Simpson Engineering Group

Document title:

Bowen Orbital Spaceport

Document Type:

Noise, Vibration and Air Quality Assessment

Prepared for:

SMEC

Document & Date issued:
210407D02.docx on Thursday, 23 September 2021

Authorised and signed

by:..
Mark A Simpson *(Principal RPEQ)*

SEG Pty Ltd
PO Box 4407
Forest Lake Qld 4078
31 Lionheart Street
Forestdale, Qld 4118
Ph: 61 7 31172468
Mobile: 0414383172
Email: mark@segroup.com.au

Revision:	Date:	Status:	Comment:
210607D02	23 Sept 2021	Discussion	Report not complete – For discussion

Contents

1 Introduction

SEG Consulting Engineers has been retained by SMEC to prepare a noise, vibration and air quality assessment associated with the operation of the Bowen Orbital Spaceport (BOS). The assessment:

- describes the intended use with respect to potential noise and vibration issues
- describes typical and non-typical operating cases
- describes the environmental values of the receiving environment to be protected
- proposes air quality goals
- presents the results of noise measurements obtained during test of the rocket motor
- presents the results of noise and air quality modelling
- assessment of the noise and air quality exposure
- recommendations to be included in the BOS environmental management plan.

1.1 Project Description

The BOS is a facility to support small class orbital launch vehicles with access to multiple Low Earth Orbit trajectories. It is located within the Abbot Point State Development Area (SDA), which falls within the Whitsunday Regional Council (WRC) area, approximately 15km west of the Bowen township, refer to Figure 1.

Figure 1: Regional Map Showing Launch Site, Bowen and Closest Sensitive Receptors

The launch site is on Lot 10 Abbot Point Road which is accessed from the Bruce Highway via Abbot Point Road. The facility footprint will be approximately 3 ha within the 94 Hectare lot in a previously cleared new growth area.

The facility shares boundaries with:

- Two unoccupied cattle properties.
- An operational hard rock quarry.
- Intermittent road and rail services along Abbot Point Road corridor to the North Queensland Bulk Ports terminal.

The separation distances from the Launch Pad to the nearest points of these properties are shown in Figure 2. None of the adjacent properties have homesteads.

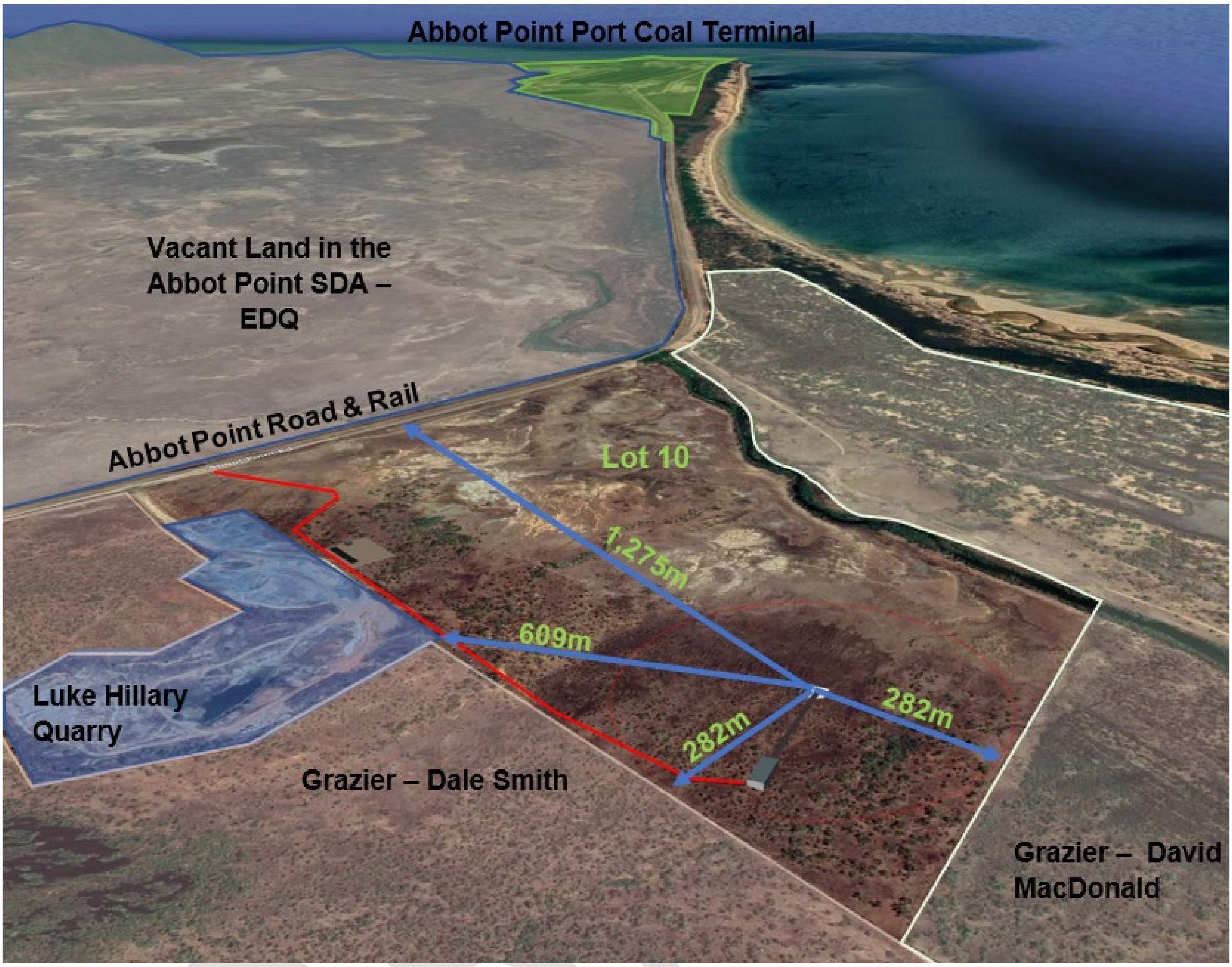

Figure 2: Oblique View of Site to NW

1.2 Context

This report forms part of the environmental assessment for the project. It has been prepared in accordance with the Queensland Environmental Protection Act and the requirements of all applicable legislation. All reasonable and practicable mitigation will be implemented to achieve the criteria nominated.

3 Operations

The BOS comprises a Launch Control Centre, Vehicle Assembly Building (VAB), launch pad and launch fluids and utilities storage. The Launch control centre is situated approximately 7km from the site in the North Queensland Bulk Ports (NQBP) footprint. The VAB is the primary operation on the site. It comprises a building approximately 50m x 20m x 8m with large roller doors at the north and south ends of the building. Internal facilities include air-conditioned clean rooms, cribbing and ablution, open plan office, tooling and equipment and a material storage room. The northern end of the VAB will be aligned with the launch pad centre.

The launch pad is proposed to be a 20x20m bunded concrete pad to support transport and erection infrastructure for Gilmour Space Eris Rockets. The launch pad may include a water deluge system that is designed to limit noise and vibrations from adversely affecting rocket operations during the moments prior to and immediately after lift-off. This sound suppression system also works to limit environmental noise emissions during this phase of the launch. All operation and management of activities on the launch pad will be managed by detailed launch operation procedures which are developed and maintained for each launch mission.

The ERIS (Small Class Orbital Expendable Launch vehicle) has an overall length of 21.2m, a mass at lift-off of 33 tonnes and comprises 3 stages. Stage 1 is a hybrid rocket that provides 560kN vacuum thrust.

Gilmour Space provided the following data for noise modelling:

- Launch trajectory for the rocket from lift off to stage separation.
- Engine operating data and nominal ascent thrust profile.
- Static fire test parameters for the rocket motor.
- Projected annual launch capabilities at BOS.

Current projections indicate there are likely to be 2 launches per year until 2025 and then increase in frequency towards a target of monthly launches. Flight paths between the 19° - 65° trajectories are considered possible from the BOS. The angle is specified anti-clockwise relative to due east. The noise modelling has been based on 33° trajectory since this alignment is likely to be the most common and it keeps the alignment close to the coastline.

The flight time from take-off to 10km (altitude of commercial jets in cruise) is approximately 60 seconds and an additional 20 seconds is required to attain an altitude of 20km (above the troposphere).

During the vertical launch, no sonic boom would be expected to occur at the ground during the vertical ascent phase of the flight because the acoustic energy of the sonic boom is directed upward, unless the atmosphere causes this energy to refract back to the ground. As the launch vehicle pitches over to access the specified target orbit, the sonic boom energy (rays) would intersect the ground. Given the proposed range of trajectories the sonic boom is not expected to be experienced on land.

In the event of a launch failure the rocket is remotely destroyed. A failure on or close to the launch pad would have the greatest blast energy since the rocket during this early phase of the launch has not consumed any fuel. Detonation of the launch vehicle is unlikely but noted as the only unexpected event with potential noise and vibration consequence.

4 Existing Environment

The site is situated near the coast between Bowen and Abbot Point coal terminal. There is a large hill to the south reaching an elevation of 280m compared to nominally 10m for the subject site and surrounding areas. There is a wetlands area and several creeks between the site and the coastline to the north.

The closest dwelling on Dry Creek Road is approximately 3km ESE of the launch pad. There are a series of dwellings along Euri Creek between 3.7km and 4.8km adjacent to Euri Creek.

Figure 3: Closest Sensitive Receptors

4.1 Existing Noise Environment

The areas to the east of the site comprise wetlands near the coast and small rural lots to the urban areas of Bowen. There is a quarry immediately to the south of the launch facility and to the west is the railway line providing coal-train access to Abbot Point Coal terminal, NW of the launch site. The areas to the east of the site would have ambient noise levels representative of rural residential and urban areas with low density traffic and commercial. Rating background level (RBL) is the overall single-figure background level representing each time period. The assumed existing RBL's, refer to Table 1, and are based on quiet rural residential areas.

Table 1: Assumed Rating Background Noise Level [dB(A)] For Rural Residential Areas

Time Period	Assumed Rating Background Noise Level [dB(A)]
Day Monday to Sunday 7am to 6pm	40 dB(A)
Evening - Monday to Sunday 6pm to 10pm	38 dB(A)
Night - Monday to Sunday 10pm to 6am	30 dB(A)

4.2 Existing Air Environment

The pollutants of interest from the launch operation are predominantly carbon monoxide and carbon dioxide.

The Department of Environment and Science, Queensland operates a network of air quality monitoring stations in Queensland. These stations monitor various pollutants at various sites. The maximum of the monitoring period levels is summarised in the yearly reports and the relevant results for the 2020 monitoring period have been used[1] as well as the State of the Environment Report 2020[2]. Where site specific measurements are not available the maximum measurement from the monitoring network has been adopted. It is likely that these levels are conservatively high.

Pollutant	Averaging Period	Level	
		PPM	mg/m^3
Carbon Monoxide	1-hour	3.9	4.5
	8-hour	1.2	1.4
Carbon Dioxide	1-hour	531	955

[1] *Queensland air monitoring 2020, National Environment Protection (Ambient Air Quality) Measure, Department of Environment and Science, State of Queensland, 2021, https://www.qld.gov.au/__data/assets/pdf_file/0032/68657/air-monitoring-report.pdf*

[2] *State of the Environment Report, State of Queensland, 2020, https://www.stateoftheenvironment.des.qld.gov.au/pollution/air-quality*

	8-hour	509	916

5 Noise Goals Discussion

Short-term increases in noise would result from the use of heavy equipment during construction and development of the site and eventual rocket launches. Construction noise is largely limited to the site being developed, and unlikely to carry to nearby sensitive receptors. Thus it is not proposed to consider construction phase noise.

The loudest noise generated at the site would result from launches. The launch is likely to lead to short-term noise effects.

5.1 Noise from Airports

At distances of several km from the launch site a launch would be perceived to be similar to that of an aircraft departure. The usual way to assess aircraft noise in Australia is the ANEF as described in AS2021-2015 :Acoustics – Aircraft Noise intrusion – Building siting and construction". However, there are insufficient launches from this site to generate an ANEF contour. Thus, for the purposes of planning the ANEF zone surrounding the site would be less than ANEF20. Consequently, it would not be necessary for future development to consider the noise from rocket launches in the design of future buildings.

Due to the short durations involved in launch activities, it is not considered necessary or justified to propose noise level goals. In this instance two metrics (L_{Amax} and SEL) are proposed to provide way to assess the comparative impact of individual launch events.

L_{Amax} is appropriate for community noise assessment of a single event, such as a rocket launch. This metric represents the highest A-weighted integrated sound level for the event in which the sound level changes value with time. The L_{Amax} metric indicates the maximum sound level occurring for a fraction of a second. The maximum sound level is important in judging the interference caused by a noise event with conversation, TV or radio listening, sleep, or other common activities. Loud individual events can pose a hearing damage hazard to people, and can also cause adverse reactions by animals. Adverse animal reactions can include flight, nest abandonment, and interference with reproductive activities.

As a guide the L_{Amax} noise levels from various plane types close to airports are provided in Table 2.

Although the L_{Amax} provides some measure of the intrusiveness of the event, it does not completely describe the total event, because it does not include the period of time that the sound is heard.

The SEL is a composite metric that represents both the intensity of a sound and its duration. Individual time varying noise events (e.g., aircraft overflights) have two main characteristics: a sound level that changes throughout the event and a period of time during which the event is heard. SEL provides a measure of the net impact of the entire acoustic event, but it does not directly represent the sound level heard at any given time. For example, during an aircraft flyover, SEL would include both the maximum noise level and the lower noise levels produced during onset and recess periods of the overflight. SEL is a logarithmic measure of the total acoustic energy transmitted to the listener during the event. Mathematically, it represents the sound level of a constant sound that would, in one second, generate the same acoustic energy as the actual time-varying noise event. For a rocket launch, the SEL is expected to be greater than L_{Amax}.

Table 2: Typical L_{Amax} Noise Levels from Aircraft Near Airports

Plane type	Carrier	Operation	Distance from runway [m]	Sideline Distance [m]	L_{Amax} [dB(A)]
Airbus A320	Qantas	Arrival	500	0	91
			1000	0	88
			5000	0	75
			5000	1000	58
Airbus A320	Qantas	Departure	2500	0	91
			3000	0	87
			7500	0	71
			7500	2000	56
Boeing 737-300	Qantas	Arrival	500	0	96
			1000	0	92
			5000	0	78
			5000	1000	60
Boeing 737-300	Qantas	Departure	2500	0	97
			3000	0	91
			7500	0	78
			7500	2000	62
Dash 8 - 300	Sunstate	Arrival	500	0	83
			1000	0	71
			5000	0	66
			5000	1000	50
Dash 8 - 300	Sunstate	Departure	2500	0	73
			3000	0	71
			7500	0	57
			7500	2000	46

5.2 Sensitive land uses

Sensitive land uses have the potential to be impacted by the launch. Sensitive land uses/receptors include:

- a dwelling (detached or attached) including house, townhouse, unit, reformatory institution, caravan park or retirement village
- a library, child care centre, kindergarten, school, school playground, college, university, museum, art gallery or other educational institution, hospital, respite care facility, nursing home, aged care facility, surgery or other medical centre
- a community building including a place of public worship
- a court of law
- a hotel, motel or other premises which provides accommodation for the public
- a commercial (office) or retail facility
- a protected area, or an area identified under a conservation plan as a critical habitat or an area of major interest under the Nature Conservation Act 1992
- an outdoor recreational area (such as public park or gardens open to the public, whether or not on payment of a fee, for passive recreation other than for sport or organised entertainment) or a private open space.

5.3 Vibration

Vibration criteria relate to both human comfort and structural/building damage. Since launch activities are relatively infrequent, the building damage criterion is considered to be the most appropriate. Vibrations are considered to be minor compared with the noise from a launch and would generally go unnoticed during a launch. The main mechanism for generating vibrations is acoustic loading on the launch pad.

From “Effect of blasting on infrastructure” by Alan Richard, Adrian More ACARP project C14057 20/10/2008 the recommended safe vibration limits without a more detailed analysis are proposed for structures near the launch facility.

Table 3: Proposed Vibration Levels to Protect Infrastructure

Item	Recommended PPV limit [mm/s]
Public Roads	100
Railway lines	100
Concrete bridges	100
Conveyor structures	100
Power Lines	100
Electrical substations	10-25
Fixed industrial plant and buildings	100
Surface pipelines	100
Buried communication cables and pipelines	100
Mine offices and houses	Up to 50

6 Predicted Environmental Noise Levels

Rockets generate significant noise from the combustion process and turbulent mixing of the exhaust flow with the surrounding air. There is a supersonic potential core of exhaust flow, surrounded by mixing region. Noise is generated in this flow. It is directional, with the highest noise levels at an angle of 40 to 50 degrees from the direction of the exhaust flow.

The emitted noise is modified in several ways as it propagates outward from the launch vehicle. These effects include source directivity, forward flight effects, doppler effect, geometric spreading, atmospheric absorption and ground interference to a receiver location.

$$Lp = Lw - (20 \log_{10}[r] + 10 \log_{10}[4\pi]) + AE$$

Where:

Lp is the sound pressure level at an observer

Lw is the sound power level of the source

$20 \log_{10}(r) + 10 \log_{10}(4\pi)$ is the distance attenuation (spherical)

AE is the excess attenuation factors.

The excess attenuation factors AE comprise:

$$AE = Aa + Ag + Am + Ab + Af$$

Where:

Aa = Excess attenuation due to air absorption

Ag = Excess attenuation due to ground reflection

Am = Excess attenuation due to meteorological effects

Ab = Excess attenuation due to barriers

Af = Excess attenuation due to forests

and rocket specific factors comprising

Affe = Excess attenuation due to forward flight effects

Adir = Excess attenuation due to source directivity azimuthal symmetry assumed

Adop = Excess attenuation due doppler effect

A digital terrain noise model of the site and surroundings has been developed using PEN3D V2.7.1.275 software. The PEN3D General Prediction Model (GPM) is based on the method contained in a book by Bies and Hansen (1988, pages 117, 127).

A launch vehicle in operation radiates less noise than the same rocket in a static environment. These are described as forward flight effects and causes a reduction in noise levels. As the differential between the forward flight velocity and exhaust velocity decreases, jet mixing is reduced, which reduces the corresponding noise emission. This effect is not noticeable at subsonic speeds, i.e. for nominally the first 60 seconds of flight.

The Doppler effect is defined as the change in frequency of a wave for an observer moving relative to its source. It leads to a downward shift in the frequency of sound. This effect is greatest under the launch vehicle and negligible perpendicular to the direction of motion of vehicle. Consequently, this implies the apparent frequency of noise is lower and has a greater attenuation due to the nature of the "A"-weighting curve. A a guide launch vehicle travelling at Mach 0.5 and an observer at 45° and below the rocket there will be an apparent frequency shift of 0.94*f.* Hence for all sensitive environmental observers situated more than several km from the launch site the doppler effect will be minor until the launch vehicle reaches significant heights.

In this instance the launch vehicle noise has been conservatively modelled as:

1. an omnidirectional noise source with the noise level representing the highest noise level at 40 to 50 degrees off axis
2. no forward flight effects
3. no doppler effect

This modelling case was selected to provide conservatism and maximum flexibility for future operations and launch vehicle configurations. The inherent conservatism in this modelling approach would permit

The noise model address flight to 20 km, slightly beyond the top of the troposphere and slightly into the stratosphere. Above this height there is insufficient atmosphere to effectively transmit noise.

The calculated L_{Amax} noise levels for the launch for the surrounding areas are contained in Figure 4 and the SEL are contained Figure 5.

The calculated noise levels at selected receptors are contained in Table 4.

Table 4: Calculated Noise Levels at Selected Receptors

Selected Receptor	Calculated L_{Amax} [dB(A)]	Calculated SEL [dB(A)]
Creek Close to Lunch Site	120	124
Beach North of Launch Site	104	112
Queens Beach (Bowen)	78	94
Dwelling Dry Creek Road	96	106
Dwelling 1 Euri Creek	94	105
Dwelling 2 Euri Creek	92	104
Dwelling 3 Euri Creek	92	104
Dwelling 4 Euri Creek	91	103
Dwelling 5 Euri Creek	90	101

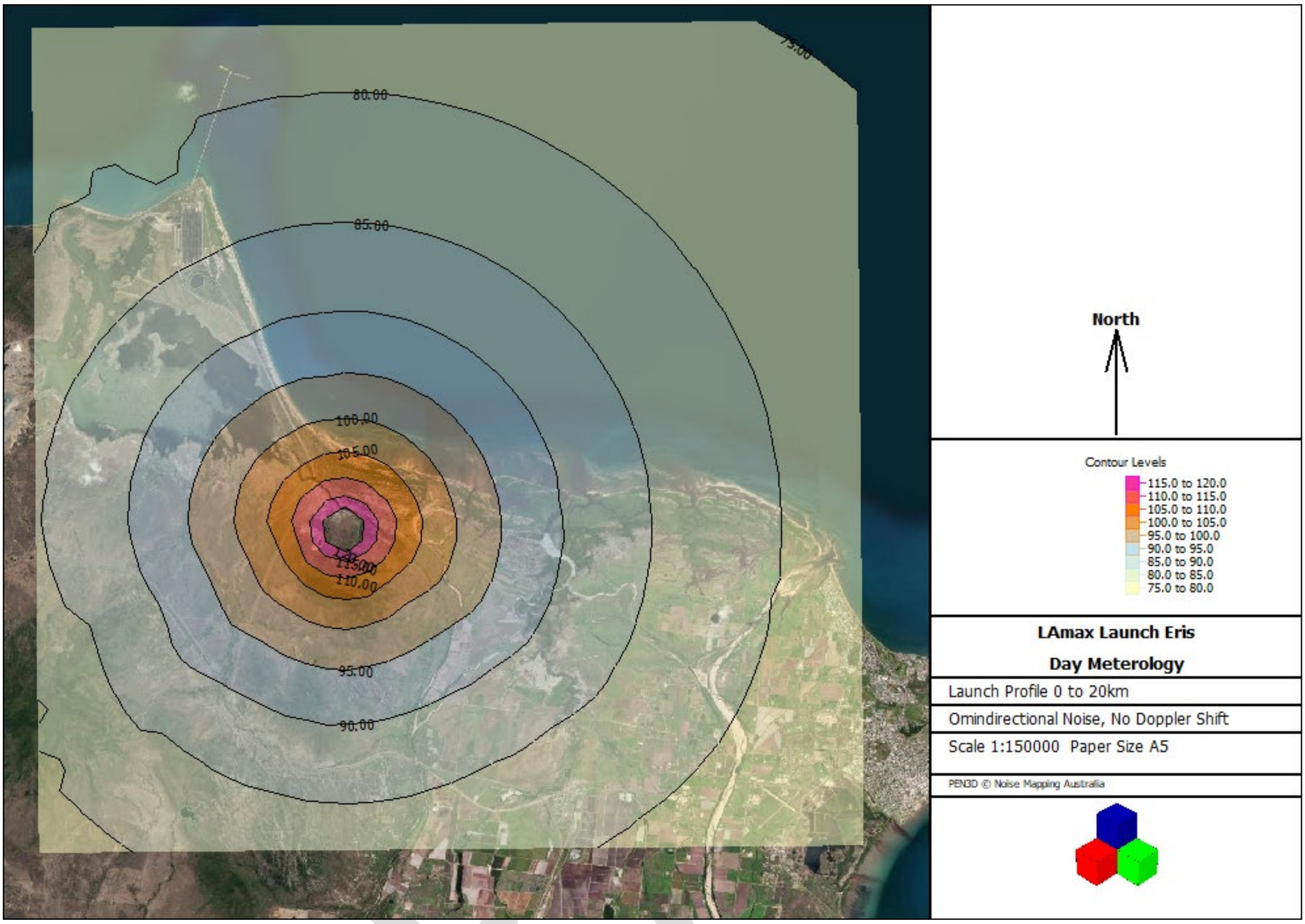

Figure 4: Calculated L_{Amax} in dB(A) from Eris Launch

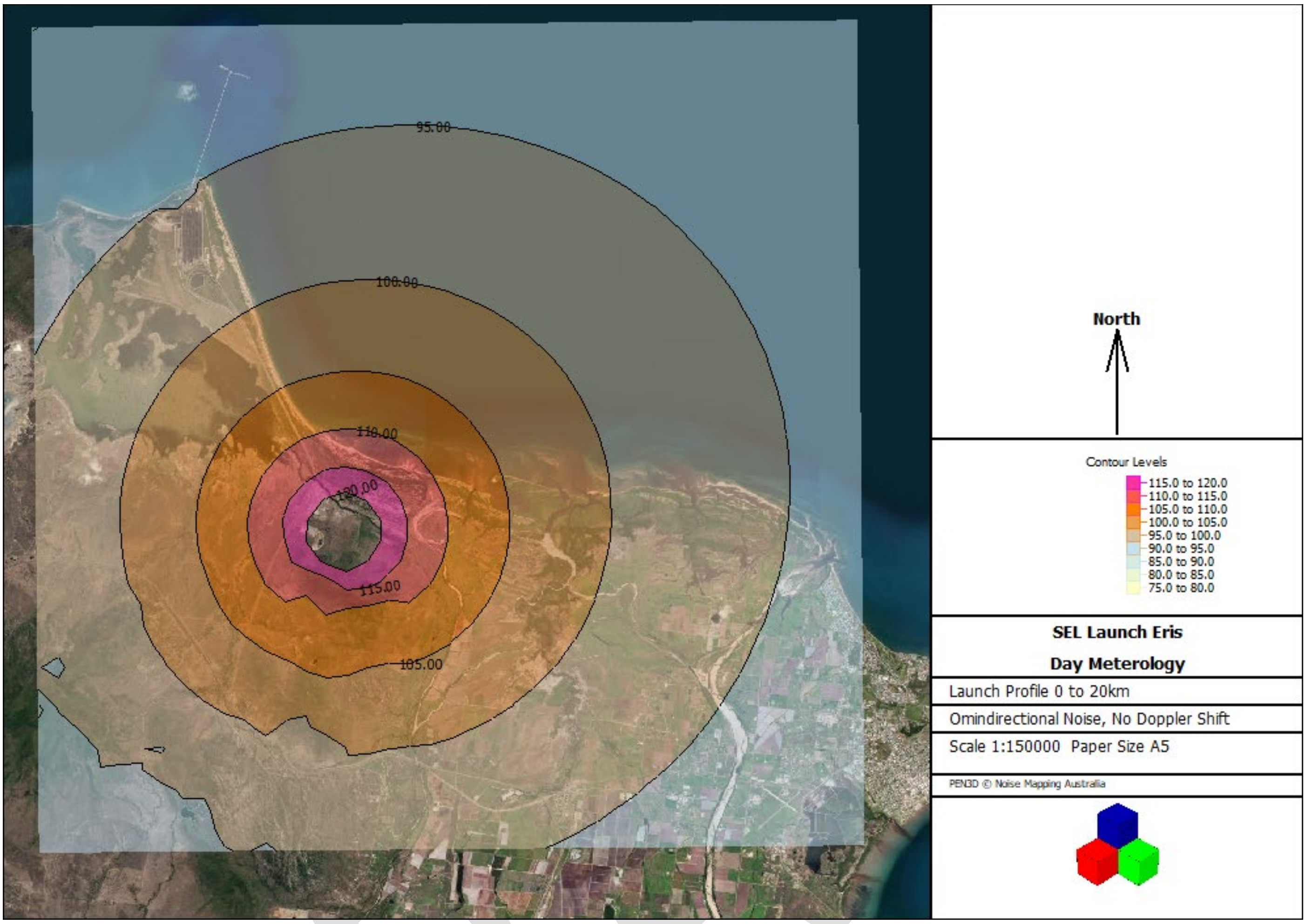

Figure 5: Calculated SEL in dB(A) from Eris Launch

6.1 Predicted Environmental Vibration Levels

There are two potential sources of ground vibration to be generated during takeoff, the ignition pulse and conversion of air-borne acoustical energy into ground vibration.

The ignition pulse is the high velocity jet from rocket motor exhaust which directly impacts the ground during the ignition phase of the launch. Significant ignition overpressure are peaks typically associated with solid rockets. The proposed hybrid rocket, like liquid rockets do not produce a significant peak (or pulse) on ignition. Rather the thrust develops gradually and maintains a relatively constant pressure on the very stiff concrete launch pad. Consequently, it is not anticipated the ignition component of the launch will generate any noticeable vibration into the ground.

At launch there will be significant acoustic energy generated and it is possible this could transmit vibrations into the launch pad, launch structure and launch vehicle from the air.

By way of guidance most acoustic energy is reflected, however even the small fraction of transmissibility could cause high power flow in the structures. The transmissibility coefficient (ratio of transmitted power to incident power) is approximately 0.0001 for a normal acoustic wave entering concrete, earth, exposed water etc. That is the transmitted wave would be 40 dB lower than the incident wave.

The acoustic energy over the surface of the launch pad and launch structure is chaotic and variable over time. Hence the generated vibration generated from the acoustic energy are typically a localised effect, of great importance to the fatigue design of the individual elements of the launch pad, launch support structure and importantly the launch vehicle. Without mitigation it is possible that localised regions of the structure could be subjected to damaging vibrations.

To address the operational issues associated with vibrations caused by high acoustic levels during launch, the site will mitigate the high acoustic levels by adopting a water deluge system to attenuate high acoustic levels during the initial phase of the launch. The launch pad will most likely have an acoustic suppression system. The suppression system is highly effective at reducing these effects while the launch vehicle is close to the ground.

When considering the high acoustic noise levels at a macroscale, there will not be large areas of in-phase or resonance vibrations and consequently environmental effects from this effect would be limited. It is conservatively estimated PPV ground vibrations at 100m from the launch pad would be below 10 mm/s.

6.2 Noise Assessment

The noise levels from the launch is expected to cause high noise levels in the immediate vicinity of the launch site. The wetland to the north of the launch site to the beach is expected to be exposed to maximum noise levels between 105 dB(A) and 120 dB(A). The closest group of dwellings, to the east of the launch site is calculated to be exposed to a maximum noise level between 90 dB(A) and 96 dB(A). This is similar in magnitude to the noise level from a Boeing 737-300 between 2.5km and 3km from the runway and under the flightpath. The noise level at queens Beach, Bowen is likely to be exposed to a maximum noise level of 78 dB(A) which is similar in magnitude to a Boeing 737-300 at 7.5km from the runway and under the flightpath. Unlike airports, the noise occurs a few times per year. Thus, the noise from the rocket launch has a magnitude at sensitive receptors similar in magnitude to common noises already occurring elsewhere in Queensland except the noise occurs much less than these other common noises.

It is understood the launch times of the rocket will be advised to nearby selected sensitive receptors and to the community generally via new releases, social media and direct contact with neighbours. It is expected the launch will generate significant interest in the community. Since the event will be notified and the expected noise levels are similar in magnitude to other noises already experienced in Queensland, it is expected the community will not be adversely impacted by the launch operations and the noise impacts would be acceptable.

7 Air Quality

The hybrid rocket design combines both a hydrogen peroxide liquid fuel and a solid fuel design. The decomposition of the hydrogen peroxide in the rocket motor produces water and oxygen. The oxygen is consumed in the combustion of the solid fuel to produce several components but primarily is carbon dioxide and carbon monoxide. A summary of the mass fractions is included in Table 5. Based on the emissions the predominant component of concern is carbon dioxide and carbon monoxide.

Table 5: Combustion Products Mass Fraction

Component	Mass Fraction [%]	Production Rate [kg/s]
Water	66	145
Carbon Dioxide	34	74
Carbon Monoxide	0.4	0.9
Other (Hydrogen Gas, Hydroxide, Oxygen, etc.)	<0.1	0.1

7.1 Air Quality Criteria

Air quality goals for the project have been determined from Safework Australia, National Environment Protection (Ambient Air Quality) Measure, and Queensland Environmental Protection (Air) Policy 2019.

Safework Australia publishes[3] limits in terms of short term exposure limit (STEL) and 8-hour time weighted average (TWA). The STEL is the average concentration of a substance over a 15 minute period and the TWA is calculated for an average eight-hour working day and five-day working week.

Table 6: Extract from Safework Exposure Limits

	TWA (ppm)	TWA (mg/m^3)	STEL (ppm)	STEL (mg/m3)
Carbon Dioxide	5,000	9,000	30,000	54,000
Carbon Monoxide	30	34		

[3] *Workplace Exposure Standards for Airborne Contaminants, Safe Work Australia, 2013, https://www.safeworkaustralia.gov.au/system/files/documents/1705/workplace-exposure-standards-airborne-contaminants-v2.pdf*

The current National Environment Protection (Ambient Air Quality) Measure[4] has been included in Table 7.

Table 7: Excerpt from NEPM Schedule 2 Table 1: Standards and Goal for Pollutants other than Particles as $PM_{2.5}$

Pollutant	Averaging period	Maximum concentration standard	Maximum allowable exceedances
Carbon monoxide	8 hours	9.0ppm	1 day a year

The Queensland Environmental Protection (Air) Policy 2019 (EPP(Air) 2019) commenced in 2019. The EPP (Air) 2019 (Part 2 Section 5) aims to achieve the object of the *Environmental Protection Act 1994* (the Act) in relation to Queensland's air environment. The object of the Act is ".. to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (ecologically sustainable development)."

Specifically, the EPP (Air) 2019 addresses the environmental values to be enhanced or protected namely—

(a) the qualities of the air environment that are conducive to protecting the health and biodiversity of ecosystems; and

(b) the qualities of the air environment that are conducive to human health and wellbeing; and

(c) the qualities of the air environment that are conducive to protecting the aesthetics of the environment, including the appearance of buildings, structures and other property; and

(d) the qualities of the air environment that are conducive to protecting agricultural use of the environment.

To meet the environmental values, Schedule 1 of the EPP (Air) nominates relevant air quality indicators and goals. Relevant air quality indicators from Schedule 1 dealing with particulates are included in Table 8.

Table 8:Excerpt from Schedule 1 Air Quality Objectives - Environmental Protection (Air) Policy 2019

Indicator	Environmental value 8 hour	Air quality objectives		Period	Days
		mg/m^3	Ppm (volume/volume)		
carbon monoxide	health and wellbeing	$11mg/m^3$	9	8 hours	1 day each year

[4] *National Environment Protection (Ambient Air Quality) Measure, Department of the Environment., https://www.legislation.gov.au/Details/F2016C00215*

Additionally, Carbon Monoxide has a peak exposure limit of 400ppm and Carbon Dioxide has a IDLH value of 40,000 ppm. that will be assessed against to 30 second measurement period.

All these indicators are qualities of the air environment that are conducive to human health and wellbeing. The indicators apply at any sensitive or commercial place, such as residences, National Parks schools etc.

In summary the site-specific air quality goals that have been adopted in this report are summarised in

Pollutant	Averaging Period	Air Quality Objective	
		mg/m^3	PPM (volume/volume)
Carbon Monoxide	30 Seconds	458	400
	8 Hours	11	9
Carbon Dioxide	30 Seconds	72,000	40,000
	15 Minute	54,000	30,000
	8 Hours	9,000	5,000

7.2 Modelling Methodology

The air quality modelling methodology comprised three phases namely:

1) preparation of meteorological data The Air Pollution Model (TAPM) and Calmet;
2) development of an emissions profile using data provided by Gilmour Space Technologies;
3) modelling of the likely downwind ground level concentrations using Calpuff.

7.2.1 Preparation of Meteorological Data

TAPM predicts meteorology and pollutant concentration for a range of pollutants important for air pollution applications. The model consists of coupled prognostic meteorological and air pollution concentration components, eliminating the need to have site-specific meteorological observations. Instead, the model predicts the flows important to local-scale air pollution, such as sea breezes and terrain induced flows, against a background of larger-scale meteorology provided by synoptic analyses.

Some limitations of TAPM include:

- it is not suitable for horizontal domain sizes above approximately 1,000 km by 1000 km.
- it cannot be used to accurately represent deep atmospheric circulations or extreme weather events (cyclones).
- it cannot be used for very steep terrain because of the use of a terrain following coordinate system in the model. Thus, the model cannot represent discontinuities in terrain height (for example, cliffs or bluffs).

- it assumes that cloud processes are resolved by the typical inner grid spacings used in the model (i.e. 3km or less). Therefore, no large-scale cloud convection parameterisation is included.

These limitations are of minor significance to the modelling of pollution for this study. The area of interest is much smaller than the maximum horizontal domain size. Extreme weather events (such as cyclones) are not of interest from an air pollution perspective. The terrain does not have significant cliffs or bluff bodies within the region and it is expected that the inclusion of large-scale cloud convection would only slightly change the radiation and moisture balances.

TAPM is highly regarded in the scientific community as a suitable tool to develop meteorological data sets for sites without site-specific meteorological observations. However, the meteorological dataset can be improved by incorporating local meteorology.

The TAPM meteorological file developed for the site covered a one-year modelling scenario of 2020. This period was used for modelling since it is the most recent data sets. TAPM was configured with 5 nested grids with grid spacing of 30000m, 10000m, 3000m ,1000m and 300m. Additionally 40 grid points were used with 50 vertical grids. The model was centred on -19°57.5' and 148°7'. All other settings were as per default.

The general features of winds affecting plume dispersion are illustrated in the wind rose diagrams for the year 2020 (Appendix A: Windrose for Site). The wind roses summarise the wind statistics at a 10m height on site, as calculated by the TAPM meteorological model. The wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points – N, NNE, NE, ENE ,E etc. The length of the bar represents the frequency of occurrence of winds from that direction, and the colour of the bar sections correspond to wind speed categories. It is noted that the predominant wind direction during the year is from the north-east through to the south-east. The representative frequency of Pasquil stability classes for the region is based on data from TAPM. Pasquil stability classes represent the stability of the atmosphere. The stability Class F conditions (stable conditions), which result in poor dispersion of pollutants does not occur during the day. Table 9 shows the frequency of stability classes for the site.

Table 9: Frequency of Stability Classes at Site

Stability Class	***Description***	***Frequency of Occurrence (%)***
A	Very unstable	1
B	Moderately unstable	7
C	Slightly unstable	10
D	Neutral	43
E	Slightly stable	17
F	Stable	21

7.2.2 Development of an Emissions Profile

Gilmour Space technologies provided both a combustion product mass fraction (see Table 5) and a proposed mission profile.

From the meteorology modelling the maximum mixing height for the site has been determined to be approximately 2700m. The mixing height sets an upper limit for the height that needs to be considered in air pollution modelling as there is generally not mixing between layer above and the layer below. This is consistent with the US's Federal Aviation Administration Aviation Emissions and Air Quality Handbook[5]. This handbook describes a "lidding" effect at the mixing height, and this restricts vertical diffusion. Based on this the maximum height considered for emissions is 4000m.

The launch has been broken into seven Segments between 0m and 4,000m with more thinner segments at the lower parts and less, thicker segments at the higher parts. The length of time in each segment has been determined and a total amount of material.

Table 10: Modelling Segment Parameters

Segment	Altitude Range		Time in Segment (s) (approx.)	Centre (UTM 55S)		Emitted Mass (kg/launch)	
	Min (m)	Max (m)		X (m)	Y (m)	CO_2 (kg)	CO (kg)
1	0	200	10	616438	7792744	756	9
2	200	400	4	616438	7792746	276	3
3	400	600	3	616439	7792747	202	2
4	600	1,000	4	616446	7792753	259	3
5	1,000	2,000	8	616537	7792803	593	7
6	2,000	3,000	5	616787	7792931	382	5
7	3,000	4,000	4	617137	7793100	296	4

7.2.3 Dispersion Modelling

Calmet was used to process the exported 3D wind data from TAPM. The metrological grid was set for 110 by 110 cells with a cell dimension of 100m by 100m. Calmet was configured to use TAPM 3D wind data as an initial guess field for the model. All other settings were kept at the recommended default. Calpuff v7 was used to determine the downwind ground level concentrations.

Each segment in Table 10 has been modelled as a volume source in Calpuff with a height corresponding to that of each segment. The segment was located spatially as per the launch profile. Calpuff was set to a 30 second time step. For the purposes of air quality modelling and to capture multiple possible meteorological scenarios, launches were simulated to occur at 3 hourly intervals during the day, i.e., at 6am, 9am, 12pm, 3pm and 6pm for a duration of 30 seconds. This was done with a 3 hourly separation as it allows for the emitted material to leave the modelling domain before the next modelled event to occur.

[5] *Aviation Emissions and Air Quality Handbook Version 3 Update 1, Federal Aviation Administration Office of Environment and Energy, https://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/media/Air_Quality_Handbook_Appendices.pdf*

By adopting a 3-hour schedule for modelling launches, there will be a potential for overestimating 8 hour statistics. This is due to the potential for multiple launches result being stacked. This potentially could increase statistics by double. The benefit of modelling launches at a 3-hour interval instead of a larger interval is that it increases the different metrological conditions that are modelled.

Table 11: Summary of Modelling Parameters

Item	**Case**					
Launch Hours	6am, 9am, 12pm, 3pm, 6pm					
Duration of Emission	30 seconds					
Modelling Time Step	30 seconds					
Segments Modelled	7					
Segment Details	Segment	Elevation Band	Centre (UTM 55S)		Mass Emitted	
			X (m)	Y (m)	CO_2 (kg)	CO (kg)
	1	0m – 200m	616438	7792744	756	9
	2	200m – 400m	616438	7792746	276	3
	3	400m -600m	616439	7792747	202	2
	4	600m – 1000m	616446	7792753	259	3
	5	1,000m – 2,000m	616537	7792803	593	7
	6	2,000m – 3,000m	616787	7792931	382	5
	7	3,000m – 4,000m	617137	7793100	296	4

7.3 Modelling Results

The calculated air quality concentrations described in Section 7.2.2 were included in the Calpuff model at the appropriate locations. The likely levels due to rocket launches at each nearby sensitive receptor have been determined and these are shown in Table 12 for the case described in Table 11.

The calculated gas contours (excluding backgrounds) are contained in Appendix B

Table 12: Predicted Concentrations for Sensitive Receptors (including assumed ambient levels)

Receptor		Calculated Level at Sensitive Receptors				
	Carbon Monoxide 30s Maximum	Carbon Monoxide 1 Hour	Carbon Monoxide 8 Hour	Carbon Dioxide 30 Second Maximum	Carbon Dioxide 15 Minute	Carbon Dioxide 1 Hour
Limit		**31.240**	**11**	**72,000**	**54,000**	**9,000**
Existing Ambient		**4.5**	**1.4**		**-**	**955**
Quarry Office	0.633	0.026	0.003	52.1		2.2
Creek	1.093	0.037	0.005	90.0		3.0
Beach	0.232	0.010	0.001	19.1		0.8
Dwelling Dry Creek Road	0.051	0.005	0.001	4.2		0.4
Dwelling 1 Euri Creek	0.123	0.005	0.001	10.1		0.4
Dwelling 2 Euri Creek	0.142	0.006	0.001	11.7		0.5
Dwelling 3 Euri Creek	0.116	0.005	0.001	9.5		0.4
Dwelling 4 Euri Creek	0.108	0.006	0.001	8.9		0.5
Dwelling 337 Dry Creek Road	0.055	0.003	0.000	4.5		0.3
Koonandah Station	0.117	0.021	0.003	9.7		1.7
Dry Creek Community	0.009	0.001	0.000	0.7		0.1
Abbot Point	0.093	0.007	0.001	7.6		0.5

7.4 Air Quality Assessment

The predicted ground level concentrations at nearby sensitive areas have been modelled and Section 7.2. The ground level predictions were made at all sensitive locations and the contours cover adjacent land.

8 Conclusions

This report provides the results of an investigation of:

- The likely existing environmental values;
- Identification of appropriate noise, vibration and air quality goals and objectives;
- Results of noise and air quality, modelling; and,
- An assessment the acceptability of the use

Definitions