will be aggravated by cloud cover and will always be higher in the down-wind direction. People living downwind of the open-cast operation will be more negatively impacted than other people around the mine.

Effective mitigation measures are available to contain air blast thus making the negative impact significance Low with these measures in place. To achieve low negative impact significance, air blast needs to be kept below 125 dB at any point of concern for all blasting operations.

[1] Stemming is the plug of waste material, such as drill cuttings or aggregate that is positioned at the top of the explosives column in each blasthole. Its function is to contain the explosives energy in the rock mass and prevent high velocity venting of gases through the hole collars of the holes. Stemming performance improves with increasing stemming length. The type of stemming material also plays a role in stemming effectiveness.

8.4 Fly Rock (Opencast blasting only)

Uncontrolled fly rock from blasting can travel hundreds of metres, with known cases up to 1000 m. This range is for extreme cases where very little blasting control is applied and is due to over-charging of holes or under-burdening of holes.

The negative impact of fly rock will be most severe for structures and people within 1000 m from blasting, but with mitigating measures in place, there will be no impact at distances further than 500 m and low at distances between 100 m and 500 m from blasting. The mitigation measures require special control on stemming and clearing of people in the zone closer than 500 m to blasting.

8.5 Dust and Fumes

Dust and fumes from blasting will be carried downwind from the blasting areas.

Excessive blast-related dust is caused by insufficient or ineffective stemming material in each hole. The negative impact significance will be reduced to medium low with effective stemming controls in place. With effective stemming control, atmospheric dust is mostly contained to within about 200 m of blasting.

Poisonous fumes from blasting are caused by incomplete detonation. Blasting normally generates water, carbon dioxide, nitrogen and some solids. However, incomplete detonation, which is caused by poorly formulated explosives or unfavourable ground conditions, can result in poisonous fumes, these mainly being nitrous oxides (red in colour) and carbon monoxide. Both disperse very quickly into the atmosphere, and will not pose a risk to people or animals at distances greater than about 1000 m. At distances closer than this, there is a risk to people's health and this would fall into the occupational health category. They are undesirable as there is risk to people accidentally breathing in these gases, and mitigating measures will be needed to keep the negative impact significance to medium low. These measures are described on Page 21.

9 RISK ASSESSMENT

The risk assessment for both surface and underground mining based on the methodology outlined is provided in Appendix 3.

The summary of receptors with the highest negative impact assessment is provided in Table 4. These values are given based on both underground and surface mining. The underground mining will have no fly rock nor air blast impact.

Table 4. Summary of receptors with highest negative impact significance unmitigated and mitigated.

	Unmitigated			
Receptor	**Vibration**	**Air blast**	**Fly Rock**	**Fumes/ Dust**
Management Offices	Medium Low	Medium High	Medium High	Medium Low
Eskom Yard	Low	Medium High	Medium Low	Medium Low
Copperton Access Road (by-passing the mine)	Low	Low	Medium Low	Medium Low
Closest borehole	Low	Low	Low	Low
Explosives Magazines	Low	Low	Low	Low
Mulilo Solar PV	Low	Low	Low	Low
HR Solar 1 to 3	Low	Low	Very Low	Low
Copperton Town	Low	Low	Very Low	Medium Low
Copperton Rail station (out of use at present)	Low	Low	Very Low	Very Low
Farm Dam	Low	Low	Very Low	Very Low
Copperton Airstrip	Low	Low	Very Low	Very Low
Proposed Copperton and Garob Wind Farms	Low	Low	Very Low	Very Low
14 Planned Solar Farms to the South of the mine	Low	Low	Very Low	Very Low
R 357	Low	Low	Very Low	Very Low
Southern Solar Farm (Mulilo Sonnedex Prieska PV)	Low	Low	Very Low	Very Low

Mitigated

Receptor	**Vibration**	**Air blast**	**Fly Rock**	**Fumes/ Dust**
Management Offices	Low	Low	Low	Low
Eskom Yard	Low	Low	Low	Low
Copperton Access Road (by-passing the mine)	Low	Low	Low	Low
Closest borehole	Low	Low	Very Low	Very Low
Explosives Magazines	Low	Low	Very Low	Very Low
Mulilo Solar PV	Low	Low	Low	Low
HR Solar 1 to 3	Low	Low	Very Low	Very Low
Copperton Town	Low	Low	Very Low	Very Low
Copperton Rail station (out of use at present)	Very Low	Low	Very Low	Very Low
Farm Dam	Very Low	Low	Very Low	Very Low
Copperton Airstrip	Very Low	Low	Very Low	Very Low
Proposed Copperton and Garob Wind Farms	Very Low	Very Low	Very Low	Very Low
14 Planned Solar Farms to the South of the mine	Very Low	Very Low	Very Low	Very Low
R 357	Very Low	Very Low	Very Low	Very Low
Southern Solar Farm (Mulilo Sonnedex Prieska PV)	Very Low	Very Low	Very Low	Very Low

<table>
<tr><td colspan="9">OPENCAST BLASTING</td></tr>
<tr><td>Project Activity</td><td colspan="2">Blast-induced <u>ground vibration</u> damage to buildings closer than 500 m from blasting</td><td colspan="2">Likelihood</td><td colspan="3">Consequence</td><td></td></tr>
<tr><td rowspan="6">Ore, waste and final wall blasting</td><td>Phase of Project</td><td>Preparation, Construction and Operational Phases</td><td>Frequency of Activity</td><td>Frequency of Impact</td><td>Severity</td><td>Spatial Scope</td><td>Duration</td><td>Significance Rating</td></tr>
<tr><td>Impact Classification</td><td>Direct Impact</td><td colspan="6">Significance Pre-Mitigation</td></tr>
<tr><td rowspan="4">Resulting Impact from Activity</td><td rowspan="4">Minor damage to buildings (real or perceived by building owners) in the form of cracks in walls</td><td>4</td><td>3</td><td>2</td><td>3</td><td>4</td><td>63</td></tr>
<tr><td colspan="6">Significance Post-Mitigation</td></tr>
<tr><td>4</td><td>2</td><td>2</td><td>2</td><td>4</td><td>48</td></tr>
</table>

<table>
<tr><td>Project Activity</td><td colspan="2">Blast-induced <u>ground vibration</u> damage to buildings farther than 500 m from blasting</td><td colspan="2">Likelihood</td><td colspan="3">Consequence</td><td></td></tr>
<tr><td rowspan="5">Ore, waste and final wall blasting</td><td>Phase of Project</td><td>Preparation, Construction and Operational Phases</td><td>Frequency of Activity</td><td>Frequency of Impact</td><td>Severity</td><td>Spatial Scope</td><td>Duration</td><td>Significance Rating</td></tr>
<tr><td>Impact Classification</td><td>Direct Impact</td><td colspan="6">Significance Pre-Mitigation</td></tr>
<tr><td rowspan="3">Resulting Impact from Activity</td><td rowspan="3">Minor damage to buildings (real or perceived by building owners)</td><td>4</td><td>2</td><td>1</td><td>2</td><td>4</td><td>42</td></tr>
<tr><td colspan="6">Significance Post-Mitigation</td></tr>
<tr><td>4</td><td>1</td><td>1</td><td>1</td><td>4</td><td>30</td></tr>
</table>

Project Activity	Blast-induced damage to wells		Likelihood		Consequence			Significance Rating
Ore, waste and final wall blasting	Phase of Project	Preparation, Construction and Operational Phases	Frequency of Activity	Frequency of Impact	Severity	Spatial Scope	Duration	
	Impact Classification	Direct Impact	Significance Pre-Mitigation					
	Resulting Impact from Activity	Loss of water perceived to be caused by blasting induced vibration	4	2	1	2	4	42
			Significance Post-Mitigation					
			4	1	1	2	4	35

Project Activity	Damage to structures or injury to people closer than 1000 m from fly rock		Likelihood		Consequence			
Ore, waste and final wall blasting	Phase of Project	Preparation, Construction and Operational Phases	Frequency of Activity	Frequency of Impact	Severity	Spatial Scope	Duration	Significance Rating
	Impact Classification	Direct Impact	Significance Pre-Mitigation					
	Resulting Impact from Activity	Serious to fatal injury or damage to property and infrastructure caused by uncontrolled fly rock	4	4	5	3	4	96
			4	2	2	1	4	42

<table>
<tr><td>Project Activity</td><td colspan="2">Damage to structures or complaints from neighbours caused by high air blast</td><td colspan="2">Likelihood</td><td colspan="3">Consequence</td><td></td></tr>
<tr><td rowspan="5">Ore, waste and final wall blasting</td><td>Phase of Project</td><td>Preparation, Construction and Operational Phases</td><td>Frequency of Activity</td><td>Frequency of Impact</td><td>Severity</td><td>Spatial Scope</td><td>Duration</td><td>Significance Rating</td></tr>
<tr><td>Impact Classification</td><td>Direct Impact</td><td colspan="6">Significance Pre-Mitigation</td></tr>
<tr><td rowspan="3">Resulting Impact from Activity</td><td rowspan="3">Complaints or minor damage to buildings and structures caused by high air blast levels.</td><td>4</td><td>3</td><td>3</td><td>4</td><td>4</td><td>77</td></tr>
<tr><td colspan="6">Significance Post- Mitigation</td></tr>
<tr><td>4</td><td>3</td><td>2</td><td>1</td><td>4</td><td>49</td></tr>
</table>

<table>
<tr><td>Project Activity</td><td colspan="2">Dust and fumes generated by blasting affecting health and wellbeing of surrounding neighbours</td><td colspan="2">Likelihood</td><td colspan="3">Consequence</td><td></td></tr>
<tr><td rowspan="5">Ore, waste and final wall blasting</td><td>Phase of Project</td><td>Preparation, Construction and Operational Phases</td><td>Frequency of Activity</td><td>Frequency of Impact</td><td>Severity</td><td>Spatial Scope</td><td>Duration</td><td>Significance Rating</td></tr>
<tr><td>Impact Classification</td><td>Cumulative</td><td colspan="6">Significance Pre-Mitigation</td></tr>
<tr><td rowspan="3">Resulting Impact from Activity</td><td rowspan="3">Dust and fumes are a risk to health of people within a zone of 2 to 3 km from blasting</td><td>4</td><td>3</td><td>3</td><td>3</td><td>4</td><td>70</td></tr>
<tr><td colspan="6">Significance Post- Mitigation</td></tr>
<tr><td>4</td><td>2</td><td>2</td><td>2</td><td>4</td><td>48</td></tr>
</table>

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UNDERGROUND BLASTING

Project Activity	Blast-induced ground vibration damage to buildings closer than 500 m from blasting		Likelihood		Consequence			
Ore, waste and final wall blasting	Phase of Project	Preparation, Construction and Operational Phases	Frequency of Activity	Frequency of Impact	Severity	Spatial Scope	Duration	Significance Rating
	Impact Classification	Direct Impact	Significance Pre-Mitigation					
	Resulting Impact from Activity	Minor damage to buildings (real or perceived by building owners) in the form of cracks in walls	4	3	2	3	4	63
			Significance Post-Mitigation					
			4	2	2	3	4	54

Project Activity	Blast-induced ground vibration damage to buildings farther than 500 m from blasting		Likelihood		Consequence			
Ore, waste and final wall blasting	Phase of Project	Preparation, Construction and Operational Phases	Frequency of Activity	Frequency of Impact	Severity	Spatial Scope	Duration	Significance Rating
	Impact Classification	Direct Impact	Significance Pre-Mitigation					
	Resulting Impact from Activity	Minor damage to buildings (real or perceived by building owners)	4	2	1	3	4	48
			Significance Post-Mitigation					
			4	1	1	3	4	40

Project Activity	Blast Induced Damage to Wells		Likelihood		Consequence			Significance Rating
Ore, waste and final wall blasting	Phase of Project	Preparation, Construction and Operational Phases	Frequency of Activity	Frequency of Impact	Severity	Spatial Scope	Duration	
	Impact Classification	Direct Impact	Significance Pre-Mitigation					
	Resulting Impact from Activity	Loss of water perceived to be caused by blasting induced vibration	4	2	1	2	4	42
			Significance Post-Mitigation					
			4	1	1	2	4	35

10 DESCRIPTION OF PROPOSED MITIGATION MEASURES

The required mitigation measures are normal for blasting operations in sensitive areas, and do not present any significant technical challenges.

10.1 Vibration

There will be a Medium Low significance for vibration for buildings located closer than 500. No mitigation measures have been provided for, except that blast designs must provide for a maximum PPV level of 5.0 mm/s for privately owned structures.

This can be achieved using timing designs and initiation systems that ensure single-hole sequential firing. This will reduce the significance to Very Low.

10.2 Air Blast

Air blast control will be critical to maintain the goodwill of neighbours around the mine. Without mitigation, air blast can generate continuous complaints and therefore the Significance has been rated Medium High. The areas where the risk of air blast is highest are:

1. Presplit blasting
2. Blasting of 5 m benches using large diameter holes
3. Over-charged blastholes

The measures that are needed to contain air blast to acceptable levels and thus lower the significance to Low are:

1. Stem all holes, except presplit holes to a <u>minimum</u> length of 20 hole-diameters.
2. Apply a quality stemming material in all blastholes. An example would be screened aggregate with a size being about 10% of the hole diameter.
3. Do not use detonating cord surface lines and lead-in lines. Only noiseless initiation systems should be used, such as shocktube systems or electronic delay detonators.
4. Use an accurate initiation system for firing each blast.
5. Match the hole diameter to bench height to accommodate the necessary minimum stemming length of 20-hole diameters. Ore blasting of 7.5 m or less will require blastholes 140 mm or less in diameter. Lower benches (2 to 3 m) will require holes of about 76 to 102 mm in diameter.
6. If further air blast mitigation is necessary because of complaints from Copperton it may be necessary to delay blasting when the wind blows towards the town.

10.3 Fly Rock

The risk rating at the sensitive receptors has been rated as Medium High.

Fly rock is extremely dangerous and must be controlled through adequate quality stemming in each blasthole and control needs to be applied to prevent the occurrence of over-charged holes.

The risk of fly rock being generated from under-burdened[2] or structurally weak free bench faces is high, and controls must be formulated to ensure that under-burdening of free faces does not occur.

For safety, it will be necessary to remove all people and animals to a minimum distance of 1000 m from each blast when blasting. This will impact the staff working in the management offices on the mine.

10.4 Dust and fumes

The measures provided for air blast control also apply to dust control.

Should any nitrous oxide fumes be observed during a blast, further blasting activity should be halted, and the cause of the fumes identified and corrected. Causes include poor charging practices, incorrect explosives formulation or holes that are too close together in softer formations.

Excessive dust from blasting can be controlled by effective stemming application.

10.5 Water pollution

Water pollution occurs from dissolved explosives salts. The dry conditions in the area are not likely to result in explosives being dissolved to any large extent. However, to completely prevent this from occurring, the following measures should be applied:

1. Use water-proof explosives in the blastholes.
2. Provide effective bunding to contain spillages of explosives from storage silos and when transferring explosives materials to and from the silos.

10.6 Monitoring programme for implementation

Vibration and air blast monitoring will be needed for all blasts to make sure that the limits are being achieved and to provide an indication of when modifications are needed to the blasting method to correct for increased vibration and air blast levels.

The best method is to have permanent calibrated vibration stations installed at strategic positions that are supported and monitored by the explosives supplier or preferably an independent third party. The seismographs should be located on mine property between the open pits and Copperton.

10.7 No-Go Areas

As a summary, the following no-go areas should apply for vibration and fly rock.

10.7.1 Houses

Vibration amplitudes at houses occupied by people should not exceed 5 mm/s. Normally houses can withstand much higher amplitudes, but the response of people to vibration is a conservative limiting criterion to apply.

At houses occupied by people, air blast amplitudes should not exceed 125 dB.

[2] Under-burdened holes occur when they are drilled to close to a free face. This distance should normally not be less than 20 x the hole diameter.

There is no limit to how close blasting can come to houses, if fly rock, vibration and air blast levels are contained to the required limits. This means stringent mitigation measures to achieve these limits. Any blasting that occurs closer than 500 m to houses will require evacuation of the houses.

11 CONCLUSION

In general, blasting in both the underground and surface mining operations will not have a High Negative Impact Significance. With standard mitigation measures in place, as outlined in this report, the impact significance all drop to Low or Very Low.

Therefore, based on the findings of the assessment and provided the measures planned and recommended are in place, it is the specialist opinion that the project may be authorised.

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13 APPENDIX 1 – Impact of Blasting on Structures and Humans

13.1 Influence of Blasting Practice on Vibration and Air blast

A few basic factors influence ground vibration[3] amplitudes. These are:

1. **The charge mass fired per instance in time.** The larger the charge mass, the higher the amplitude of the ground vibration. The charge mass can be limited by timing blasts so that holes fire one at a time or by reducing the blasthole diameters. These practical measures have a marked influence on vibration amplitudes.
2. **The distance from the blast.** Vibration energy is attenuated in the rock through friction, reflections and increased distribution of the wave front as distance increases from a blast. Normally, structures that are farther from blasting experience lower amplitudes than those closer to blasting. This phenomenon is discussed in more detail in the Section entitled Attenuation and Prediction of Peak Amplitudes.

Air blast is the air pressure wave generated by a detonation. Air blast amplitudes are strongly influenced by the following factors:

1. Unconfined charges produce very high air pressure waves. Unconfined charges are those that are not confined in a hole that is properly stemmed. Examples are lay-on charges used for secondary blasting purposes and detonating cord that is sometimes used for connecting holes on surface. The amplitude of the air blast is proportional to the mass and the surface area of the exposed charge. Limiting the use of unconfined charges is important to controlling air blast amplitudes.

2. Ineffective stemming material, un-stemmed holes (often used in presplit blasts) and overcharged holes all create high air blast amplitudes and increase the risk of fly rock. Blast designs and control during application are the two important factors in helping to combat excessive air blast levels from these sources. Blasts that are the noisiest are usually presplit blasts that are normally fired un-stemmed. Control of air blast in this case could be achieved by firing presplit holes sequentially away from a sensitive receptor with short delays between each presplit hole.

3. Atmospheric conditions can amplify air blast amplitudes to damaging levels. High wind velocities, thick cloud cover or temperature inversions are the main amplifying factors. Normally, well-designed and controlled blasts where all holes are properly stemmed and the blast is correctly timed, amplification effects are insignificant. However, these effects become very significant with poor control and air blast related damage, such as broken window panes or loosened ceilings, can occur as far as 10 km from a blast under certain atmospheric conditions.

Air blast is more commonly a problem to nearby homeowners than vibration, because it is felt through response of large surfaces such as ceilings and windows. Homeowners usually confuse these effects as being caused by ground vibration. The result is that complaints are more frequent for noisy blasts that may be small than large well-controlled blasts.

[3] Ground vibration is the vibration that is measured close to the surface of the ground. It does not include any structural resonance effects.

13.1.1 Attenuation and Prediction of Peak Amplitudes

It is possible to predict, with a degree of confidence, the peak amplitude of the ground vibration wave by scaling the distance from the blast as a function of the charge mass fired per delay in the blast. This is referred to as the scaled distance relationship and takes the following form (Borg *et.al.*):

Equation 1

$$C = a\left(\frac{R}{\sqrt{W}}\right)^{-b}$$

Where *C* is the peak amplitude or peak particle velocity, *R* is the distance between the blast and the point of concern and *W* is the charge mass detonated per delay or instance in time. The constants *a* and *b* are site-specific constants that are a function of the transmission properties of the rock mass. The constants *a* and *b* are usually determined from vibration measurements at a specific site. There is no historical vibration data measured from the area and global constants have been applied for Equation 1:

a = 1143
b = -1.65

Once blasting is commenced, vibration measurements must be taken so that the vibration attenuation constants *a* and *b* can be determined for the ground conditions surrounding the two mines.

For the underground blasting, the following equation applies:

Equation 2

$$C = a\left(\frac{R}{W^{0.3}}\right)^{-b}$$

13.1.2 Air Blast Prediction

Due to varying atmospheric conditions, it is more difficult to predict air blast levels with certainty. Persson *et.al.* (1994) have published a general-purpose attenuation equation that can be used as an approximate guide:

Equation 3

$$p = 7\times10^{4}\left(\frac{W^{\frac{1}{3}}}{R}\right)$$

Where *p* is the predicted air blast amplitude in Pascals, *W* is the **exposed** charge mass per delay in kg and *R* is the distance from the source in metres.

Equation 3 is only relevant for exposed charge masses. Under normal blasting conditions, the charges will be confined and air blast levels will be much lower. For limiting disturbance to neighbours, air blast amplitudes must be lower than **125 dB** at any receptor.

13.2 Ground Vibration Limits

13.2.1 Building response to ground vibration

Although there are no formalized limits to vibration, the US Bureau of Mines (USBM) limits are commonly applied in Africa. The limiting curve is shown in Figure 3 and has been developed from empirical studies (Siskind *et.al.* 1980).

The limiting curve in Figure 3 represents the limit for potential cosmetic damage to a house. The maximum ground vibration amplitudes are frequency dependent with higher frequencies allowing higher peak amplitudes. Most modern blasting seismographs will display the vibration data in terms of the USBM limiting criterion. In general, at lower frequencies, the ground vibration should not exceed 12.7 mm/s, but at higher frequencies, the limit can increase to 50 mm/s.

Because of human sensitivity, however, the limits for this study have been reduced to 5 mm/s. This is the limit, above which, people find very disturbing.

13.2.2 Human response to ground vibration

Although buildings can withstand ground vibration amplitudes of 12.7 mm/s or more, depending on the frequency, human beings are easily disturbed at lower levels. Table 1 provides typical human response to ground vibration

Ground vibration levels received at a structure of 0.76 to 2.54 mm/s are quite perceptible, but the probability of damage is almost non-existent. Levels in the 2.54 to 7.6 mm/s can be disturbing and levels above 7.6 mm/s can be very unpleasant, although permanent damage is unlikely.

Human perception is also affected by frequency. The approximate human response curves are combined with the USBM limiting curve for damage in Figure 4. These curves slope in the opposite direction. In other words, humans are more tolerant to low frequency vibrations.

To avoid damaging buildings, the USBM limiting curve should be applied. However, to avoid constant complaints and possible litigation from neighbours, the vibration should preferably be kept beneath the *unpleasant* curve and definitely be kept beneath the *intolerable* curve.

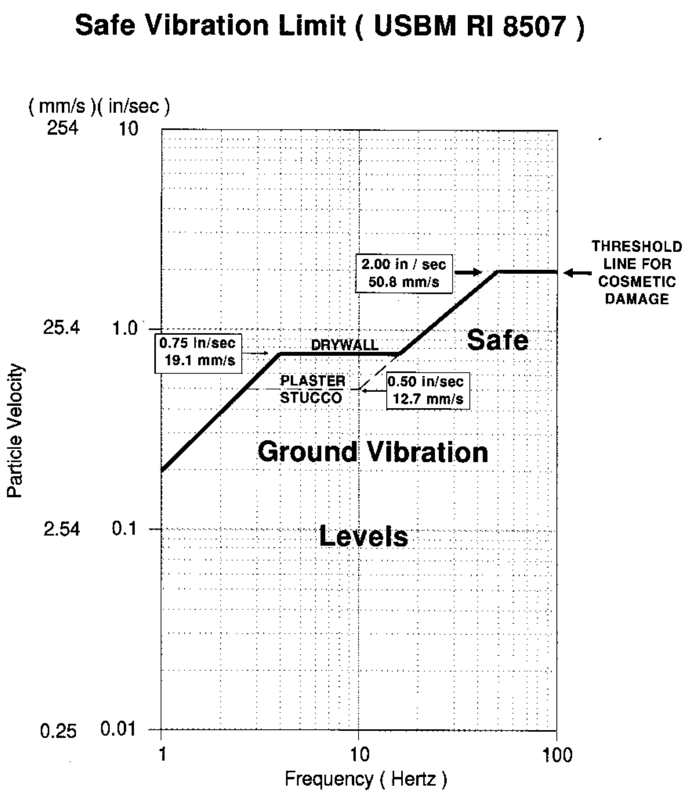

Figure 3. USBM curve that is generally used in Africa. (After Chiappetta, March 2000). This is a very conservative limit as it applies to structures build with timber frames and dry walls. Concrete block and mortar buildings are much stronger and will withstand much higher vibration amplitudes without damage.

Table 5. Human response to vibration (Chiappetta, 2000)

Effects on Humans	Ground Vibration Level mm/s
Imperceptible	0.025 – 0.076
Barely perceptible	0.076 – 0.254
Distinctly perceptible	0.254 – 0.762
Strongly perceptible	0.062 – 2.540
Disturbing	2.540 – 7.620
Very disturbing	7.620 – 25.400

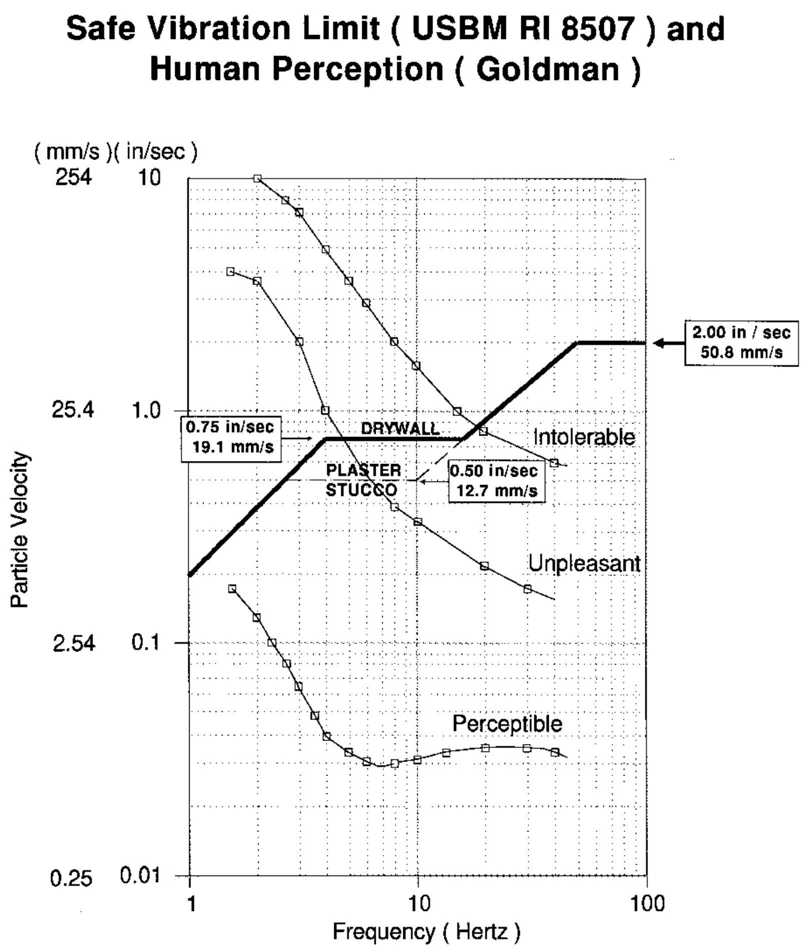

Figure 4. Human response curves compared with potential damaging limits. (After Chiappetta, 2000)

13.2.3 Vibration on other Structures

Vibration limits have been published in the literature for different types of equipment and structures. Although these may differ slightly from application to application, the guidelines by Bauer and Calder (1977) are based on empirical information. These limits are provided in Table 6.

Table 6. Vibration amplitudes for structures and equipment other than buildings.

Type of Structure	Type of Damage	PPV at which Damage starts (mm/s)
Rigidly mounted mercury switches	Trip-out	12.7
Concrete blocks (e.g. floor slabs)	Hairline cracks in concrete	203
Cased drill holes	Horizontal offset	381
Mechanical equipment (e.g. pumps and compressors)	Shaft misalignment	1016
Prefabricated metal buildings on concrete pads	Cracked floor, building twisted and distorted	1524

13.3 Air Blast Limits

Based on work carried out by Siskind *et.al.* (1980), monitored air blast amplitudes up to 135 dB are safe for structures, provided the monitoring instrument is sensitive to low frequencies (down to 1 Hz). Persson *et.al.* (1994) have published the following estimates of damage thresholds based on empirical data (Table 7).

Table 7. Damage limits for air blast.

120 dB	Threshold of pain for **continuous** sound
>130 dB	Resonant response of large surfaces (roofs, ceilings). Complaints start.
150 dB	Some windows break
170 dB	Most windows break
180 dB	Structural Damage

14 APPENDIX 2 – Impact of Blasting on Wells and Aquifers

A literature review of blasting induced vibration impact is very unlikely to result in damage to any boreholes or aquifers surrounding the two mines. It has been established that vibration of earthquake magnitude and frequency of vibration is needed for damage to become apparent. The ground vibrations generated by blasting will be orders lower than earthquake magnitude vibration.

14.1 Water oscillation

The information provided in this Section is based on work Published by Oriard (2005).

It is possible for water in open wells to respond to seismic waves caused primarily by dilatation that occurs in the aquifer as a result of a passing vibration wave. The factors that have an impact are:

a. The dimension of the well and its construction detail
b. The rock/soil formation (porosity and transmission properties)
c. The period and amplitude of the seismic wave and its type

In measurements during some earthquakes, the water level fluctuated in response to the passage of the different wave forms, but did not produce long term or permanent changes. However, in a few cases strong earthquakes appeared to result in some permanent changes in the aquifers, but the physical effect responsible is not understood.

Oriard is not aware of any such effects for lower level elastic vibrations that would be associated with blasting. He notes that the strain levels from earthquakes are far greater and transmitted to far greater distances than blasting vibrations. He notes that the effects aquifers seen from strong ground motion caused by earthquakes is not present where vibration particle velocities are lower than 20 mm/s

The oscillation of the water is strongly dependent on the frequency of the vibration wave. In earthquakes, very low frequencies are generated (periods greater than 10 seconds) which are similar to the resonant frequencies of aquifer systems, thus causing the water level fluctuations. Blasting generates much higher frequencies (periods of a fraction of a second), and thus would not cause the water system in an aquifer to respond to the vibration.

14.2 Damage to rock

The pressure induced in an aquifer by the passage of a seismic wave can be determined as follows:

Equation 4

$$P = \rho c V$$

P is the pressure in KPa, ρ is the density of the medium (soil or rock) in kg/m^3, V is the particle velocity in mm/s.

Based on this relationship, the induced pressures for different particle velocities are provided in Table 8.

Table 8. Induced pressure in an aquifer as a function of particle velocity (vibration). This is based on a wave propagation velocity of 3000 m/s and a rock density of 2650 kg/m^3.

Particle Velocity (mm/s)	**Induced Pressure (KPa)**
1	7.95
5	39.75
10	79.50
15	119.25
20	159.00
100	795.00
200	1590.00
300	2385.00
400	3180.00
500	3975.00
600	4770.00
700	5565.00
800	6360.00
900	7155.00
1000	7950.00

Rock begins to fail at particle velocities above 600 mm/s which are equivalent to a pressure of about 5000 KPa (Table 8). With reference to Table 3, which provides an estimate of likely particle velocity amplitudes as a function of distance from blasting, particle velocity will exceed 600 mm/s at distances closer than 70 m from blasting. Therefore, damage to the aquifer host-rock by blasting vibration is very unlikely at distances greater than 70 m from blasting.

15 Appendix 3 – Risk Assessment Methodology

The first stage of risk/impact assessment is the identification of environmental activities, aspects and impacts. This is supported by the identification of receptors and resources, which allows for an understanding of the impact pathway and an assessment of the sensitivity to change. The definitions used in the impact assessment are given below.

- An **activity** is a distinct process or task undertaken by an organization for which a responsibility can be assigned. Activities also include facilities or pieces of infrastructure that are possessed by an organization.
- An **environmental aspect** is an 'element of an organizations activities, products and services which can interact with the environment'[4]. The interaction of an aspect with the environment may result in an impact.
- **Environmental risks/impacts** are the consequences of these aspects on environmental resources or receptors of particular value or sensitivity, for example, disturbance due to noise and health effects due to poorer air quality. Receptors can comprise, but are not limited to, people or human-made systems, such as local residents, communities and social infrastructure, as well as components of the biophysical environment such as aquifers, flora and palaeontology. In the case where the impact is on human health or well-being, this should be stated. Similarly, where the receptor is not anthropogenic, then it should, where possible, be stipulated what the receptor is.
- **Receptors** comprise but are not limited to people or man-made structures.
- **Resources** include components of the biophysical environment.
- **Frequency of activity** refers to how often the proposed activity will take place.
- **Frequency of impact** refers to the frequency with which a stressor (aspect) will impact on the receptor.
- **Severity** refers to the degree of change to the receptor status in terms of the reversibility of the impact; sensitivity of receptor to stressor; duration of impact (increasing or decreasing with time); controversy potential and precedent setting; threat to environmental and health standards.
- **Spatial scope** refers to the geographical scale of the impact.
- **Duration** refers to the length of time over which the stressor will cause a change in the resource or receptor.

The significance of the impact is then assessed by rating each variable numerically according to defined criteria as outlined in Table 9. The purpose of the rating is to develop a clear understanding of influences and processes associated with each impact. The severity, spatial scope and duration of the impact together comprise the consequence of the impact and when summed can obtain a maximum value of 15. The frequency of the activity and the frequency of the impact together comprise the likelihood of the impact occurring and can obtain a maximum value of 10. The values for likelihood and consequence of the impact are then read off a significance rating matrix (Table 10), and Table 11 is used to determine whether mitigation is necessary[5].

The assessment of significance should be undertaken twice. Initial significance is based only on natural and existing mitigation measures (including built-in engineering designs). The subsequent assessment considers the recommended management measures required to mitigate the impacts. Measures such as demolishing infrastructure, and reinstatement and rehabilitation of land, are considered post-mitigation.

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[4] The definition has been aligned with that used in the ISO 14001 Standard.

[5] Some risks/impacts that have low significance will however still require mitigation

The model outcome of the impacts is then assessed in terms of impact certainty and consideration of available information. The Precautionary Principle is applied in line with South Africa's National Environmental Management Act (No. 108 of 1997) in instances of uncertainty or lack of information by increasing assigned ratings or adjusting final model outcomes. In certain instances where a variable or outcome requires rational adjustment due to model limitations, the model outcomes are adjusted.

Table 9. Criteria for assessing significance of impacts

Severity of impact	**RATING**
Insignificant / non-harmful	1
Small / potentially harmful	2
Significant / slightly harmful	3
Great / harmful	4
Disastrous / extremely harmful	5

Spatial scope of impact	**RATING**
Activity specific	1
Mine specific (within the mine boundary)	2
Local area (within 5 km of the mine	3
Regional	4
National	5

Duration of impact	**RATING**
One day to one month	1
One month to one year	2
One year to ten years	3
Life of operation	4
Post closure / permanent	5

CONSEQUENCE

Frequency of activity/ duration of	**RATING**
Annually or less / low	1
6 monthly / temporary	2
Monthly / infrequent	3
Weekly / life of operation / regularly /	4
Daily / permanent / high	5

Frequency of impact	**RATING**
Almost never / almost impossible	1
Very seldom / highly unlikely	2
Infrequent / unlikely / seldom	3
Often / regularly / likely / possible	4
Daily / highly likely / definitely	5

LIKELIHOOD

Table 10. Significance Rating Matrix

	CONSEQUENCE (Severity + Spatial Scope + Duration)														
LIKELIHOOD (Frequency of activity + Frequency of impact)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**
	3	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**	**42**	**45**
	4	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**	**44**	**48**	**52**	**56**	**60**
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**
	6	**12**	**18**	**24**	**30**	**36**	**42**	**48**	**54**	**60**	**66**	**72**	**78**	**84**	**90**
	7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**	**105**
	8	**16**	**24**	**32**	**40**	**48**	**56**	**64**	**72**	**80**	**88**	**96**	**104**	**112**	**120**
	9	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**	**90**	**99**	**108**	**117**	**126**	**135**
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**

Table 11. Positive/Negative Mitigation Ratings

Significance Rating	**Value**	**Negative Impact Management Recommendation**	**Positive Impact Management Recommendation**
Very high	126-150	Improve current management	Maintain current management
High	101-125	Improve current management	Maintain current management
Medium-high	76-100	Improve current management	Maintain current management
Medium-low	51-75	Maintain current management	Improve current management
Low	26-50	Maintain current management	Improve current management
Very low	1-25	Maintain current management	Improve current management

16 Appendix 4 Author Curriculum Vitae

A J Rorke

Curriculum Vitae
May 2018

16.1 A J Rorke

I am a Blasting Specialist and provide consulting services to BME.
I have specialised in blasting technology since 1986. I live in Johannesburg, South Africa.
My knowledge and experience include blast optimisation for mining and wall control, blasting related environmental studies, development of technologies for blasting (examples being blasting software and precise electronic detonators detonators) and blasting consultancy.
Since 2005, I have been responsible for managing a group of mining engineers, software engineers, scientists and technicians.

16.2 Previous Experience

1990–2005

Blasting Consultant

- Supply a blasting consultancy services to surface and underground mining operations. This work has included blast auditing, blast monitoring and optimisation, designs for complex blasting problems and wall control. Modern blast monitoring equipment is used for monitoring of blast performance and vibration.
- Carry out environmental impact studies related to blast induced vibration, noise and dust.
- Generate blast design software for surface and underground blasting operations. Several blasting codes have been developed that are being used by the mining industry. Main achievement: The development of the BlastMap blast design software that is used by most BME clients.
- Supervise and carry out blasting research projects for underground mines, surface hard rock mines and coalmine operations.
- Develop and provided training courses in underground and surface blasting
- Manage a team of Explosives Engineers who provide monitoring and consulting services to BME clients
- Direct the development, testing and application of BME’s newest electronic delay detonator system, AXXIS.

During this period, I have consulted to many of the mining and civil contracting operations in South Africa, Namibia, Zimbabwe, Zambia, Tanzania, Mali, Botswana, Malawi, Ethiopia, Ghana, Mauritania and Guinea. I have also provided advice for operations in the Philippines, China and the UAE.

In the early 90’s, I formed a private consultancy company, Blastech (Blasting and Geotechnologies (Pty) Ltd), that provided a high-tech consultancy and monitoring service to South African mining and civil engineering operations. This company stopped functioning when I joined BME in 1995.

I have had numerous papers on blasting technology published at local and international blasting conferences.

1987 - 1990 Chamber of Mines Research Organization, Johannesburg

Research Project Manager

- Planned and managed a rock de-stressing project for deep level gold mines.
- Applied sophisticated drill and blast methods and fluid injection methods to relieve stress in rockburst prone areas.

1985–1986 AECI Ltd, Johannesburg

Blasting Physicist

- Provided blasting consultancy service mainly to open cast mines.
- Involved in blast simulations and numerical modelling of blasts.
- Set up a rock testing lab and rock testing procedures for input into blast models.

1979–1985 Chamber of Mines Research Organization, Johannesburg

Research Engineer

- Conducted research in rockburst source mechanisms.
- Managed several seismic projects on different deep-level gold mines for measuring rock burst phenomena.
- Involved with computer coding to analyse seismic data.

1976–1978 Kloof Gold Mining Company, Johannesburg

Learner Miner

- Production miner and shift boss in tunnelling and stoping projects
- Learner miner.

16.3 Education

1982-1983 Rand Afrikaans University, Johannesburg

- MSc degree in Geology focusing in Seismology (With distinction)

1970-1975 University of the Witwatersrand, Johannesburg

- BSc (Mining Geology) degree in Engineering.

16.4 Examples of Recent Publications

A J Rorke, 2007, *An evaluation of precise short delay periods on fragmentation in blasting*, EFEE Conference, Vienna, Austria.

A J Rorke, 2005, *Wave interference patterns: predicting vibration concentrations from blasting using precise detonators*, EFEE Conference, Brighton, UK

A J Rorke, S Thabethe. 2004, *Large-hole blasting next to a pillar supporting a public road*. 23rd ISEE Symposium, New Orleans, USA

A J Rorke, 2002, *Strict Blasting Control in a High Production Hard Rock Mine,* Seventh International Symposium for Rock Fragmentation by Blasting, Beijing, China

A J Rorke. 2000, *The effectiveness of electronic detonators in surface blasting.* BAI 2000 International High Tech Blasting Seminar, Orlando, USA.

A J Rorke and J Botes. 2000, *Highwall control measures at Optimum Colliery*. BAI 2000 International High Tech Blasting Seminar, Orlando, USA.

A. M. Milev S. M. Spottiswoode M. W. Hildyard A. J. Rorke and G. J. Finnie. 2000, *Simulated rockburst – source design, seismic effect and damage.* ISRM Symposium, Seattle, USA.

A. J. Rorke and A. M. Milev. 1999, *Near field vibration monitoring and associated rock damage*. Sixth International Symposium for Rock Fragmentation By Blasting, Johannesburg, South Africa.

16.5 Affiliations

Associate Member of the International Society of Explosives Engineers

Fellow of the Institute of Quarrying

Organising Committee, Fragblast 6

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17 Appendix 5 Vibration prediction for multiple-hole firing

This information is an addendum to the original report (EIA_Blasting_Prieska_Rev2). It deals with induced ground for more than one hole firing at a time.

The relevant design of the charged holes for surface and underground mining are provided in Table 1. The Table also provides a maximum number of holes that potentially could fire simultaneously in a blast without mitigation measures.

Table 12. Designs for surface and underground blasting for the blasts that will contain maximum charge mass per hole.

	Surface Blasting	**Long-hole stoping (Underground)**
EXPLOSIVE		
Explosive Type	Emulsion	Emulsion
Charge Mass/Metre (kg/m)	27.17	9.42
Explosive Mass Per Hole (kg)	266	264
Effective Charge Diameter (mm)	171	102
Average In-hole Density (g/cm3)	1.18	1.15
BLAST GEOMETRY		
Stemming Length (m)	3.5	2
Column Length (m)	9.8	28
Hole Depth (m)	13.3	30
Bench Height (m)	12.0	30
Sub-Drill (m)	1.30	
Hole Diameter (mm)	171	102
Maximum likely holes per delay	5	3

Based on the explosives mass per hole and the assumption of multiple holes firing simultaneously, the predicted ground vibration data based on Equation 1 and the conservative constants, a and b, are presented in Table 13. The data are calculated down to a vibration value of zero. The decay in vibration is exponential as shown in the plotted data in

At a distance of 6000 m the maximum predicted vibration in the unmitigated case (multiple holes per delay) is 0.2 mm/s. This is considered barely perceptible for humans and is orders below the generally accepted limits for structures (Table 6).

Therefore, at 6000 m from blasting, the negative impact from ground vibration will not exist for mitigated blasting and will be negligible for the unmitigated blasting. In terms of impact significance, both are rated at the lowest possible rating of Very Low for Ground Vibration.

Table 13. Calculated vibration for the maximum charge mass per delay. For comparison, the calculated values for one hole per delay are also presented. The decay as a function of distance is exponential. The distance represents an approximately radial distance from the blast point.

	Surface Blasting Single Hole	Surface Blasting Multiple Holes	Long-hole Stoping Single Hole	Long-hole Stoping Multiple Holes
Charge mass per delay (kg)	233	1165.5	263.8	791.4
Max likely holes per delay	1	5	1	3
Charge mass per hole (kg)	233.1	233.1	263.8	263.8
Distance (m)	**PPV (mm/s)**	**PPV (mm/s)**	**PPV (mm/s)**	**PPV (mm/s)**
50	161.4	609.0	178.8	442.5
100	51.4	194.1	57.0	141.0
200	16.4	61.8	18.2	44.9
500	3.6	13.6	4.0	9.9
1000	1.2	4.3	1.3	3.2
2000	0.4	1.4	0.4	1.0
3000	0.2	0.7	0.2	0.5
4000	0.1	0.4	0.1	0.3
5000	0.1	0.3	0.1	0.2
6000	0.1	0.2	0.1	0.2
7000	0.0	0.2	0.1	0.1
8000	0.0	0.1	0.0	0.1
9000	0.0	0.1	0.0	0.1
10000	0.0	0.1	0.0	0.1
16000	0.0	0.0	0.0	0.0

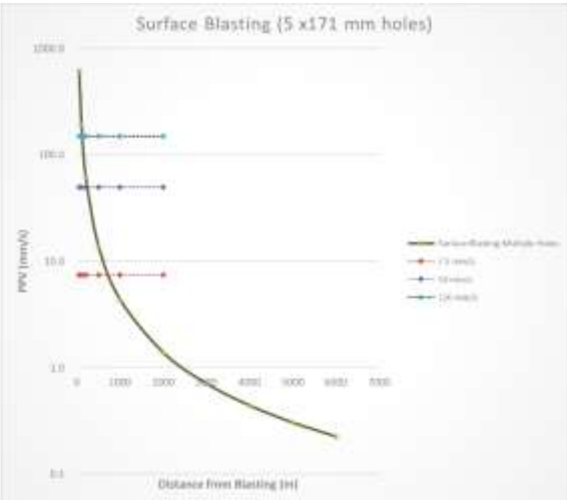

Figure 5. Vibration decay curve as a function of distance from blasting plotted from the maximum-value data in Table 13 (5 x 171 mm holes per delay). The vertical axis is presented as a logarithmic scale (base 10) to emphasize the change in vibration at the very small values in excess of about 1000 m from blasting. At 6000 m, the predicted vibration value is barely perceptible at 0.3 mm/s.

18 Appendix 6 Vibration Impact Assessment Vardocube

18.1 Locality

An extension to the Repli Section of the underground mining has been added to the project, referred to as the Vardocube Section. The relative positions are shown in as detailed in the plan shown in Figure 6. Depth of blasting below surface is assumed to be the same as the Repli Section.

Figure 6. Plan showing the relative position of the Vardocube extensions to the Repli Section of the proposed underground mining area. Area 5 is the Eskom Yard and 6 is a steel tower.

18.2 Blasting Method

The blasting methods will be the same as those applied in the Repli Section, with the highest impact coming from long-hole blasting. The charge mass per hole is the variable that has the major influence on induced ground vibration and therefore, the number of holes that fire per instance in time give the charge mass that is used to determine ground vibration.

Table 14. Charge mass per hole likely for the source of highest ground vibration in the Vardocube Section.

	Long-hole stoping
EXPLOSIVE	
Explosive Type	Emulsion
Charge Mass/Metre (kg/m)	9.42
Explosive Mass Per Hole (kg)	264
Effective Charge Diameter (mm)	102
Average In-hole Density (g/cm3)	1.15
BLAST GEOMETRY	
Stemming Length (m)	2
Column Length (m)	28
Hole Depth (m)	30
Bench Height (m)	30
Hole Diameter (mm)	102
Maximum likely holes per delay	3

18.3 Vibration environmental aspect

Blast induced vibration is the only aspect that will impact receptors as fly rock and air blast aspects will not be evident on surface.

As outlined in Appendix 5, there is a possibility that up to three holes will fire simultaneously, thus providing a maximum risk of 790 kg firing per instant in time.

The PPV values presented in Table 15 are based on Equation 2 (Appendix 1) and the charge mass per hole as defined in Table 14. The scaled distance equation (Equation 2) has been used. The calculations are conservative and estimate the worst likely case. Table 15 presents estimated vibration amplitudes as a function of distance from blasting for underground long-hole open stoping and explosives having a density of 1.18 g/cm^3 and 1.20 g/cm^3 as outlined in Table 14. Vibration values have been calculated for a single hole firing (mitigated case) and three holes firing per instance in time (unmitigated case).

Table 15. Vibration calculations as a function of distance for one hole firing per instance in time (mitigated) and potentially three holes firing per instance in time (unmitigated).

	Long-hole Stoping Single Hole	Long-hole Stoping Three Holes
Charge mass per delay (kg)	264	792
Max likely holes per delay	1	3
Charge mass per hole (kg)	264	264
Distance (m)	**PPV (mm/s)**	**PPV (mm/s)**
50	178.8	442.5
100	57.0	141.0
200	18.2	44.9
500	4.0	9.9
1000	1.3	3.2
2000	0.4	1.0
3000	0.2	0.5
4000	0.1	0.3
5000	0.1	0.2
6000	0.1	0.2
7000	0.1	0.1
8000	0.0	0.1
9000	0.0	0.1
10000	0.0	0.1
16000	0.0	0.0

The chart in Figure 7 provides a spatial impact radially around the mine.

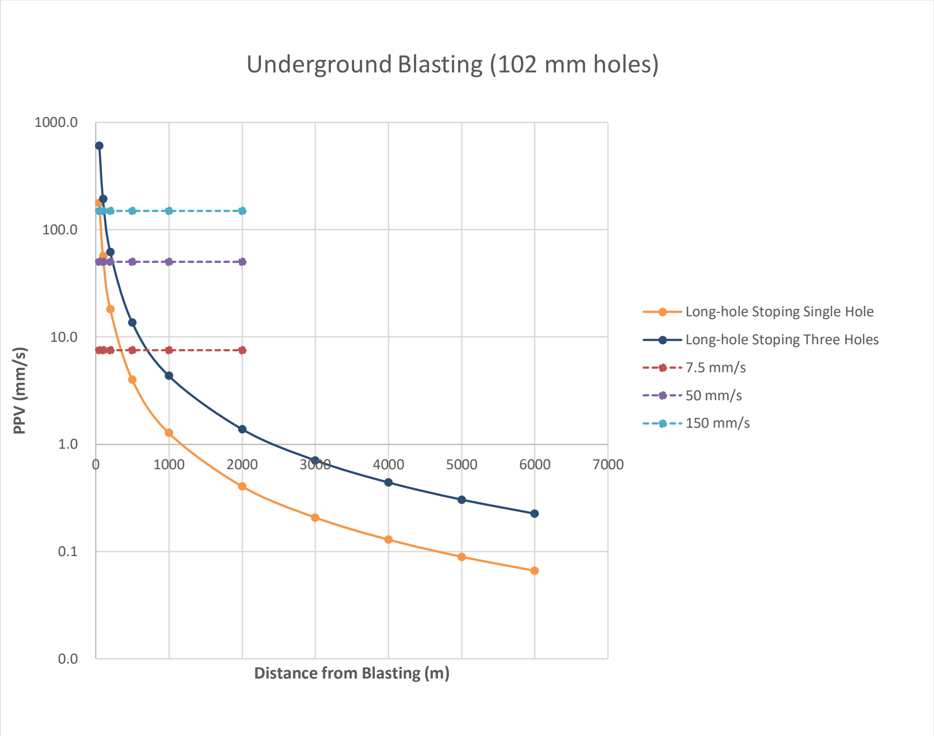

Figure 7. Radial zone of influence for long hole stoping blasts from the underground Repli and Vardocube Sections. The curve for the single hole stoping represents mitigated blasting methods where only one hole fires per instance in time. Mitigated blasting has more benefit at distances closer than 1000 m from blasting. The data are plotted from the data in Table 14. The vertical axis is presented as a logarithmic scale (base 10) to emphasize the change in vibration for the very small values in excess of about 1000 m from blasting. 7.5 mm/s is the value above which humans find ground vibration very unpleasant and will lodge complaints. 50 mm/s represents the limit below which structural damage risk to buildings will be low. 150 mm/s is the limit at which desegregation of compacted soils on roads and earth dam walls begins to occur.

18.4 Receptors

Blasting will occur from a depth of about 900 m. Therefore, receptor distances are calculated from the vertical and horizontal component distances.

For larger horizontal distances in excess of 2000 m, the distances between blasting and receptors are approximately the same as described in Table 2 on Page 7. At such distances, there will be no vibration impact and the significance will be **very low** (lowest scale in the risk assessment method).

For closer structures the calculated distances as a function of depth of blasting below surface are presented in Table 16. The vibration limits are calculated for the unmitigated condition where potentially three holes could fire per instance in time.

In all three cases, the ground vibration levels will be lower than damaging limits. It is probable that people who may be in the buildings in the Eskom Yard and PV facility during blasting will feel the vibration, but it should not alarm them. The impact significance will be Low. Despite there being no risk of damage from blast induced ground vibration to the structures, some complaints may be received, in which case the mitigation measure described on Page 43 can be applied.

Table 16 Calculated distances of the closest receptors to blasting and the predicted PPV levels.

	Horizontal Distance Component (m)	**Depth of mining below surface (m)**	**Shortest Distance (m)**	**Predicted Unmitigated Maximum PPV (mm/s)**
Buildings in the Eskom Yard	250	900	934	3.5
Steel tower adjacent to the Eskom Yard	50	900	901	3.7
Mulilo Solar PV	810	900	1211	2.3

18.5 Mitigation

There will be a Low significance for vibration for the three receptors that are closest to the Vardocube underground mining (Table 16). No prescribed mitigation measures are necessary, except that, in the very unlikely event that complaints are received by people inside the buildings during blasting, blast timing designs should be modified to limit the number of holes firing peer delay to one.

18.6 Conclusion

The underground blasting for the Vardocube Section will not generate any significant risk to surface receptors.

The blasting induced vibration impact Significance will be Low, and, in terms of blasting impact, the project can be authorised.

18.7 Vardocube Blasting Impact Risk Assessment

UNDERGROUND BLASTING (Less than 1000 m from blasting)

Project Activity	Blast-induced ground vibration damage to receptors closest to the blasting		Likelihood		Consequence			
Ore, and waste blasting	Phase of Project	Preparation, Construction and Operational Phases	Frequency of Activity	Frequency of Impact	Severity	Spatial Scope	Duration	Significance Rating
	Impact Classification	Direct Impact	Significance Pre-Mitigation					
	Resulting Impact from Activity	Minor damage to buildings (perceived by building owners)	4	2	1	3	4	48
			Significance Post-Mitigation					
			4	1	1	2	4	35