Appendix K – Greenbushes Mine Expansion Prediction of Vibration and Air Overpressure (George Boucher Consulting 2018)

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Prediction of Blast-Induced Ground Vibration and Air Overpressure

Greenbushes Open Pit - Expansion Project

Greenbushes WA

Talison Lithium Pty Ltd

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1. Introduction

At the request of Talison Lithium Pty Ltd (Talison), George Boucher Consulting (GBC) conducted a review of previous Greenbushes Open Pit mine environmental data and developed predictive models for blast-induced ground vibration and air overpressure. These models were used to predict the likely blast-induced ground vibration amplitude (peak particle velocity or ppv) for the different types of blasts planned for the Greenbushes expansion project.

2. Blast-Induced Ground Vibration and Air Overpressure

2.1 Prediction of Ground Vibration

Best Practice for blasting operations is defined within the Australian Standard AS2187.2(2006) which describes the phenomena of blast-induced ground vibration in the following way:

"*Ground vibration from blasting is the radiation of mechanical energy within a rock mass or soil. It comprises various vibration phases travelling at different velocities. These phases are reflected, refracted, attenuated and scattered within the rock mass or soil, so that the resulting ground vibration at any particular location will have a complex character with various peaks and frequency content.*"

The magnitude of the ground vibration, together with ground vibration frequency, is commonly used to define likelihood of annoyance of near neighbours and potential for damage criteria. Studies and experience show that well designed and controlled blasts are unlikely to create ground vibrations of a magnitude that causes damage to structures. AS2187.2(2006) – Appendix J further states:

"*It is recognised that ground vibration and airblast produced by blasting falls into two categories-*

(a) Those causing human discomfort; and

(b) Those with the potential for causing damage to structures, architectural elements and services.

Generally, human discomfort levels set by authorities are less than the levels that are likely to cause damage to structures, architectural elements and services. Ground vibration and airblast levels are influenced by a number of factors, some of which are not under the control of the shotfirer."

Cracks in buildings may be attributable to causes other than ground vibration, including ground or foundation movements (settlement and swell) associated with natural progressive deterioration of buildings over time and/or cyclical expansion/contraction of reactive clay soils during periods of prolonged dry or wet weather.

Many site-based factors including rock type, structure, topography, explosive type, blast design and geometry determine the vibration level that will be transmitted to a particular location remote from the blast location. Consequently the accurate prediction of ground vibration by calculation requires the use of site measurements to quantify the site factors represented in the prediction formula.

The Australian Standard AS2187.2 (2006) Appendix J provides a prediction equation in the form:

$$\mathbf{V = K\ (R/Q^{1/2})^{-b}}$$

Where:

V = peak particle velocity (ppv) in mm/sec

K & b = Site Constants (specific to the attenuation character of the rock between the blast and monitoring locations)

R = Range (distance) to structure (m)

Q = Charge mass per delay (Often expressed as Maximum Instantaneous Charge or MIC) (kg)

AS2187 states that, where no data from previous blasting is available, K=1140 and b=-1.6 are applicable to prediction of mean ppv (i.e. 50% Confidence Limit) for “Free face-average rock” (Refer to paragraph J7.3).

However, the compliance limits set for ground vibration in AS2187 for sensitive sites are 95% compliance with 5mm/s and 100% compliance with 10mm/s.

Talison is required to comply with these vibration limits, measured or calculated in accordance with section J4.2 of Australian Standard AS2187.2(2006), for the protection of human comfort at any houses and low rise buildings, theatres, schools and other similar buildings occupied by people and not owned by Talison. Essentially, the vibration limits apply to sensitive premises.

The Greenbushes expansion project is adjacent to the Greenbushes townsite which is made up of a mixture of residential and commercial buildings/premises/land use.

The Australian Standard AS2187.2(2006) Appendix J specifies that the limit applicable to such premises/land use is 10mm/s for all blasts and 5mm/s for 95% of blasts (as shown in the following table taken from the standard):

TABLE J4.5(A)

GROUND VIBRATION LIMITS FOR HUMAN COMFORT CHOSEN BY SOME REGULATORY AUTHORITIES (see Note to Table J4.5(B))

Category	Type of blasting operations	Peak component particle velocity (mm/s)
Sensitive site*	Operations lasting longer than 12 months or more than 20 blasts	5 mm/s for 95% blasts per year 10 mm/s maximum unless agreement is reached with the occupier that a higher limit may apply
Sensitive site*	Operations lasting for less than 12 months or less than 20 blasts	10 mm/s maximum unless agreement is reached with occupier that a higher limit may apply
Occupied non-sensitive sites, such as factories and commercial premises	All blasting	25 mm/s maximum unless agreement is reached with occupier that a higher limit may apply. For sites containing equipment sensitive to vibration, the vibration should be kept below manufacturer's specifications or levels that can be shown to adversely effect the equipment operation

*A sensitive site includes houses and low rise residential buildings, theatres, schools, and other similar buildings occupied by people.

NOTE: The recommendations in Table J4.5(A) are intended to be informative and do not override statutory requirements with respect to human comfort limits set by various authorities. They should be read in conjunction with any such statutory requirements and with regard to their respective jurisdictions.

2.2 Prediction of Air Overpressure

The publication "ICI – Handbook of Blasting Tables" describes a method for prediction of air overpressure. This method is described in the equation below:

$$P = C\ (R/Q^{1/3})^{-1.2}$$

P = pressure (kPa)
C = Constant (determined mainly by level of confinement and atmospheric conditions)
R = Range (metres)
Q = Quantity of explosives (kg per unit time)

Most limits applied to air overpressure are expressed in terms of decibels linear (dBL) (as is the case for the limits applied at Talison). To convert kPa to dBL the following equation is used:

$$dBL = 20\ \log_{10}(P/2.0265\text{x}10^{-8})$$

The main challenge inherent to the numerical prediction of air overpressure is determination of the constant C. This value must be determined from the degree of confinement of the charge combined with consideration of the atmospheric conditions at the time of firing. Industry experience has shown that atmospheric conditions exert a high level of dominance upon actual air overpressure results making prediction of air overpressure very difficult.

The publication "ICI – Handbook of Blasting Tables" suggests that for "fully confined blasthole charges" in average atmospheric conditions, the constant C = 3.3 (See Appendix D) while for unconfined charges (such as the proposed pilot charge) the constant C = 185.

The Talison Lithium Australia Greenbushes Operation Noise Emissions Approval 2015 specifies the air overpressure limits as follows:

Table 2.2.1

Type of premises receiving noise	Time of day	Approved airblast level (dB $L_{Z\ peak}$)	Approved airblast level (dB $L_{Z\ peak}$) not to be exceeded for 9 in any 10 consecutive blasts
Sensitive site	0700 to 1800 Monday to Saturday	125	120
	0700 to 1800 Sunday or a public holiday	120	115

3. Talison Blast Monitoring System

Compliance with ground vibration and air overpressure limits are measured/verified using a ground vibration (geophone) and an air overpressure (microphone) sensor that are connected to data logger and transmission instruments.

The purposes of each of these monitors includes:

- To measure the blast-induced ground vibration and air overpressure that would be experienced by the nearest/average neighbours to the mining operation or from which the experienced ground vibration and air overpressure may be calculated by extrapolation or interpolation
- To avoid measurement of ground vibration and air overpressure from other sources (i.e. ambient vibration and air overpressure/noise)
- To resist degradation of instrumentation due to exposure to outdoors conditions
- To resist accidental and other damage/interference from human activity
- To avoid any interference with normal activities by other land users

It can be argued that these criteria are most well met when monitoring sites are located on land that the mining operator owns. However this also limits the choice of locations available to the mine.

3.1 Current Open Pit Blast Monitors and History

Open Pit blast monitoring is undertaken at a combination vibration and air overpressure monitoring site located within the Greenbushes town. This monitoring program was commenced in the early 1990's when hard rock operations commenced in close proximity to the town of Greenbushes. Monitoring occurred at up to 8 sites around the community, however based on the vibration and air blast results obtained, the locations of sensitive receivers who contacted the company and the more optimal/consistent performance of permanently installed vibration sensors, it was agreed with the WA Environment Department to establish a permanent monitoring site within the townsite. This site has been retained and upgraded as new technology has become available.

Up to 2003, the majority of blasting at Greenbushes occurred in the Cornwall pit (which ranges from 100 to 500m to the closest sensitive receiver/neighbour). These blasts utilised blast holes of up to 165mm diameter and 5, 7.5 and 10m bench heights. Blasting in the proposed Greenbushes Expansion will be at least 400m from a sensitive receiver/neighbour.

In November 1993, blasting operations were conducted to within 200m of a number of residences and at about this time the Greenbushes Mine entered into an agreement with the owners of these residences in respect to blast clearance procedures. As part of this agreement, the company commenced property/structural inspections and these were performed by an independent firm of professional consulting engineers. These properties included the Greenbushes Primary school and 6 private residences. The inspections occurred every 6 months during the period when blasting in close proximity and since this time the company continues to conduct the inspections on an annual basis. The detailed records of gradual dilapidation of these buildings over a 25 year period is consistent with:

- The types of structures (including the type of ground and foundations used)
- The age of the structures
- The amount of maintenance applied to the structures

Within the monitor "shed" there is the data recording and transmission equipment. Adjacent to the shed is a triaxial geophone which is well coupled to the ground – by burial (in accord with the Australian standard and industry best practice.

Above the monitoring shed, there is also a microphone shown in the image below

The location of the open pit blast monitor in the Greenbushes town (labelled with yellow star) and the planned crests and toes for the Greenbush Expansion Project are shown in the figure below.

3.2 Review of Current Monitoring

As part of these analyses, the location of the current monitor was reviewed against the criteria listed in Section 3 to ensure the location would be appropriate for blasting activities within the Expansion Project area.

While the current monitor site does a good job of assessing the average air overpressure and ground vibration from Greenbushes blasts, it is subject to many false triggers (on both vibration and air overpressure) due to the relatively high level of community activity in close proximity to the monitors.

The current trigger levels used for the sensors are as follows:

- Ground vibration = 0.2mm/s
- Air overpressure = 110dBl

These trigger levels are appropriate to the limits:

- For ground vibration specified in AS2187.2(2006) – Table J4.5(A)
- For air overpressure specified in the Greenbushes Environmental License – shown above as Table 2.2.1

Any decrease in trigger levels would only exacerbate the current frequency of false trigger of instrumentation.

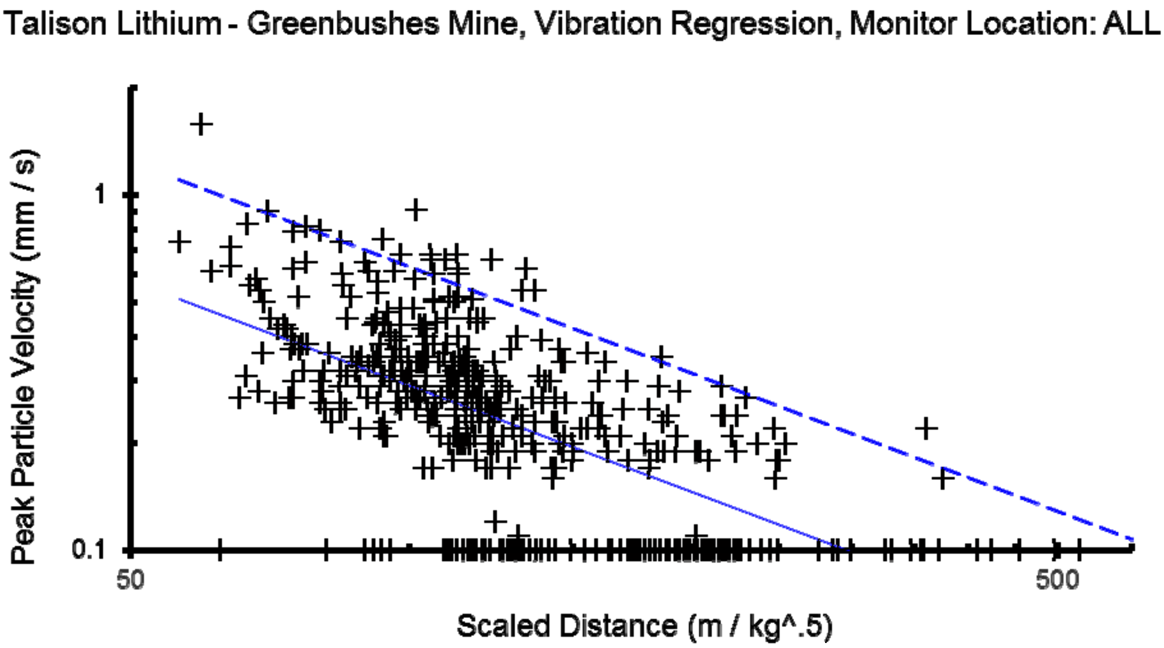
4. Prediction of Ground Vibration for the Greenbushes Expansion Project

4.1 Analysis of Talison Ground Vibration Records

GBC conducted a review of actual blast vibration measurements from the Greenbushes Open Pit operation since early January 2014. Data from all blasting monitored during 2014-2018 was supplied by Talison and this constituted about 900 blast events over this five year period. The data was reviewed, filtered and collated into a structure/form suitable for the analyses. Some data was found to incomplete and was excluded from consideration

Many blast events resulted in failure of the monitors to trigger (which is unsurprising considering the distance at which some events occurred). These “No trigger” and “DNT” events were used in the data set as PPV measurements of 0.1mm/s (ie the midpoint or mean value between the trigger level and zero).

4.2 Vibration Regression – Greenbushes Town Monitor – Jan 2014-Jul 2018



Vib'n Regression Parameters	
Location Filter	ALL
Slope	-0.98
K (avg)	27.146
Design percentile	
K (95%)	58.489
Quality of Fit (r^2)	0.411
No of points	471

The 50% and 95% lines of best fit for the data were calculated and then represented by square root scaled distance equations (as per AS2187.2). These equations were:

50% Confidence Limit $\mathbf{V= 27.146(R/Q^{1/2})^{-0.98}}$

95% Confidence Limit $\mathbf{V= 58.489(R/Q^{1/2})^{-0.98}}$

The r squared, correlation coefficient or "goodness of fit" value for this data set was 0.411 which is moderate. This was most likely due to:

- The data set including several different types of blast (with various MIC, timing, confinement and other factors)
- The data from many years of blasting activity and numerous blast locations – resulting in numerous different vibration attenuation paths (with presumably different techniques, geology and attenuation characteristics)
- The data being very low levels of ppv (all less than about 1.5mm/s) and mostly not very much larger than the lower measurement limit of the instruments and their set trigger level
- The likelihood that at least some measurements include some component of background/non-blasting vibrations coincident with the blast event

5. Prediction of Air Overpressure for the Greenbushes Expansion Project

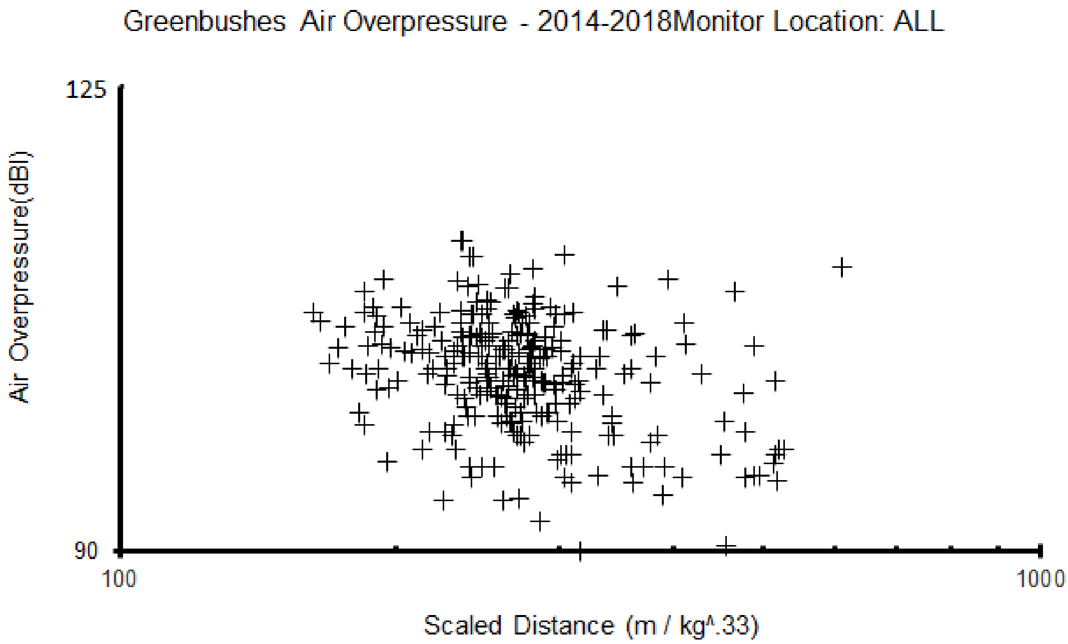
As discussed in Section 2.2, regression analyses of air overpressure data does not usually yield formulae from which accurate predictions of over pressure level can be derived. This is due to the strong influence that ambient environmental conditions at the time of each blast (which are not included in the prediction equations) exert of actual air overpressure levels that will be measured at any particular distance.

However, regression analyses were conducted upon the Talison data to assess the usefulness of prediction equations.

5.1 Analysis of Talison Air Overpressure Records

AS1055.1(1997) Section 6.3.1 suggests that noise measurements conducted (outdoors) where the wind velocity exceeds 5m/s may well be invalid. The Greenbushes Townsite monitor air overpressure sensor is located unusually high above the surrounding ground (about 4m).While this was probably done to reduce the shadow effect of nearby structures, it also increases the probability of wind velocity around the sensor exceeding the 5m/s specified in AS1055.

5.2 Air Overpressure Regression - Greenbushes Town Monitor – Jan 2014-Jul 2018



Vib'n Regression Parameters	
Location Filter	ALL
Slope	-0.09
K (avg)	164.531
Design percentile	
K (90%)	176.510
Quality of Fit (r^2)	0.128
No of points	171

The 50% and 90% lines of best fit for the data were calculated and then represented by cubed root scaled distance equations (as per AS2187.2). These equations were:

50% Confidence Limit **$V= 164.531(R/Q^{1/3})^{-0.09}$**

90% Confidence Limit **$V= 176.510(R/Q^{1/3})^{-0.09}$**

The r squared, correlation coefficient or "goodness of fit" value for this data set was 0.128 which is very low. This was most likely due to:

- The dependency of air overpressure levels upon ambient environmental conditions
- The data set including several different types of blast (with various MIC, timing, confinement and other factors)
- The data from many years of blasting activity and numerous blast locations – resulting in numerous different air overpressure attenuation paths (with presumably different techniques, topography and attenuation characteristics)
- The likelihood that at least some measurements include some component of background/non-blasting air overpressure coincident with the blast event

6. Prediction of Maximum Instantaneous Charge by Zone

The 90% confidence limit vibration prediction equation was used to analyse distance between the monitor location and the proposed Greenbushes Expansion Project area to assess the maximum instantaneous charge (MIC) that would be predicted to achieve compliance with a peak particle velocity of 5mm/s.

Table 6.1: Predicted PPV for combinations of distance and MIC

	MIC(kg)	300	320	340	360	380	400	420	440	460	480	500	520	540	560	580	600
Distance(m)		Predicted PPV (mm/s)															
200		4.4	4.6	4.7	4.9	5.0	5.1	5.2	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.2	6.3
220		4.1	4.2	4.3	4.4	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7
240		3.7	3.8	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.1	5.2
260		3.4	3.5	3.7	3.8	3.9	4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.8
280		3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.9	4.0	4.1	4.2	4.3	4.3	4.4	4.5
300		3.0	3.1	3.2	3.3	3.4	3.4	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.1	4.2
320		2.8	2.9	3.0	3.1	3.1	3.2	3.3	3.4	3.5	3.5	3.6	3.7	3.7	3.8	3.9	3.9
340		2.6	2.7	2.8	2.9	3.0	3.0	3.1	3.2	3.3	3.3	3.4	3.5	3.5	3.6	3.7	3.7
360		2.5	2.6	2.7	2.7	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.3	3.3	3.4	3.5	3.5
380		2.4	2.4	2.5	2.6	2.7	2.7	2.8	2.9	2.9	3.0	3.0	3.1	3.2	3.2	3.3	3.3
400		2.3	2.3	2.4	2.5	2.5	2.6	2.7	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.1	3.2
420		2.1	2.2	2.3	2.3	2.4	2.5	2.5	2.6	2.6	2.7	2.8	2.8	2.9	2.9	3.0	3.0
440		2.1	2.1	2.2	2.2	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9
460		2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8
480		1.9	1.9	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.6
500		1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.5
520		1.7	1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.4
540		1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.2	2.2	2.3	2.3	2.4
560		1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.2	2.2	2.2	2.3
580		1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.2	2.2
600		1.5	1.6	1.6	1.7	1.7	1.7	1.8	1.8	1.9	1.9	1.9	2.0	2.0	2.1	2.1	2.1
620		1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.0	2.1
640		1.4	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9	1.9	2.0	2.0
660		1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.8	1.8	1.8	1.9	1.9	1.9
680		1.3	1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.8	1.8	1.8	1.9	1.9
700		1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.8	1.8

6.1 Prediction of Air Overpressure

The regression relationship developed from the database was not sufficiently reliable in nature to derive predictions. As noted in Section 2, this was expected and consistent with industry experience from around the world.

7. Conclusions

1. The application of the vibration limits shown in AS2187.2(2006) Table J4.5A imply that a 95% confidence limit prediction equation be used for prediction of compliance with the 5mm/s ppv.

2. The application of the air overpressure limits historically applied by the Department of Water and Environmental Regulation (DWER) and/or in the "Talison Lithium Australia Greenbushes Operation Noise Emissions Approval 2015 to Greenbushes" and shown in Table 2.2.1, imply that the 90% confidence limit prediction equation be used for prediction of compliance with the 115dBl and 120dBl air overpressure limits for nine out of ten blasts. Unfortunately the prediction equations derived from the data were not mathematically useful.

3. The analyses showed that blasting in the Greenbushes Expansion Project area will very probably achieve compliance with ground vibration limits as stipulated in AS2187. This assessment is predicated upon the use of similar techniques to those previously applied to blasting at Talison over the last five years and hence inherent to the vibration data gathered over that time.

4. Analysis of the air overpressure dataset was not useful in predicting air overpressure for the Greenbushes Expansion Project area due to the poor correlation coefficients that result from the influence of ambient environmental conditions. These influences could not be taken into account. However, it is anecdotally indicated that compliance with air overpressure limits should be achievable using techniques already used at Greenbushes, those previously used during mining of the Cornwall Pit or those used at other mines in WA that blast at distances from residences similar to those applicable to the Greenbushes Expansion project. These techniques could (if found to be necessary) include:

    a. Very accurate QA/QC applied to loading and stemming operations
    b. Use of specific row and face orientation relative to sensitive receivers
    c. Use of individual blast hole logs to customise the charge and stemming length for each blast hole to localised geologic character
    d. Use of longer than normal stemming length
    e. Survey of face shape and conformity of face row holes (to achieve minimum confineable face burden
    f. Use of reduced MIC, hole diameter and bench height
    g. Use of sand covering within and over presplit hole collars
    h. Use of longer than normal interhole delay time
    i. Use of specific initiation point location relative to sensitive receivers
    j. Assessment of atmospheric stratification prior to blasting
    k. Embargo of blasting during times of specific wind direction relative to sensitive receivers

5. Talison should review the current monitoring location to establish whether an alternate location would provide reduced frequency of false triggering and better compliance with the wind velocity limits specified in AS1055 while ensuring

measurements representative of the vibration and air overpressure experienced (on average or otherwise) by Greenbushes residents.

8. DISCLAIMER OF LIABILITY

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Before using the information or blast designs contained in this document in a particular situation it is essential that, amongst other things, the following criteria be taken into account:

- whether the particular technique proposed to be used is appropriate for the circumstances;
- whether the persons using it have the necessary competency and experience;
- the environmental conditions in which it is to be used;
- the specific aims intended to be achieved and whether those aims are achievable in the particular circumstances; and
- the sequence of steps which need to be followed in the particular circumstances.

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