APPENDIX B3:

VIBRATION IMPACT ASSESSMENT

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Vibration Impact Assessment for the uMkhomazi Water Project Phase 1 – Raw Water

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Prepared for

Nemai Consulting CC

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EXECUTIVE SUMMARY

As part of the effort to meet the growing demand for water in the Kwa-Zulu Natal (KZN) Province, the proposed uMkhomazi Water Project Phase 1 (uMWP-1) is earmarked to transfer water from the uMkhomazi River Catchment to the existing Mgeni System. Due to the presence of the critically endangered (in South Africa) Blue Swallow species, a Ground-borne Vibration Assessment was undertaken as part of the Environmental Impact Assessment (EIA) for the proposed uMWP-1.

This Ground-borne Vibration Impact Assessment involved a desktop study of the area to ascertain the local ground composition and envisaged construction sites. This information was used to generate models that were used to project expected levels of ground-borne vibration. Furthermore, conservative thresholds were generated by quantifying vibration thresholds that the Blue Swallows are expected to accept without disturbance. This was based on personal communication with the Avifaunal Specialist, Mr. David Allan, by quantifying the vibrations levels that they are typically exposed to. These levels were compared against the expected ground vibration levels of blasting, tunnelling and general construction works. In addition, the background vibrations levels present near known Blue Swallow nesting sites were measured and reported according the ISO (International Standards Organisation) 4866:2010 Standard.

In this Ground-borne Vibration Impact Assessment, assumptions were made regarding the ground composition (soft soil). Typical construction machines present on site are assumed to be Vibratory rollers, Breaker Excavators, Haul trucks, Jackhammers and Bulldozers. Controlled blasting practices are assumed to be applicable during all construction activities, including tunnel inlet and outlet construction.

It is expected that if blasting, tunnelling and general construction are performed during the time when the Blue Swallows are present, a moderate to severe impact on the Blue Swallow population is expected. This is primarily due to blasting induced ground-borne vibrations (at the tunnel outlet portals and Borrow Pit A) exceeding the vibration thresholds in large region of Blue Swallow habitat, which contains a current active nest, but may also affect future nests built in the area. A smaller area of the habitat is affected by ground-borne vibrations exceeding the threshold during tunnelling and general construction activities.

As such, it is reccomended that blasting and tunneling at the tunnel outlet portals are scheduled while the Blue Swallows are on migration, as this will minimise the Blue Swallows' exposure to severe ground vibrations. In addition, careful blast design (including much reduced charge) may also assist in mitigating the effects of the blasts, as well employing non-explosive rock breaking techniques. Increased material extraction and stockpiling while the Blue Swallows are on migration, would also allow the blasting at Borrow Pit A to be ceased while the Blue Swallows are present. Tunnel Alignment Options B or C are slighly favoured in assessment, due to a slightly decreased ground vibration impact on Blue Swallow habitat Finally, a Ground-borne Vibration Monitoring Program is advised to more accurately characterise the vibration attenuation aspects of the soil. If the assumed soil constants are significantly different, scheduling may be affected (either positively or negatively).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Definition
DEA	Department of Environmental Affairs
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
FRA	Federal Railroad Administration
ICP	Integrated Circuit Piezoelectric
ISO	International Standards Organisation
KZN	KwaZulu-Natal
NEMA	National Environmental Management Act
NRF	National Research Foundation
PPV	Peak Particle Velocity
RI	Report of Investigation
SANS	South African National Standards
TBM	Tunnel Boring Machine
uMWP-1	uMkhomazi Water Project Phase 1 project
USBM	United States Bureau of Mines
WSS	Water Supply System

LIST OF UNITS

Unit	Definition
ft	feet
g	Acceleration of gravity
Hz	Hertz
kg	Kilogram
kHz	Kilohertz
km	Kilometer
m	Meter
mm	Millimeter
mm/s	Millimeter per second
mm/s^2	Millimeter per second squared
ms	Millisecond
mV/g	Millivolt per g

REPORT LAYOUT

The layout of this Specialist Report with regard to **Appendix 6** of the **EIA Regulations (2014)** is summarised in **Table (i)** below:

Table (i): Specialist Report Requirements in terms of Appendix 6 of the EIA Regulations (2014)

A Specialist Report prepared in terms of the Environmental Impact Regulations of 4 December 2014 must contain:	Relevant section in the Report
Details of the specialist who prepared the report	Appendix D
The expertise of that person to compile a specialist report including a Curriculum Vitae (CV).	Appendix D
A declaration that the person is independent in a form as may be specified by the competent authority.	Appendix E
An indication of the scope of, and the purpose for which, the report was prepared	Section 1
The date and season of the site investigation and the relevance of the season to the outcomes of the assessment	Sub-section 3.5
A description of the methodology adopted in preparing the report or carrying out the specialised process.	Section 4
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure.	Section 5
An identification of any areas to be avoided, including buffers.	Not applicable
A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers.	Section 5 & 8
A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 3
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment.	Sections 8
Any mitigation measures for inclusion in the Environmental Management Programme (EMPr).	Sub-section 10.1
Any conditions for inclusion in the Environmental Authorisation	Section 11
Any monitoring requirements for inclusion in the EMPr or Environmental Authorisation.	Sub-section 10.2
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised	Section 11
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that	Section 10

A Specialist Report prepared in terms of the Environmental Impact Regulations of 4 December 2014 must contain:	**Relevant section in the Report**
should be included in the EMPr, and where applicable, the Closure Plan.	
A description of any consultation process that was undertaken during the course of undertaking the study.	Appendix A
A summary and copies if any comments that were received during any consultation process.	Not applicable
Any other information requested by the competent authority.	None requested

1. INTRODUCTION AND SCOPE

In order to meet the long-term water supply requirements of the Integrated Mgeni Water Supply System (WSS) in KwaZulu-Natal (KZN), the uMkhomazi Water Project Phase 1 (uMWP-1), referred to as the Project hereafter, is earmarked to augment the existing Mgeni WSS. Following the Department of Environmental Affairs' (DEA's) review of the Final Environmental Impact Assessment (EIA) Report for uMWP-1 Raw Water, the DEA requested more information pertaining to the effects of noise and vibration on the endangered Blue Swallows, due to construction in the area.

The project area is situated in the southern part of KZN, primarily within the uMgungundlovu District Municipality. As such, the project area is situated in a region of high avifaunal sensitivity. The Blue Swallows in particular, are of high concern in the area due to the few breeding pairs left. Therefore, before construction work can commence on the Project, the expected ground vibration (ground-borne noise) needs to be characterised and assessed according to allowable limits pertaining to its effect on the Blue Swallow population. The following are discussed in this Report:

- Key sensitive receptors.
- Results from local background vibration measurements.
- Quantitative estimation of expected ground-borne vibration impacts resulting from the use of Tunnel Boring Machines (TBMs), construction and blasting.
- Suggested vibration thresholds.
- Assessment of the projected ground-borne vibration levels with regard to the suggested vibration thresholds.
- A reccomendation for proposed mitigation measures.
- A recommendation for a Monitoring Program.

2. REGULATORY AND LEGAL FRAMEWORK

In the scientific and engineering literature, investigations have been undertaken that deals with human comfort and structural damage to buildings. The most well-known is the United States Bureau of Mines (USBM) RI 8507 Standard by Siskind, D.E., Stagg, M.S. Kopp, J.W and Dowding, C.H (1980), which deals with ground vibrations due to blasting and the effect thereof on human comfort and damage to buildings.

The above-mentioned USBM Standard is, however, not suitable for steady state ground-borne vibrations, as typically encountered in construction related vibrations, due to the fact that it is based on blasting events. As blasting events are impulsive in nature, they elicit a different dynamic response than steady state vibrations and therefore cannot be compared.

For steady state ground-borne vibrations, the Federal Railroad Administration (FRA) provides a comprehensive standard relating to construction vibration (FRA, 2012). Although the bulk of this document is aimed at high speed rail transport impact assessment, it contains information pertaining to construction vibration that is applicable to generic construction work. In the 2012 edition of this standard (the latest, at the time of this report), the relevant section is Chapter 10.

Quantitative information in the scientific literature is extremely scarce on how birdlife is affected by ground-borne vibrations. This lack of verifiable information is compounded by the large of number of variables, including duration of vibration, character of vibration (steady state, or transient) and bird response to vibration (abandoning the nest, temporary fly away, habituation).

South Africa does not have legislation which limits ground vibration levels (e.g. SANS), nor are there any international standards that limit ground vibrations. Against this background, this Vibration Impact Assessment was undertaken against international best practice, rather than South African legislation. Therefore, there has been heavily drawn upon empirical research results produced by the USBM, the FRA, and other research documented in the open- and scientific literature.

This Report complies with the requirements of the National Environmental Management Act (NEMA) 107 of 1998 and the EIA Regulations of 2014 (GNR 982 of 2014). A summary of the NEMA requirements, with cross references to the relevant sections in this Report where these requirements have been addressed, is given in **Table (i)** above.

3. ASSUMPTIONS AND CONSIDERATIONS

3.1. Ground Composition

The ground composition has an effect on the vibration propagation characteristics due to disturbances such as blasting and tunnelling. The soil composition is known to consist primarily of soft soil types (shale and diamictite), therefore the soil constants are assumed to be that of soft rock. This aspect is discussed in more detail in **Sub-Sections 7.1** and **7.3** below, where it relates to blasting and tunnelling.

3.2. Construction Ground Vibration Projections

A number of different construction machines are considered. Although various types and sizes of machinery are available, the values described in **Sub-Section 7.2** below are assumed to be representative.

3.3. Blasting

The ground vibration projections for the purposes of this assessment are based on controlled blasting practices.

3.4. Tunnelling Ground Vibration Projections

Several empirical studies have been undertaken to determine the relationship between ground vibrations and tunnelling operations. According to Hiller (2011), the primary variables in these studies were rock type and distance from the TBM. For the purposes of this assessment the intermediate soil constant was used (as opposed to very hard and very soft), due to the fact that the ground type is known to be of the softer type,.

3.5. Seasonal and Meteorological Impacts

Ground-borne vibrations are not generally accepted to have a measurable dependence on meteorological conditions and no references in the scientific literature could be found.

3.6. Vibration Thresholds

A very important factor in this Study is the effect of vibration on the behaviour of the Blue Swallow population in the area. It is anticipated that the following impacts are possible:

- Moderate startle response: The birds may fly off and return shortly afterwards. No harm is done to the breeding.
- Severe startle response: The birds may fly off and abandon the nest and breeding fails.
- Steady state vibrations severe enough to cause the birds to leave the area.
- Steady state vibrations sufficient to cause enough nest damage to risk the nest falling off the ceilings of holes in the ground (such as Aardvark holes or man-made holes).
- Habituation: The birds get used to the vibration and they are not harmed.

In the scientific- and open literature, no quantitative information could be found to link any of the above-mentioned hypothetical impacts to a quantitative vibration value, and therefore the following inferences can be made:

- The highest steady state background vibration observed in the Blue Swallow habitat is an acceptable level of vibration, due to the fact that these birds have not left the area and have habituated to this level.
- The highest peak vibration level measured was less than required for the Blue Swallows to abandon their nests.
- The FRA (2012) Standard provides guidelines on continuous vibration and its effect on buildings. The weakest category (buildings highly susceptible to vibration damage) will be assumed to correspond with a vibration level that will cause damage to the nests.

If the ground-borne vibration levels, as discussed under the bullets above, are accepted as a threshold then the results will likely be inaccurate and overly conservative. The following key observations can be considered to yield a more accurate threshold (personnel communication with David Allan, see **Appendix A**):

- Breeding birds are somewhat resilient to transient disturbances, with due recognition that repeated transient disturbances (ground vibration resulting from nearby blasting) may disturb them enough to permanently abandon their nest;
- In Tanzania, Blue Swallows nest under bridges and road culverts, although this hasn't been observed in South Africa;
- Blue Swallow Nest 5, which was shown to avifaunal specialist Mr. David Allan by the local Blue Swallow monitor, is located approximately 50 m away from a road with expected occasional forestry truck traffic (see **Figure 5-3** below), and
- Other swallow species in South Africa regularly nests underneath bridges and culverts.

The most conservative approach is that the highest measured steady state level should not be exceeded, since this level has been observed near current Blue Swallow nests. However, the measured vibration levels on which this threshold is based, are extremely low due to the fact that there is no major human activity in the vicinity of the measurement sites and merely represents the naturally occurring ground vibration levels. Therefore, this threshold may be overly conservative as the Blue Swallows might be tolerant to higher levels of ground vibration.

Based on the fact that a Blue Swallow nest was found 50 m from a road for forestry purposes, it is possible to make a comparison with the expected vibration from trucks at this distance. **Figure** 7-2 in **Section 7.2** below suggests that a haul truck at 50 m from a nest would induce 0.1 mm/s Peak Particle Velocity (PPV) at the nest, which is suggested to be a safe and conservative threshold. This suggested threshold would then apply to tunnelling and construction vibration.

The same reasoning as above is applied to the maximum impulse vibration. The highest measured instantaneous background ground-borne vibration can safely be assumed to be acceptable to the Blue Swallows in terms of startle response. However, it must be noted that the on-site experiences of the Measurement Team indicate that no major shocks were felt, certainly not high enough to elicit a startle response of any birds.

However, it has been ascertained by personal communication with Avifaunal Specialist David Allan (see **Appendix A)**, that Blue Swallows generally tend to be more tolerant of impulsive vibrations and disturbances than steady state vibrations and disturbances, as illustrated by the birds nesting under bridges and culverts. The impulsive vibration on the bridge structure as a vehicle passes over the bridge, (due to the slightly different height of the road surface on the bridge and the road surface on the surrounding terrain), can be considered a safe threshold, as the Blue Swallows are known to nest in this environment. For this purpose, a representative bridge was instrumented, and the impulsive vibrations measured on the structure (see **Appendix C**).

The impulsive vibrations on the bridge were, however, found to be slightly lower than those during field measurements. Therefore, the maximum impulsive ambient vibrations are to accepted to represent a reasonable threshold.

In the steady state vibration threshold for nest damage, the FRA (2012) Guidelines for building damage were used (detailed in **Table 7-5** in below). The most severe category – buildings extremely susceptible to vibration damage – was used: representing 3 mm/s. To obtain an intuitive feeling for this level of vibration, it compares with vibrations in lower threshold of being “Disturbing to humans” (Afeni and Osasan, 2009), see **Table 7-2** below.

4. TESTING METHODOLOGY

4.1. Protocol

The measurement protocol followed the procedures and requirements of the International Standards Organisation (ISO) 4866:2010 Standard, which involved the following:

The background ground vibration measurements involved driving a 300 mm stake with a metal base at one end into the ground until the base was flush with the ground. This was done to maximise vibration transmissibility to the vibration transducers.

The transducers used were 1000 mV/g Integrated Circuit Piezoelectric (ICP) seismic accelerometers, mounted tri-axially. These, in turn, was fixed to the metal base of the abovementioned 300 mm stake by means of a screw that fastend the mounting block to the stake. The data was logged by means of a Coco-80 Data Logger, which recorded a time history of the ground vibrations, as measured by the seismic accelerometers.

Once the instrumentation was set up, the measurement was initiated and continued for a total of thirty (30) minutes. During that time, the Measurement Team moved away from the measurement location (at least 100 m) and remained there with as little movement as possible so as to get a representative background vibration measurement.

Three (3) measurements were taken at each measurement location. As close as practicable, these measurements were taken in the morning, afternoon and early evening, in order to ascertain whether the background vibrations vary as a function of the time of day.

The sections of data that contained the vibrations caused by the Measurement Team (such as footsteps and vehicle movement) were cut from the recorded data in post-processing. Therefore, only the ambient vibrations were used in this Study.

The acceleration data recorded was converted from units of ‘g’ (acceleration of gravity) to units of mm/s^2 and then numerically integrated with respect to time to obtain velocity vibration in units of mm/s.

4.2. Test Setup

Figure 4-1 and **Figure 4-2** below represents photos of the test setup used during the field measurements for this project. The legend for the numbered items in these photos is given in **Table** 4-1 below.

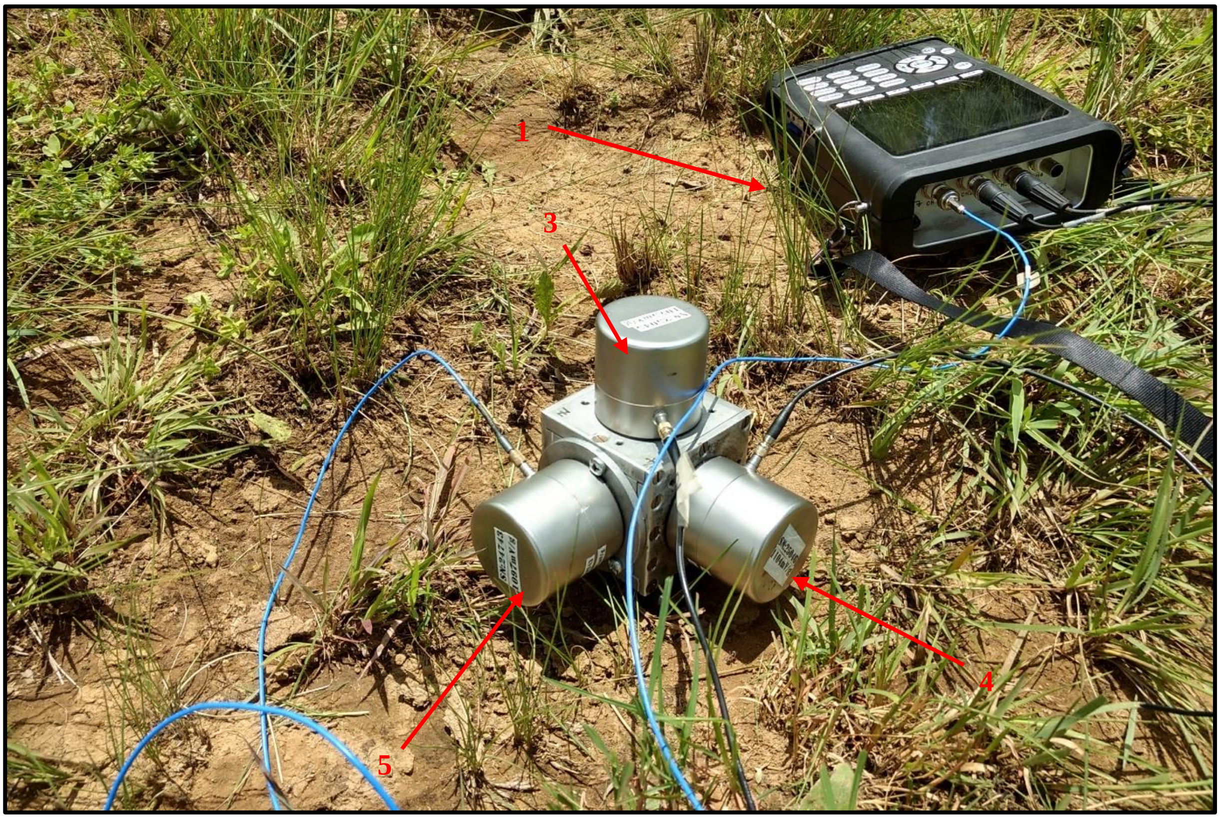


Figure 4-1: Illustration of the test setup including seismic accelerometers and Svantec Data Logger

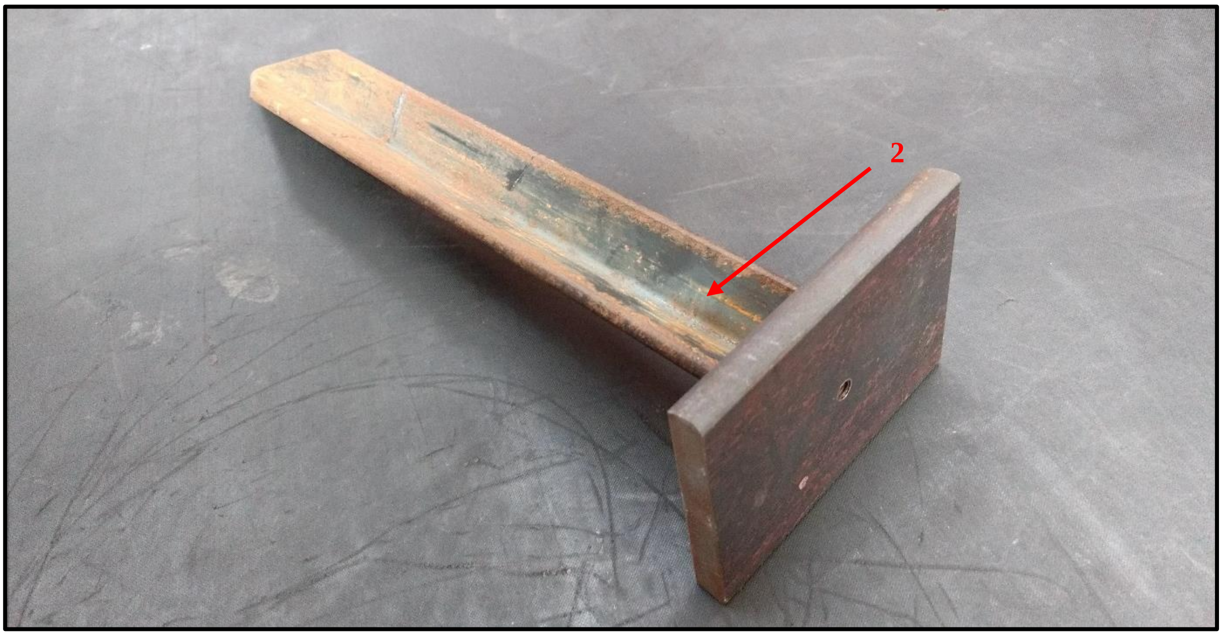


Figure 4-2: The 300 mm Stake

Table 4-1: Equipment used for the Ground Vibrations Measurements

No.	Item	Serial Number	Details
1	Coco-80 logger	33826	Resolution: 24 bit Sampling frequency: 2.0 kHz
2	Stake		300 mm penetration
3	Seismic accelerometer (V)	SN 24743	1097 mV/g
4	Seismic accelerometer (H)	SN 25046	1104 mV/g
5	Seismic accelerometer (H)	SN 25045	1075 mV/g

4.3. Derivation of Peak Particle Velocity Values

$$V(i)_{mag} = \sqrt{V(i)_x^2 + V(i)_y^2 + V(i)_z^2}$$ **Equation 1**

$$PPV = \max\left(V(i)_{mag\ steady\ state}\right)$$ **Equation 2**

$$PPV = \max\left(V(i)_{mag\ impulse}\right)$$ **Equation 3**

Where $V(i)_{x,y,z}$ represents the measured, discrete, velocity signals in the x (horizontal 1), y (horizontal 2) and z (vertical) directions at instant *i*. The result of Equation 1, $V(i)_{mag}$, represents the magnitude of the velocity ground vibrations at the measurement location at instant *i*. The PPV represents the maximum velocity vibration magnitude measured during steady state and impulse regimes.

The velocity signals were not directly recorded, but derived from the recorded acceleration signals, as described in **Sub-section 4.1** above.

5. POTENTIAL RECEPTORS

Guidance from the Nemai Consulting pertaining to the general vicinity of the Blue Swallow nesting sites principally guided the location of the measurement locations. Mr. David Allan (avifauna specialist consultant) assisted with specific locations to ensure that no active sites were disturbed during the measurement process.

Figure 5-1 to **Figure 5-4** below illustrate where the nesting sites can be observed in relation to anticipated sources of ground-borne vibration. In these figures (maps), the green pin markers identify the measurement locations, yellow pin markers identify locations of possible blasting and red pin markers indicate active, or recently active Blue Swallow nests.

The green shaded polygons in **Figure 5-1** to **Figure 5-4**, indicate habitat suitable for blue swallows on the Baynesfield Estate, and the green outlined (no shading) polygons indicate habitat suitable for blue swallows on the Trewirgie property. The black and white squares depict nesting sites from Ezemvelo KZN Wildlife historical data and may be somewhat outdated. In addition, the Tunnel Alignment Option A is indicated with a blue line, Tunnel Alignment Option B is indicated with a green line and Tunnel Alignment Option C is indicated with a pink line. The shaded blue polygons on the eastern side of the study area indicate possible locations for the proposed balancing dams. See **Table 5-2** below for the complete legend of **Figure 5-1** to **Figure 5-4** below.

The areas affected by ground-borne vibration due to blasting, construction and tunnelling are discussed and mapped in **Sub-sections 8.1**, **8.2** and **8.3** below.

Table 5-1 below summarises the relevant details of the identitied key sensitive receptors in the project area.

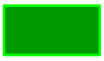
Table 5-1: Key Sensitive Receptors with Standoff Distances to the Nearest Anticipated Source of Ground-borne Vibration

Key Sensitive Receptor Location Number	Description	Distance to Boundary	Disturbance	Distance to Nearest Nest
1	North-eastern boundary of Baynesfield Blue Swallow nesting habitat	0 m	Tunnel Alignment Option A Outlet	2.5 km
2	South-eastern boundary of Baynesfield Blue Swallow nesting habitat	200 m	Tunnel Alignment Options B and C Outlet	1.7 km
3	South-eastern boundary of Baynesfield Blue Swallow nesting habitat	0 m	Borrow Area A	750 m
4	South-western boundary of Baynesfield Blue	< 50 m	Onrust Ventilation	2.5 km

Key Sensitive Receptor Location Number	Description	Distance to Boundary	Disturbance	Distance to Nearest Nest
	Swallow nesting habitat		Shaft	
5	Southern boundary of Impendle Nature Reserve Blue Swallow nesting habitat	2 100 m	R617 Deviation	3.7 km
6	Southern boundary of Impendle Blue Swallow nesting habitat	7 700 m	Tunnel Inlet Area	8.8 km

Table 5-2: Legend for Figure 5-1 to Figure 5-4

Map Object	Description
	Tunnel Alignment Option A
	Tunnel Alignment Option B
	Tunnel Alignment Option C
	Road to balancing dam (background of legend shaded for clarity)
	R617 Deviation Option 2 (preferred)
	R617 Deviation Option 3
	R617 Deviation Option 1B
	R617 Deviation Option 1A
	Baynesfield Balancing Dam (Northern balancing dam).
	Mbangwenni Balancing Dam (Central balancing dam).
	Langa Balancing Dam (Southern balancing dam).
	Smithfield Dam

Map Object	Description
	Baynesfield Estate Blue Swallow nesting habitat.
	Trewirgie Blue Swallow nesting habitat
	Blue Swallow nesting habitat expected to be exposed to ground vibrations in excess of the steady state vibration threshold.
	Blue Swallow nesting habitat expected to be exposed to ground vibrations in excess of the background vibration.
	Historical Blue Swallow nesting sites from Ezemvelo KZN Wildlife.
	Confirmed active Blue Swallow nest.
	Ground Vibration Measurement Location.
	Potential source of man-made ground vibrations.

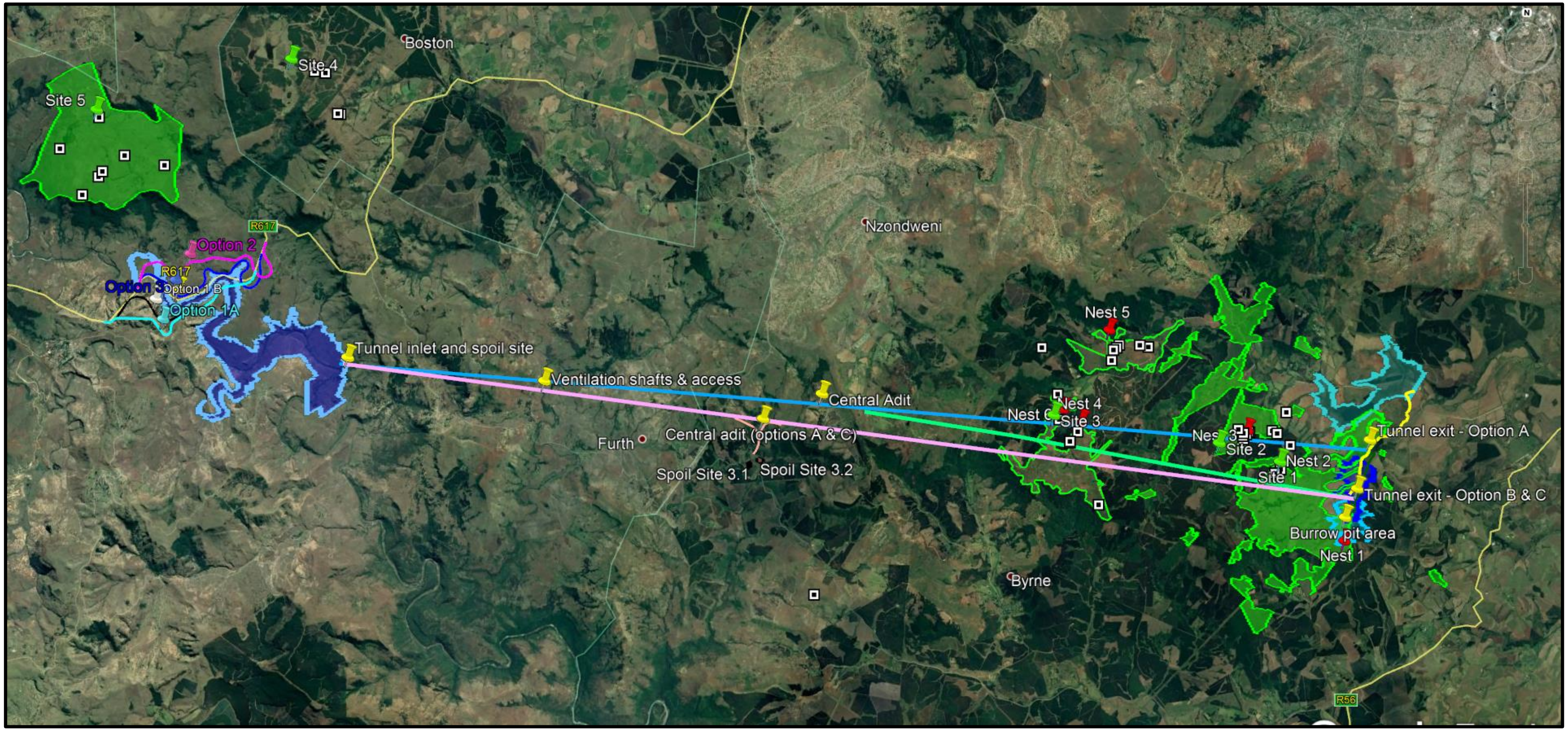


Figure 5-1: Overall Map of the Study Area

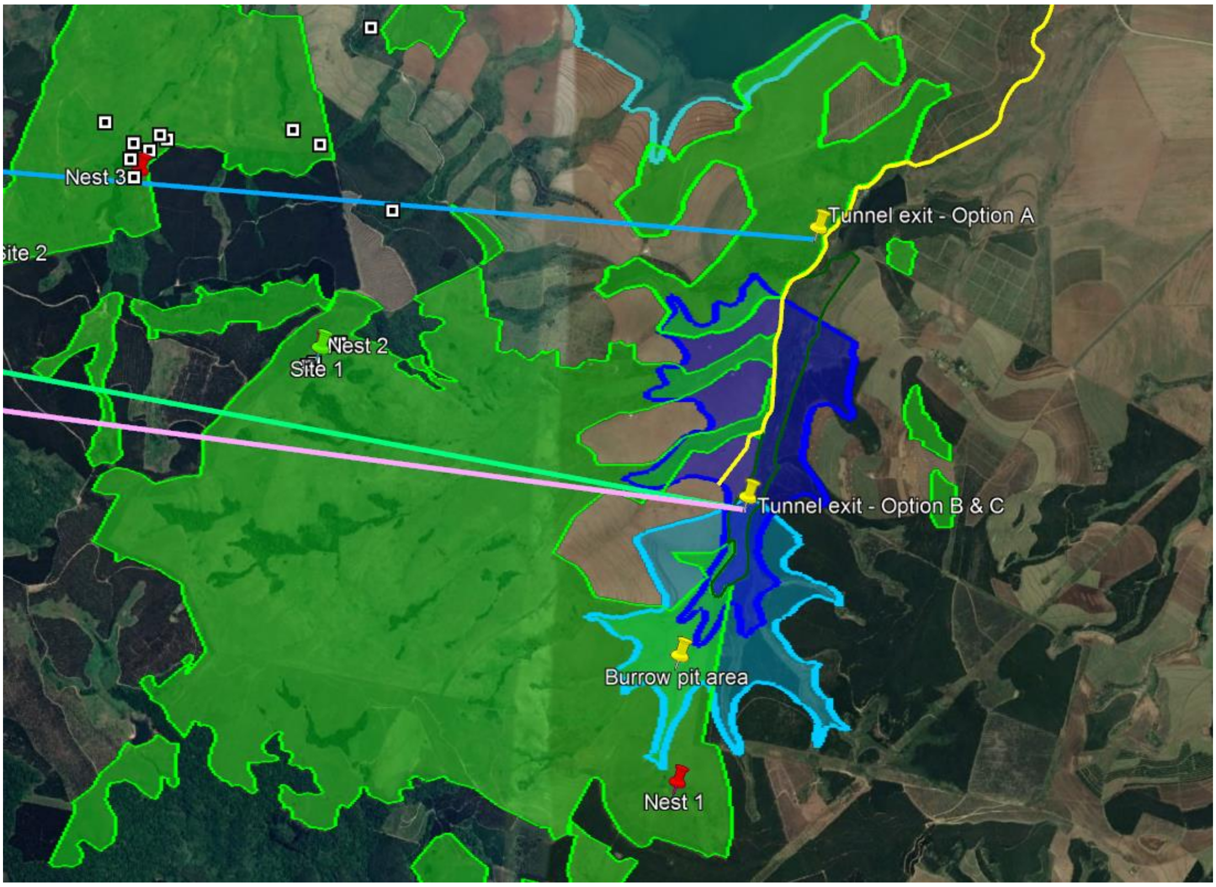


Figure 5-2: Map of the Study Area - Eastern Side

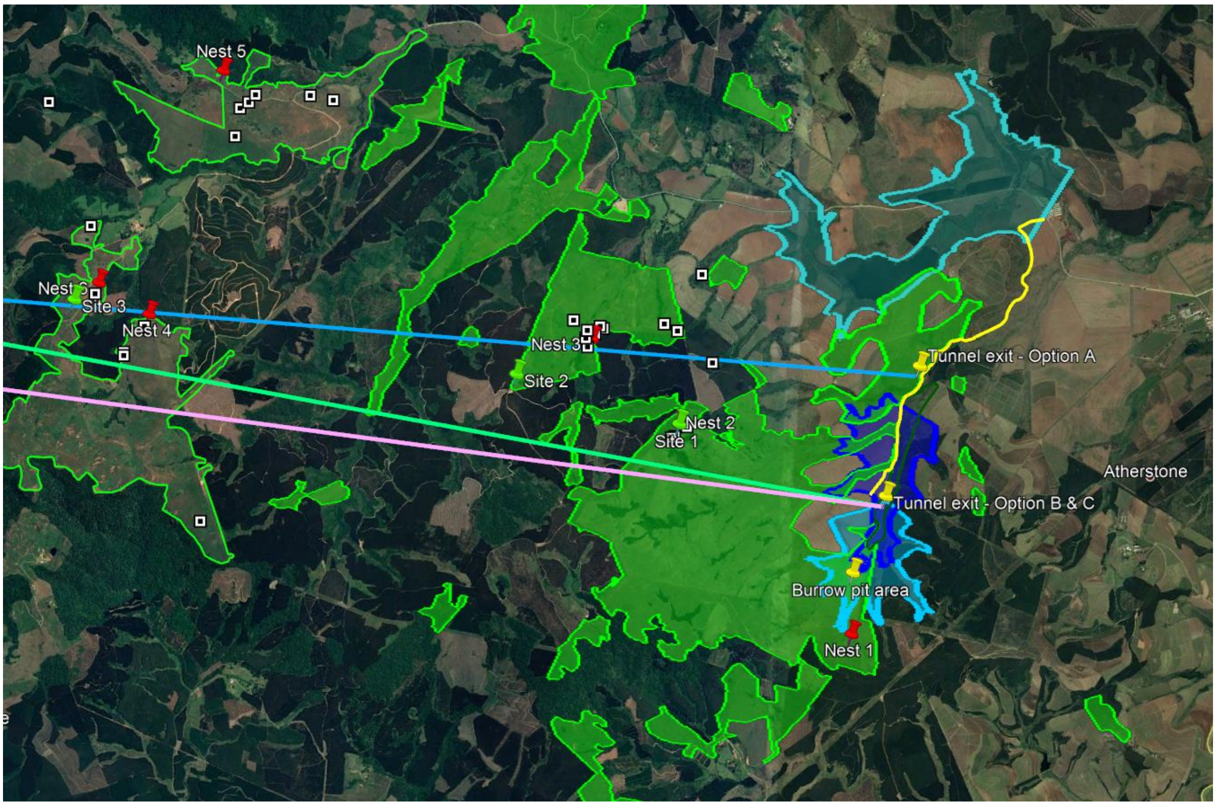


Figure 5-3: Extended Map of the Study Area - Eastern Side

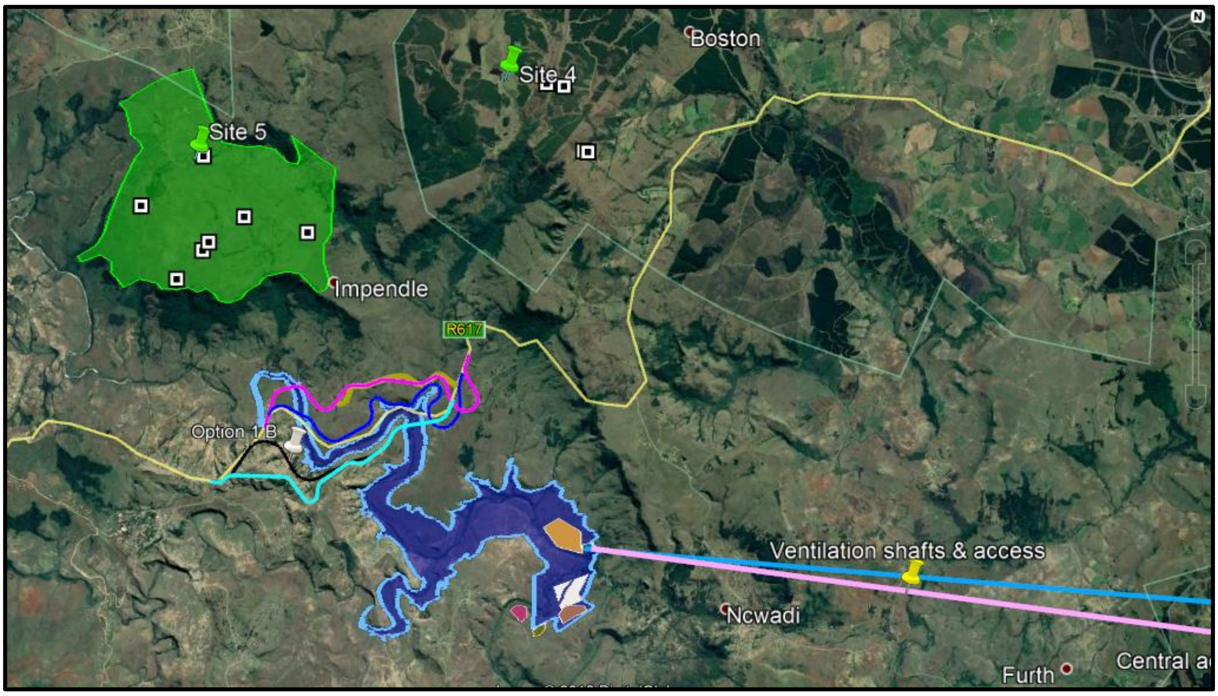


Figure 5-4: Map of the Study Area's Western Side

6. BACKGROUND VIBRATION MEASUREMENTS

Local background ground vibrations were measured at the locations described in **Section 5** above. During this time, no blasting occurred at the active quarry (to the north of Baynesfield Estate) that the measurement team was aware of. The result is therefore the ambient vibrations.

As mentioned in **Sub-section 4.1** above, it was attempted to perform three (3) measurements at each measurement location, as summarised in **Table 6-1** below. Due to the practicalities of timeframes and distances involved, only two (2) measurements were taken at Measurement Location 4. It was therefore decided to extend the final measurement to forty five (45) minutes at Measurement Location 4. This final measurement was timed to coincide with he general transition time between afternoon and evening (15:45 - 16:30).

The processed, time dependent, results, as obtained from **Equation 1** to **Equation 3**, above are provided in **Figure 6-1** to **Figure 6-5** below. From this data array, two parameters were extracted for each measurement run: The maximum impulsive peak value and the maximum steady value. The impulsive peak value is simply the maximum PPV in the data series, while the 95th percentile of the PPV in the data series was found to correspond well with a steady-state maximum value. This level is also illustrated in **Figure 6-1** to **Figure 6-5** below.

Table 6-1: Background Vibration Measurement Locations

Measurement Location Number	Description	Coordinates [D° M' S"]
1	Baynesfield Site 1 (Western nesting habitat border)	29˚46'53.8"S 30°16'20.6"E
2	Baynesfield Site 2 (Eastern nesting habitat border)	29°46'37.4"S 30°15'04.5"E
3	Trewirgie (Western nesting habitat border)	29°46'17.0"S 30°11'39.0"E
4	Mount Shannon (Southern nesting habitat border)	29°40'39.4"S 29°55'38.9"E
5	Impendle Nature Reserve (Southern nesting habitat border)	29°41'43.9"S 29°51'42.2"E

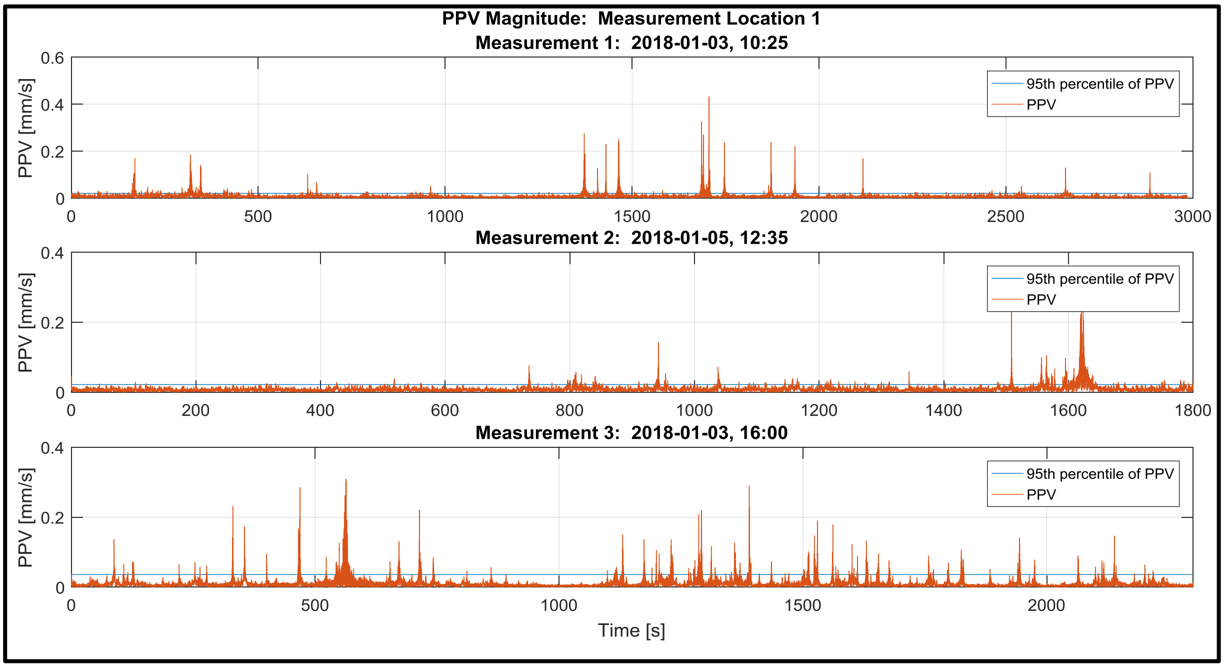


Figure 6-1: PPV Magnitude as a Function of Time for Measurement Location 1

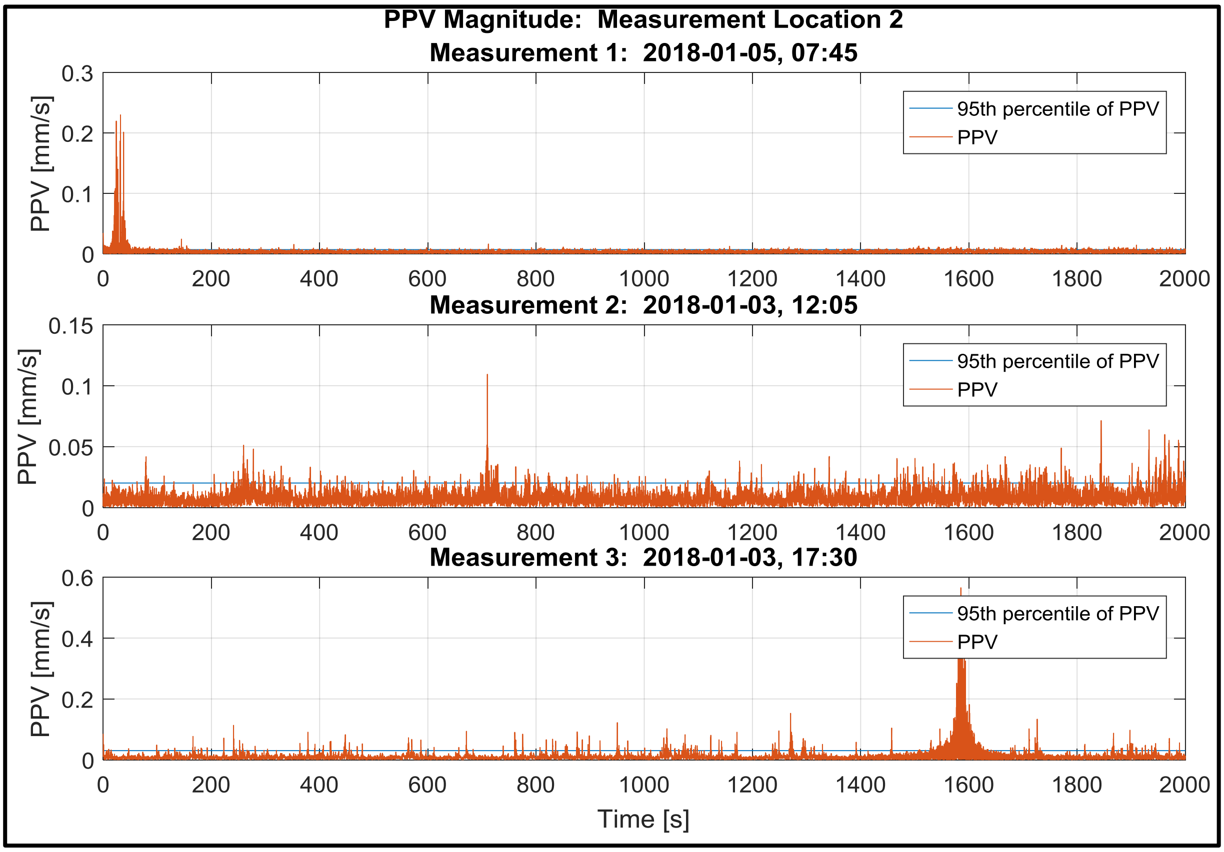


Figure 6-2: PPV Magnitude as a Function of Time for Measurement Location 2

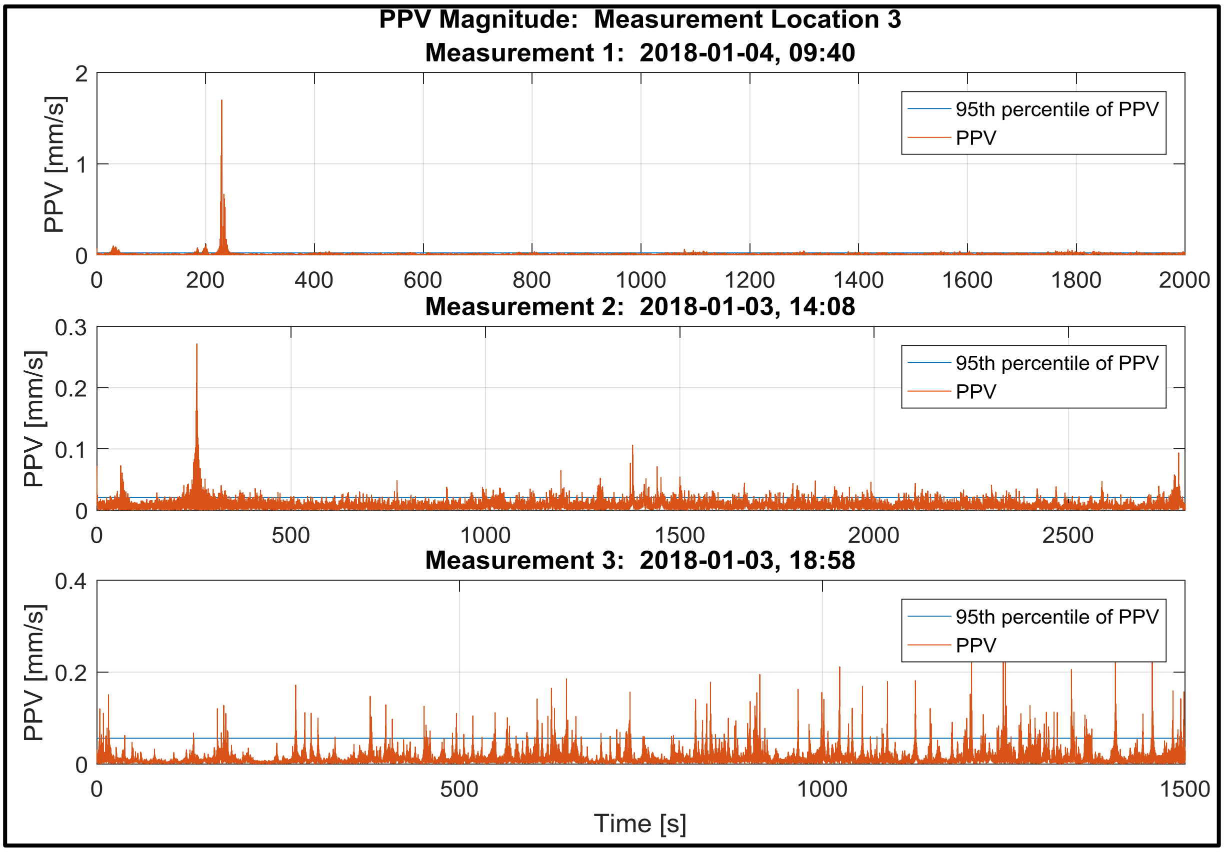


Figure 6-3: PPV Magnitude as a Function of Time for Measurement Location 3

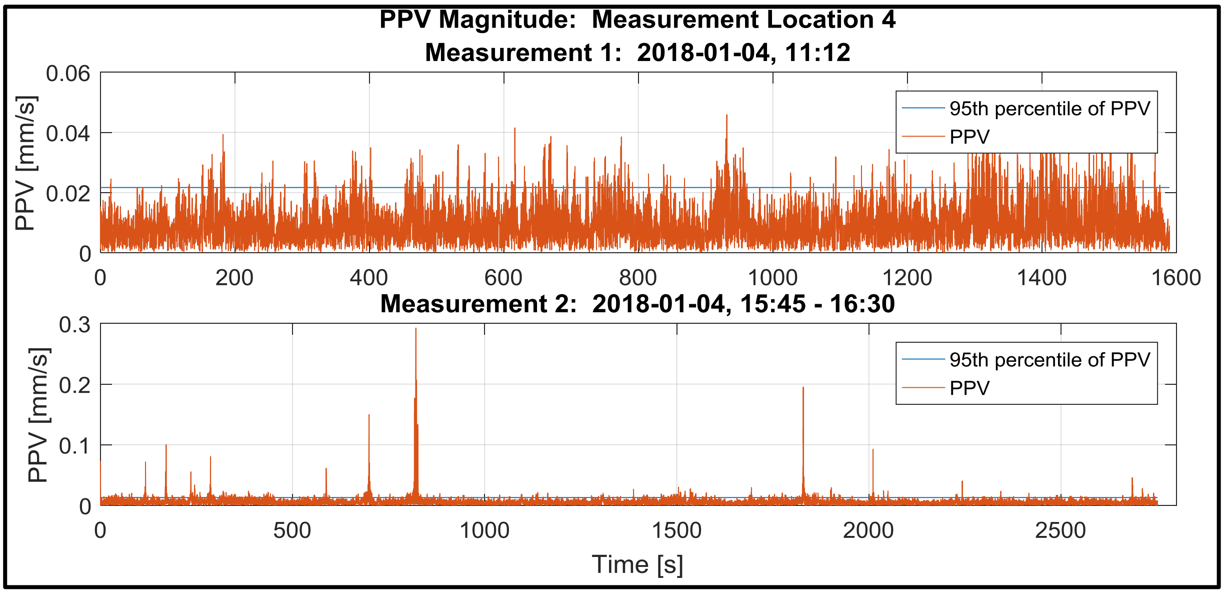


Figure 6-4: PPV Magnitude as a Function of Time for Measurement Location 4

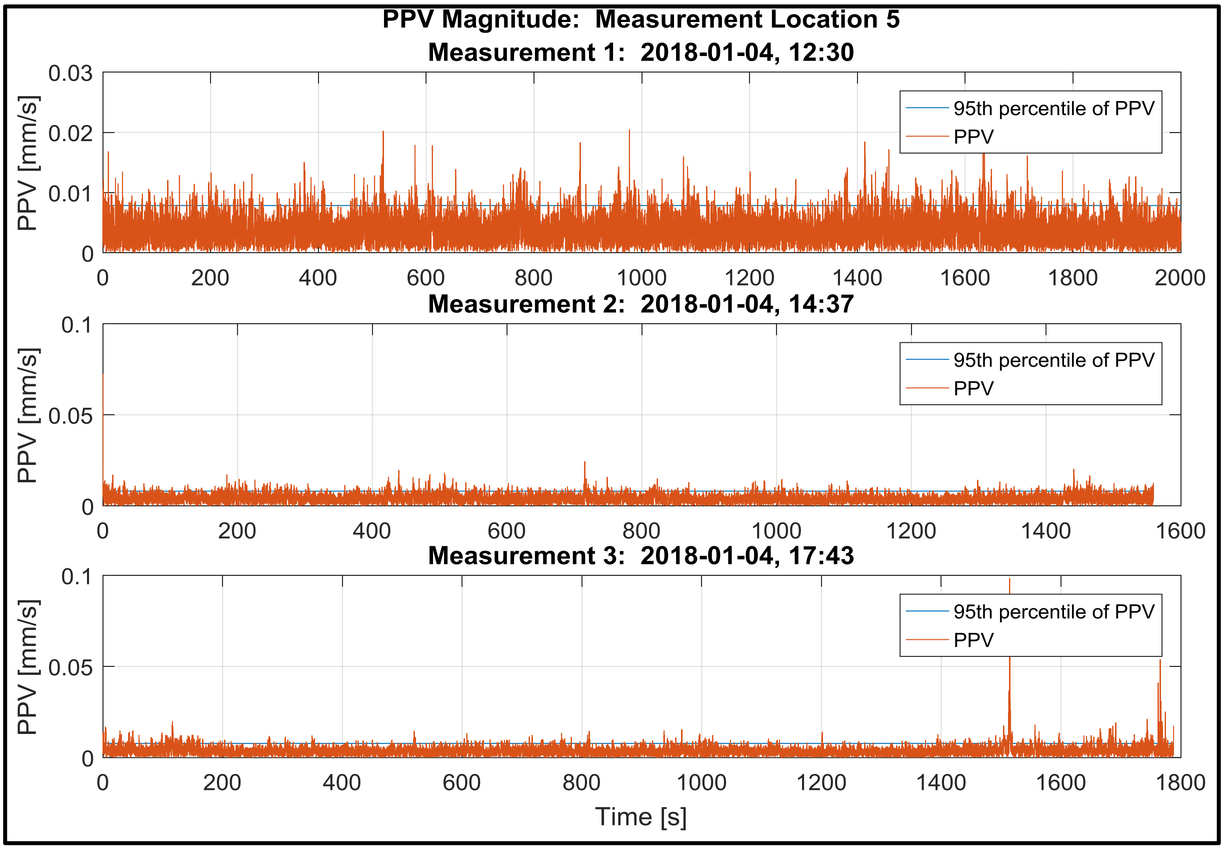


Figure 6-5: PPV Magnitude as a Function of Time for Measurement Location 5

A summary of the results is given in **Table 6-2** below, with maximums of impulsive and steady-state vibrations highlighted. A maximum impulsive value of 1.70 mm/s was measured at Trewirgie (Measurement Location 3) during the first measurement exercise, which seems excessively high. Therefore, the second highest measured impulsive vibration value was taken (0.57 mm/s at Measurement Location 3 of the Baynesfield Estate Site 2).

Table 6-2: Summary of SteadyState and Impulsive PPV Vibrations

Measurement Location	Measurement 1 [mm/s]		Measurement 2 [mm/s]		Measurement 3 [mm/s]	
	St. State	Impulse	St. State	Impulse	St. State	Impulse
1	0.020	0.43	0.022	0.32	0.036	0.31
2	0.0068	0.23	0.020	0.11	0.030	0.**57**
3	0.022	1.70	0.021	0.27	**0.056**	0.31
4	0.022	0.052	0.013	0.29	0.013	0.29
5	0.0079	0.020	0.0081	0.024	0.0078	0.098

See **Appendix B** for photographs taken at the measurement locations, vibration "time-histories" and vibration spectra observed during the measurement exercise.

7. ENVIRONMENTAL IMPACT MECHANISMS

7.1. Ground Vibration due to Blasting

When explosives are detonated in a hole, it generates shock waves that crush the material around the hole and creates many of the initial cracks required for fragmentation. As this wave travels outward, it becomes a seismic or vibration wave which causes the ground to vibrate. Excessively high ground vibration levels can damage structures, but even moderate to low levels can be irritating and cause claims of damage and nuisance.

Excessive vibrations can be caused by either introducing too much explosive energy into the ground, or by improper design of the blast. The vibration level at a specific location is primarily determined by the maximum mass of the explosive charge that is used in any delay period, and the distance of that location from the blast. A delay of 8 to 9 ms (milliseconds) is usually regarded as the minimum delay between charges, to be considered as separate charges for vibration estimation purposes. Two further factors may also influence the level of ground vibration, namely over-confinement which usually implies excessive burden or excessive sub-drilling. Delays which proceed in sequence along a row, may also cause higher vibrations in that direction (Dick, Fletcher and D'Andrea, 1983). Vibration levels are very intimately related to the precise blast design and in particular also the delays between the detonations of the charges.

Ground vibration levels are usually characterised in terms of PPV (refer **Sub-section 4.3** above). PPV refers to the maximum amplitude associated with the motion of a particle at the point in the ground which is being considered. Velocity is usually considered because it is best correlated with historical data of damage occurrence, since strain induced in ground is proportional to particle velocity. This strain is because of distortion as well as inertial effects.

The PPV is usually related to the mass of the explosive charge and the distance to the point of observation. There are numerous empirical relationships, all with a number of empirical site constants, which could be determined through systematic blast tests and subsequent multiple regression analysis. Kujur (2010) provides a useful overview of many of these relationships.

Unless there is prior knowledge of the site constants, the basic problem is to find constants that could be regarded as representative of the condition for which the investigation needs to be undertaken. For this Study such constants are not available, and the results that were obtained during a comprehensive set of experiments on a large range of mines, ranging from coal, limestone and iron ore to hard rock mines were used. These experiments were conducted by the National Institute of Rock Mechanics in India (2005).

In the above-mentioned report, PPV is modelled as a function of distance from the blast, blast charge and soil constant (note that in the original text of the above-mentioned reference, there is a typing mistake and the exponent is typed as *b* instead of -*b*):

$$PPV = K\left(\frac{D}{\sqrt{Q}}\right)^{-b}$$ **Equation 4**

In **Equation 4** above, *K* represents the site and rock factor constant, and *Q* represents the maximum instantaneous charge per delay [kg]. The constant *b* is related to the rock and site. *D* is the distance from the charge [m] and $D/\sqrt{Q}$ is referred to as the scaled distance.

Full details of *K* and *b* values are tabulated in Table 2.1 in the National Institute of Rock Mechanics (2005) Report. The site constants expected for the path of vibration propagation are summarised in **Table 7-1** below.

Table 7-1: Typical Site Constants for Soft Rock Environments

Industry	K	b
Limestone	320.89	1.3

The estimated vibration levels must be assessed against accepted criteria. With regard to the Blue Swallows, a conservative threshold for blasting is the maximum impulsive vibrations observed during the measurement campaign, specifically 0.57 mm/s (see **Table 6-2** above), as this vibration value is present in the Blue Swallow habitat. As described in **Sub-section 3.6** above, this level was decided upon based on follow-up vibration measurements performed on a representative bridge (as may be chosen by the Blue Swallows as a nesting location, see **Appendix C**).Table 7-3 below summarise the effects of ground-borne vibration on structures as well as human comfort. From these tables it is clear that humans will find the ground-borne vibration disturbing (2.5to 7.6 mm/s) before structural damage might be expected (in this case probably around 12.5 mm/s or less). However, the levels at which people start to complain about blasting vibrations vary considerably.

Table 7-2: Perceptible Ground Vibration as Reported by the USBM
(truncated after adapted by Afeni and Osasan (2009) from Siskind, Stagg, Kopp and Dowding (1980))

Effects on Humans	Ground Vibration Levels [mm/s]
Imperceptible	0.03 – 0.08
Barely perceptible	0.08 – 0.25
Distinctly perceptible	0.25 – 0.80
Strongly perceptible	0.80 – 2.5
Disturbing	2.5 – 7.6
Very disturbing	7.6 – 25.0

Table 7-3: Safe Levels of Blasting Vibrations for Residential Type Structures (Siskind, Stagg, Kopp and Dowding, 1980)

Type of Structure	Ground Vibration (PPV mm/s)	
	(<40 Hz)	(>40 Hz)
Modern homes	19.0	51
Older homes, plaster on wood lath construction	12.5	51

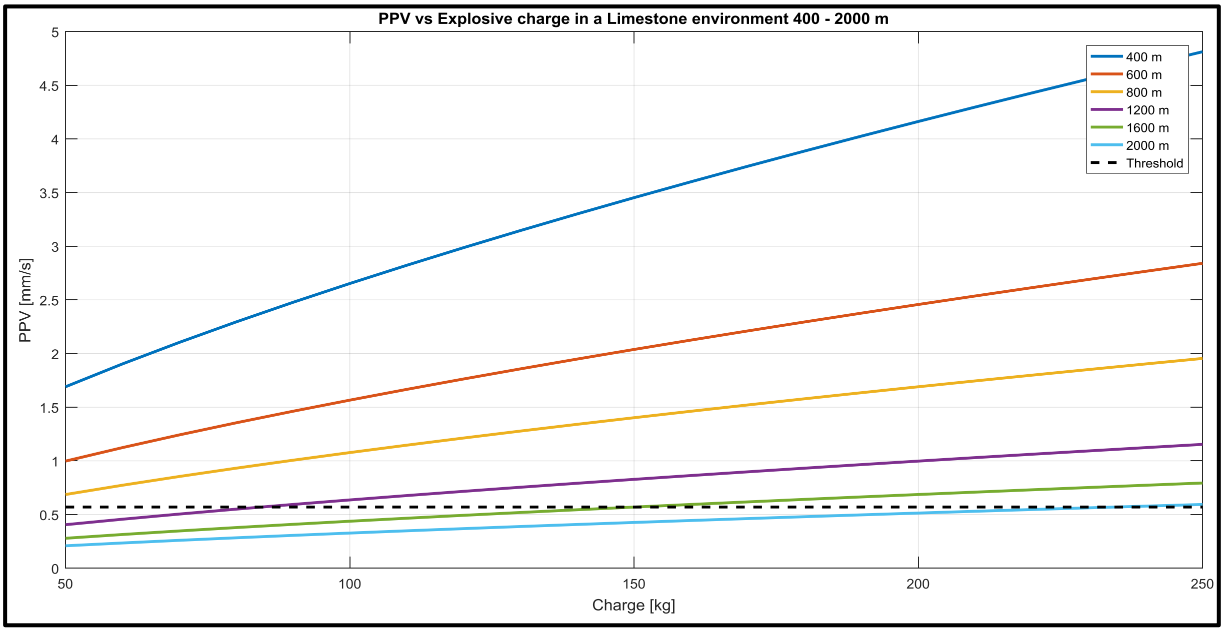


Figure 7-1: Estimated PPV as Function of Explosive Charge for 400 m – 2 km Distances

Figure 7-1 above illustrates that blasting at 1200 m away (minimum distance to a known nesting habitat (refer to **Figure 5-1** and **Table 5-1** above), is not expected to cause ground vibrations higher than the recommended threshold for charges less 90 kg.

7.2. General Construction Vibrations

Ground vibrations will occur due to construction activities and are typically much less than blasting related ground vibrations. Typical construction levels, in terms of PPV, are provided in **Table** 7-4 below as obtained from the FRA Report (2012) at 7.6 m (converted from 25 ft) from the source of the ground-borne vibration.

Table 7-4: Reference Vibration Values at 7.6 m of Anticipated Construction Machinery

Construction Machine	PPV at 7.6 m (converted to meters from source)
Vibratory Roller	5.3
Breaker Excavator	2.3
Haul Truck	1.9
Jackhammer	0.9
Large Bulldozer	2.3

Approximating the sources as point sources, the following relationship describes the attenuation of the vibration magnitude with increasing distance (adapted from FRA (2012) to yield metric units):

$$PPV = PPV_{ref}\left(\frac{7.62}{D}\right)^{1.5}$$ **Equation 5**

In **Equation 5** above, PPV_{ref} represents the constants in **Table 7-4**above. When these constants are applied to **Equation 5**, then **Figure 7-2** below is yielded:

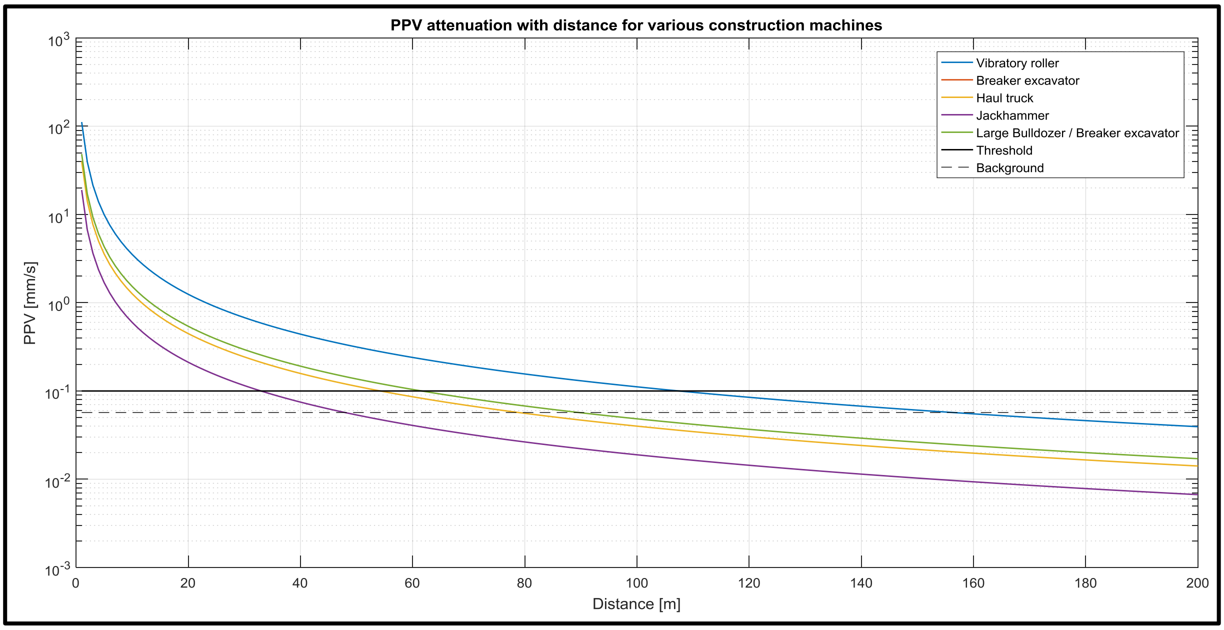


Figure 7-2: PPV Resulting from Construction Machinery as a Function of Distance to the Source

From the FRA (2012) Standard, construction vibration damage to structures occurs at a level depending on the type of structure. These vibration damage criteria for different building types are given in **Table 7-5** below:

Table 7-5: Vibration Damage Criteria for Different Building Types

Building Category	PPV [converted to mm/s from source]
Reinforced-concrete, steel or timber (no plaster)	12.7
Engineered concrete and masonry (no plaster)	7.62
Non-engineered timber and masonry buildings	5.08
Buildings extremely susceptible to vibration damage	3.05

As discussed in **Sub-section 3.6** above, the construction vibration can be compared to a threshold level equivalent to a haul truck at 50 m away from an observer, which was found to be approximately 0.1 mm/s of PPV.

In addition it was assumed that that nest damage may occur at approximately the same level as buildings extremely susceptible to vibration damage, which is 3.05 mm/s (refer **Sub-section 3.6** above).

As can be seen, it is expected that nest damage would occur at a vibration level far in excess of the recommended threshold of 0.1 mm/s PPV. The machine causing the highest levels of vibrations is a Vibratory Roller (see **Table 7-4** above). This machine would likely cause steady state background vibrations in excess of the maximum measured (0.056 mm/s of PPV) at a distance of approximately 160 m and exceed the mentioned threshold (0.1 mm/s of PPV) at ranges closer than approximately 100 m.

The closest source of construction vibration to a boundary of the Blue Swallow habitat is that of the Onrust ventilation shaft, as described in **Section 5** above, which is approximately 50 m away from this boundary (the closest known nest is approximately 2.5 km away). Other earth-moving equipment, such as haulers and bulldozers are expected to generate ground vibration less than the vibratory roller and is not deemed a concern at ranges of 50 m or more from a nesting site.

7.3. Tunnelling Vibrations

Vibration resulting from mechanised tunnelling activities can be significant very close to the source, but is rapidly attenuated as distance from the source increases. Although many variables exist that would affect the ground vibrations due to tunnelling, approximate empirical equations have been developed based on a number of case studies. According to Godio et al., (1992 cited in Hillar & Crabb, 2000), the following relationship exists:

$$PPV = Ar^{-1.3}$$ **Equation 6**

In **Equation 6** above, *A* represents a constant that depends on the soil type and *r* represents the distance from the source to an observer in meters. Hillar & Crabb (2000) found in a study that the following relationships exist between ground vibrations caused by tunnelling and distance from the operating location of the TBM. **Figure 7-3** below is excerpted from that source. The data in this figure matches the behaviour described by **Equation 6** above.

Considering the rock soil type, the expression for PPV as generated by TBMs can be derived from the values given in **Figure 7-3** below as:

$$PPV = 41.8r^{-1.42}$$ **Equation 7**

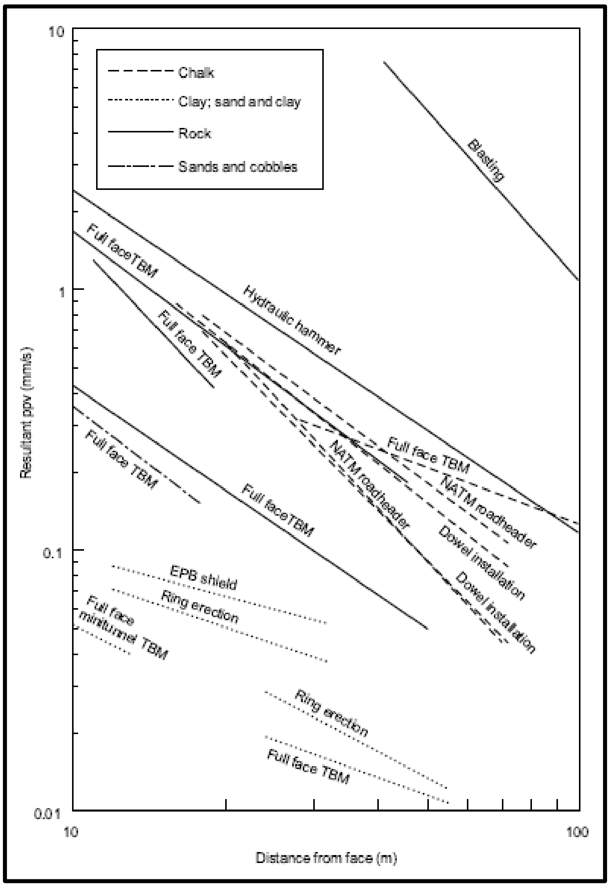


Figure 7-3: Relationship between PPV, Distance from TBM Face and Soil Type

Rahman & Orr (2011) suggests the following relationships, based on **Equation 6** above, for the upper and lower bounds for various types of soil:

$$PPV = 176r^{-1.18}$$ **Equation 8**

$$PPV = 7.4r^{-1.07}$$ **Equation 9**

Equation 7, **Equation 8** (upper bound) and **Equation 9** (lower bound) are graphically illustrated in **Figure 7-4** below along with the background PPV as reported in **Section 6** above.

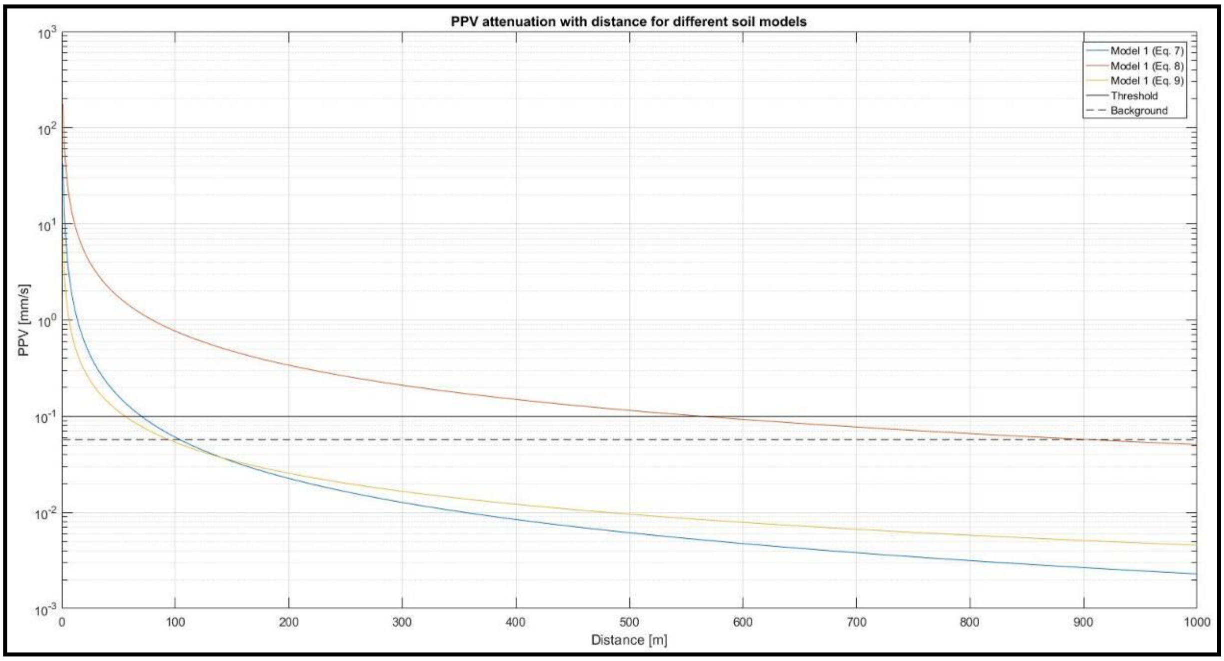


Figure 7-4: PPV Resulting from Tunnelling as a Function of Distance to the TBM Face

As can be seen from **Figure 7-4** above, in close proximity to the TBM operation, significant vibration amplitudes can be expected, depending on the soil constants in use. The constants from **Equation** 8 result in a very aggressive profile with relatively high PPVs as a result, with background PPV (0.056 mm/s) being exceeded from 920 m away. Both **Equation 9** and **Equation 7** predicts PPVs somewhat closer to each other. With **Equation 9** and **Equation 7** predicting that the steady-state background PPV will be exceeded from 110 m and 95 m away, respectively.

The key factor in determining which soil model to use is found in the uMWP-1: Geotechnical Report (2014). Focussing on the eastern side of the study area (the Baynesfield/Trewirgie Region where the vulnerable Blue Swallow nests are located). The TBMs will tunnel mostly through shale and diamictite (both soft rocks), though there is a small section where the TBM will have to tunnel through a dolerite dyke (hard rock type).

As the soil type is known to be of a softer type, the hardest rock soil model can be ruled out (represented by **Equation 8** above). However, to remain as conservative as possible the second hardest soil model will be used (refer to **Equation 7** above, when the TBM face is closer than 140 m to an observer and **Equation 9** above when the observer is further than 140 m from the TBM face).

8. DESCRIPTION OF PROJECT IMPACTS

8.1. Blasting Vibration

As summarised in **Section 5** above, some blasting will take place within the Blue Swallow nesting habitat (Tunnel Alignment Option A Outlet and Borrow Area A). In addition, the tunnel outlet of alignment Options B and C are located 200 m from a Blue Swallows nesting habitat boundary (see **Figure** 5-2 above).

The fact that some blasting will take place within potential Blue Swallow habitat does not necessarily imply that specific Blue Swallow breeding pairs will be affected, but that blasting will affect potential habitat or future nests in the habitat. The nearest known Blue Swallow nest is an active nest located 750 m away from Borrow Area A.

As outlined in **Sub-section 7.1** above, a stand-off distance of 1200 m from a sensitive receptor (such as a Blue Swallow nest or the boundary of a Blue Swallow habitat) should ensure that the suggested threshold of 0.57 mm/s PPV is not exceeded (for charges of less than 90 kg per delay, which is expected to be sufficient).

As can be seen by the blast radius of Borrow Area A in **Figure 8-1** below, impulsive vibrations in excess of the suggested impulsive vibration threshold (0.57 mm/s PPV) may be induced at Blue Swallow Nest 1. This nest is located 740 m away from the nearest point on the Borrow Area A.

There are two options for tunnel exit portals. The exit portal of Tunnel Alignment Option A is located to the north-east of the study area, while Tunnel Alignment Options B and C share a single exit portal location to the south-east of the study area. The impulsive vibration threshold radius from the construction of either tunnel exit portal options intrude into the Blue Swallow nesting habitat, but does not appear to negatively affect any current nests (see **Figure** 8-1 below).

Figure 8-2 below illustrates the impulsive vibration threshold radius on the western side of the study area. Blasting in this area is expected to arise due to the construction of the proposed Smithfield Dam Wall, as well as construction of the R617 deviation. As can be seen in **Figure 8-2** below, no known Blue Swallow nests are expected to be negatively affected, as none are present within the impulsive vibration threshold radii at the western side of the study boundary.

Table 8-1: Legend for Figure 8-1 and Figure 8-2

Map Object	Description
	Tunnel Alignment Option A.
	Tunnel Alignment Option B.
	Tunnel Alignment Option C.
	Road to balancing dam (background of legend shaded for clarity)

Map Object	Description
	Quarry and Borrow Area (background of legend shaded for clarity)
	Quarry II
	Quarry III
	Quarry I
	Borrow Area A
	Borrow Area B
	Baynesfield Balancing Dam (Northern balancing dam).
	Mbangwenni Balancing Dam (Central balancing dam).
	Langa Balancing Dam (Southern balancing dam).
	Smithfield Dam
	Baynesfield Estate Blue Swallow nesting habitat.
	Suggested blast radius (1 200 m)
	Historical Blue Swallow nesting sites from Ezemvelo KZN Wildlife.
	Confirmed active Blue Swallow Nest.
	Ground Vibration Measurement Location.
	Potential source of man-made ground vibrations.

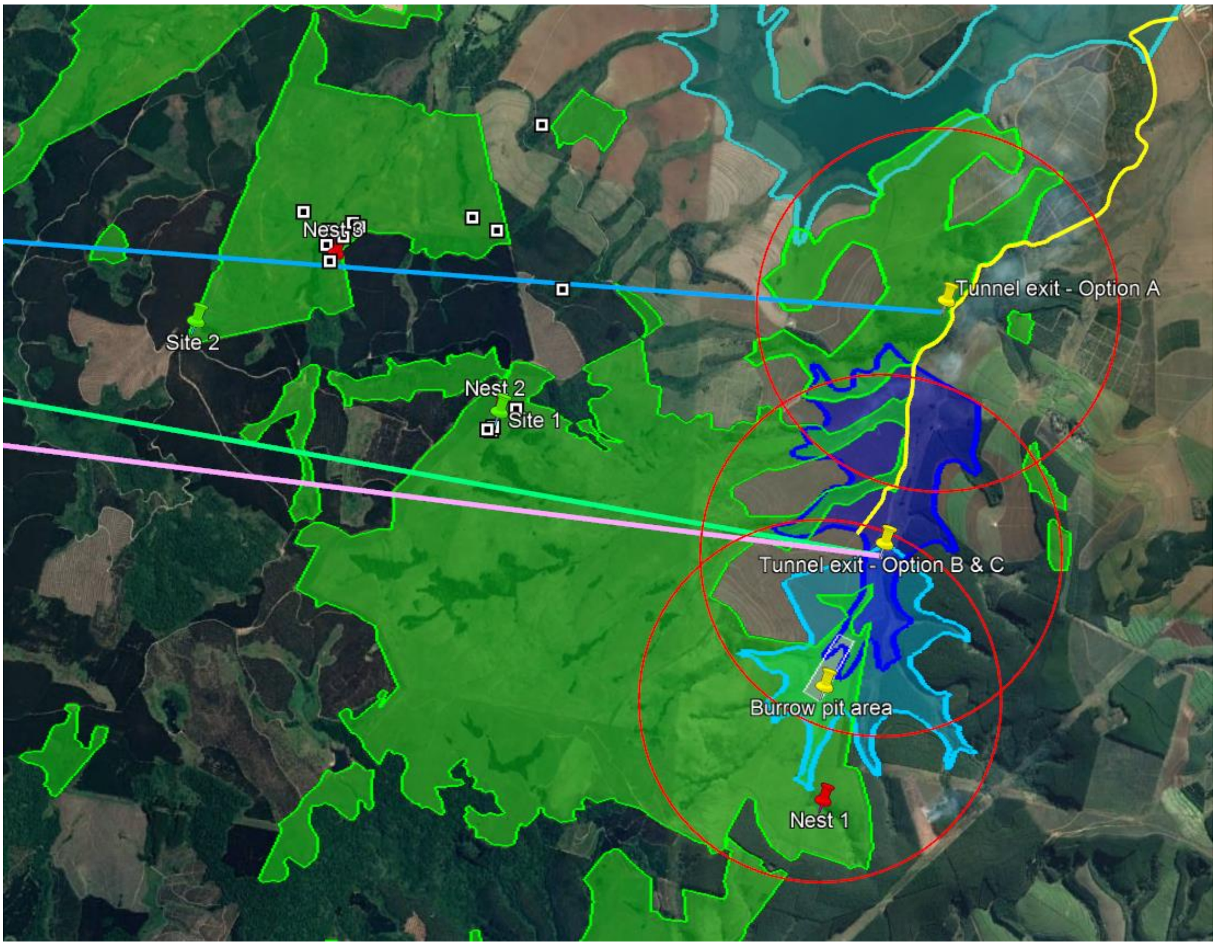


Figure 8-1: Expected Blasting Locations and Threshold Radii on the Eastern Side of the Study Area

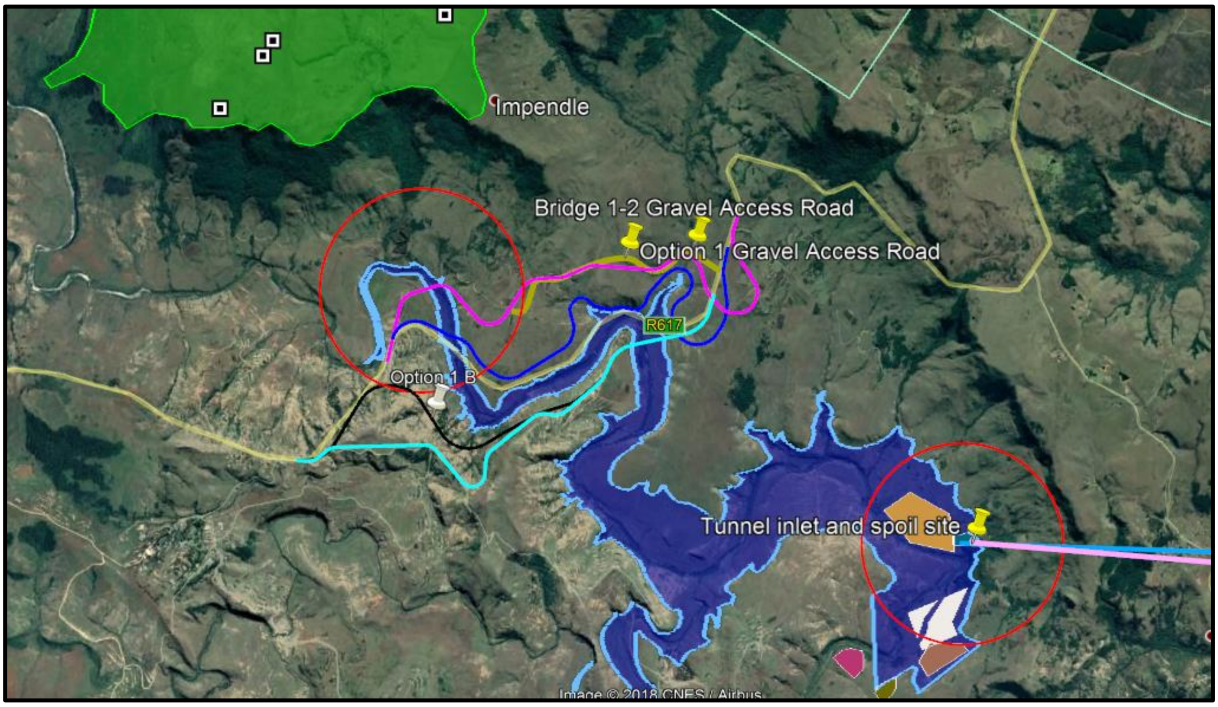


Figure 8-2: Expected Blasting Locations and Threshold Radii on the Western Side of the Study Area

8.2. Construction Vibration

General construction vibration was considered in **Sub-section 7.2** above, and was compared to the PPV generated by a Haul Truck at 50 m from a receptor (generating approximately 0.1 mm/s PPV). As a disturbance, the Vibratory Roller was primarily considered as it typically generates the most intense ground vibrations at a given distance. The PPV generated by the Vibratory Roller was estimated to attenuate below the maximum observed ambient steady-state PPV at a distance of 160 m, and below the threshold at approximately 100 m away from a receptor.

The Onrust Ventilation Shaft Construction Site is located the closest to the Blue Swallow nesting habitat (at the south-western boundary of the Baynesfield Estate), see **Figure 8-3** below. In this figure, the red shaded area falls within the threshold radius of 100 m. As this construction site is approximately 50 m from the Blue Swallow nesting habitat, the boundary of this habitat region will be infringed somewhat by the threshold radius (as can be seen by the red shaded area in **Figure** 8-3 below), although the nearest known Blue Swallow nest is located 2.5 km away. Therefore, if no Blue Swallow nests are located within 100 m of a construction site, construction related ground vibration is not expected to adversely affect the breeding and welfare of the Blue Swallows. For reference, see **Table 8-2** for the legend of **Figure** 8-3.

Figure 8-4 below illustrates the western side of the study area, with regard to the construction works of the R617 deviation. Option 2 of the proposed R617 deviation approaches the Impendle Nature Reserve the closest (with Options 1A, 1B and 3 being further away). Option 2 is therefore considered to be the worst-case in terms of potential ground vibration impacts for the R617 deviation construction work and is considered next.

Option 2 of the R617 deviation approaches the general Blue Swallow nesting habitat to a distance of 2.1 km and approaches the nearest known Blue Swallow nest to a distance of 3.7 km. The rest of the planned R617 deviation construction works, including the access roads and construction roads, are futher away from the Blue Swallow nesting habitats. For reference, see **Table 8-2** below for the legend of **Figure 8-3** and **Figure 8-4**.

Table 8-2: Legend for Figure 8-3 and Figure 8-4

Map Object	Description
	Tunnel Alignment Option A
	Tunnel Alignment Option B
	Tunnel Alignment Option C
	R617 Deviation Option 2 (preferred)
	R617 Deviation Option 3
	R617 Deviation Option 1B

Map Object	Description
	R617 Deviation Option 1A
	Gravel Access Road
	Current R617 route (background of legend shaded for clarity)
	Steady state vibration threshold radius (100 m radius for 0.1 mm/s)
	Historical Blue Swallow nesting sites from Ezemvelo KZN Wildlife.
	Potential source of man-made ground vibrations.
	Baynesfield Estate Blue Swallow nesting habitat
	Trewirgie Blue Swallow nesting habitat
	Blue Swallow nesting habitat expected to be exposed to ground vibrations in excess of the steady state vibration threshold.

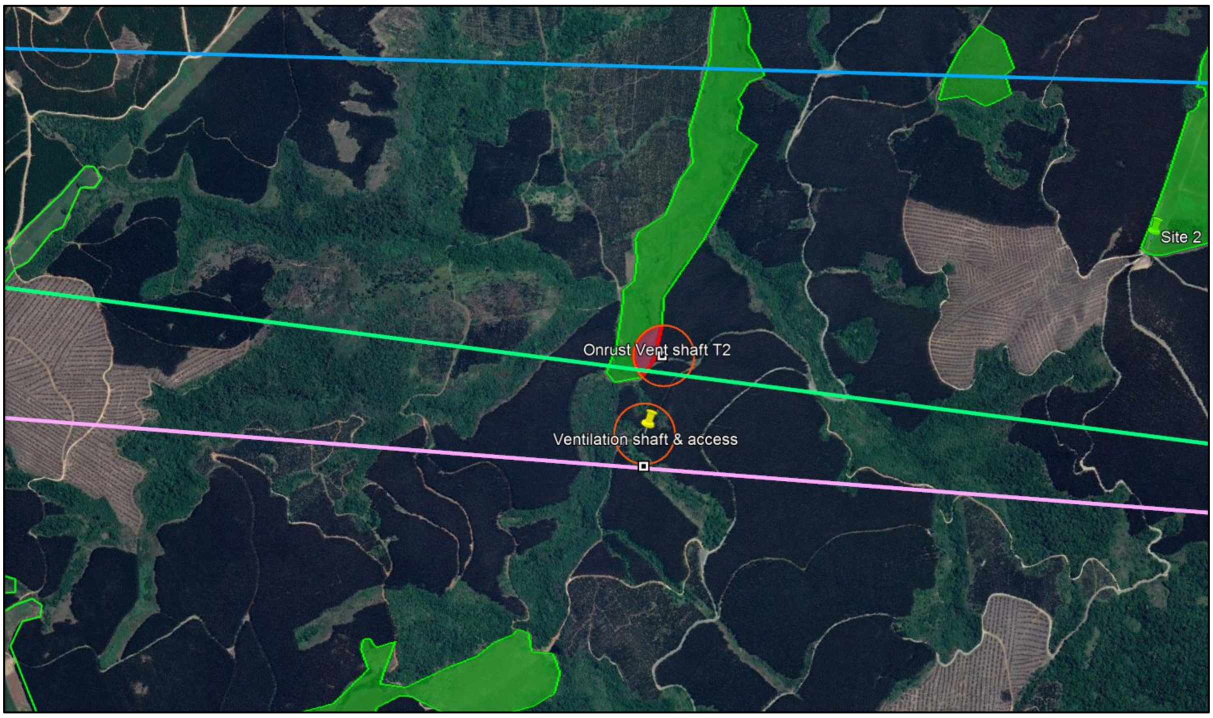


Figure 8-3: Construction Vibration Impact Zone near the Onrust Ventilation Shaft

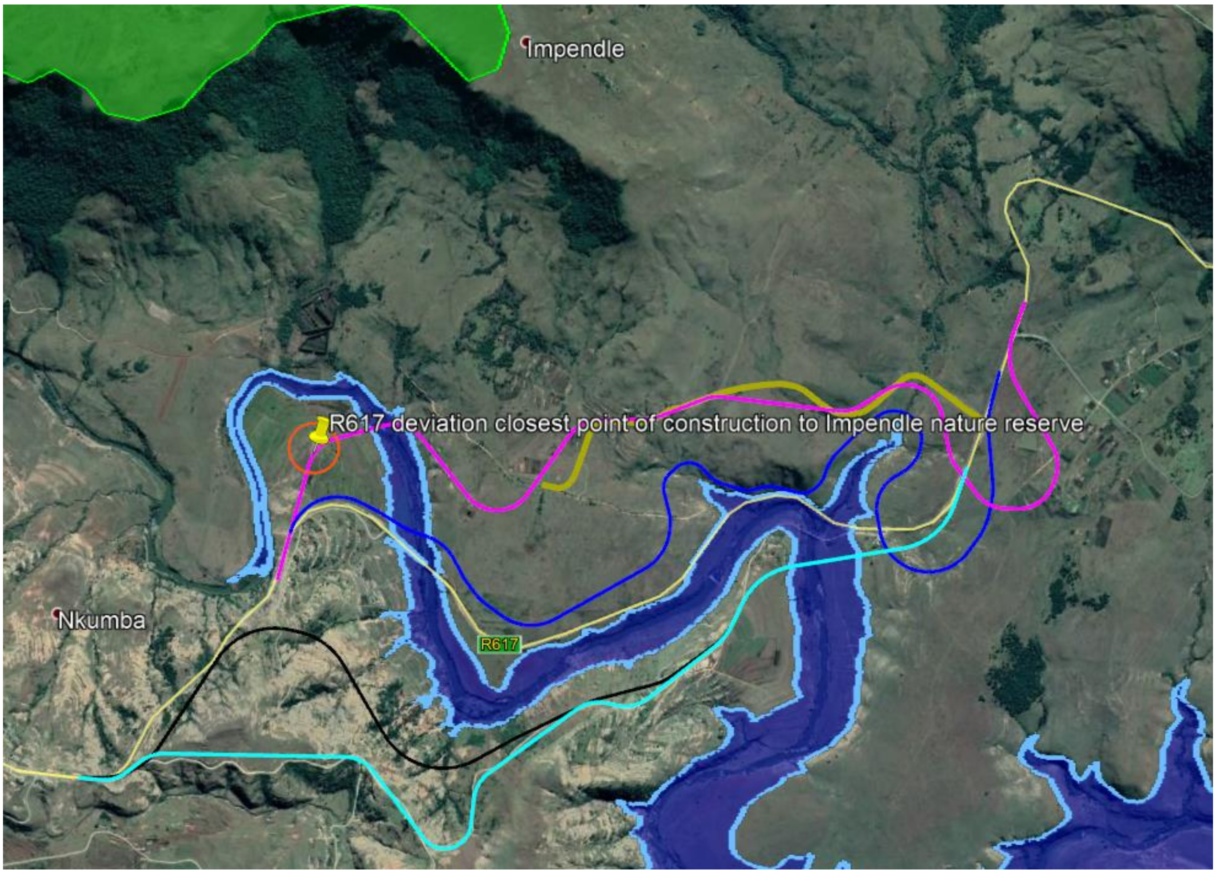


Figure 8-4: Construction Vibration Impact None nearest to the Impendle Nature Reserve Habitat Zone due to the R617 Road Works

The construction of roads near the proposed balancing dam options, as indicated on **Figure 8-5** below, will result in the ground-borne vibrations within 100 m of the construction road exceeding the suggested steady-state threshold of 0.1 mm/s. As the proposed road is located along the eastern boundary of the habitat zone near the balancing dams, the area of the habitat zone within a 100 m of the construction road will likley experience ground vibrations in excess of the steady state threshold of 0.1 mm/s. For reference, see **Table 8-3** below for the legend of **Figure 8-5** below.

Table 8-3: Legend for Figure 8-5

Map Object	Description
(blue line)	Tunnel Alignment Option A.
(green line)	Tunnel Alignment Option B.
(pink line)	Tunnel Alignment Option C.
(yellow line)	Road to balancing dam (background of legend shaded for clarity)
(cyan box)	Baynesfield Balancing Dam (Northern balancing dam).

	Mbangwenni Balancing Dam (Central balancing dam).
	Langa Balancing Dam (Southern balancing dam).
	Baynesfield Estate Blue Swallow nesting habitat.
	Blue Swallow nesting habitat expected to be exposed to ground vibrations in excess of the steady state vibration threshold.
	Historical Blue Swallow nesting sites from Ezemvelo KZN Wildlife.
	Confirmed active Blue Swallow Nest.
	Ground Vibration Measurement Location.
	Potential source of man-made ground vibrations.

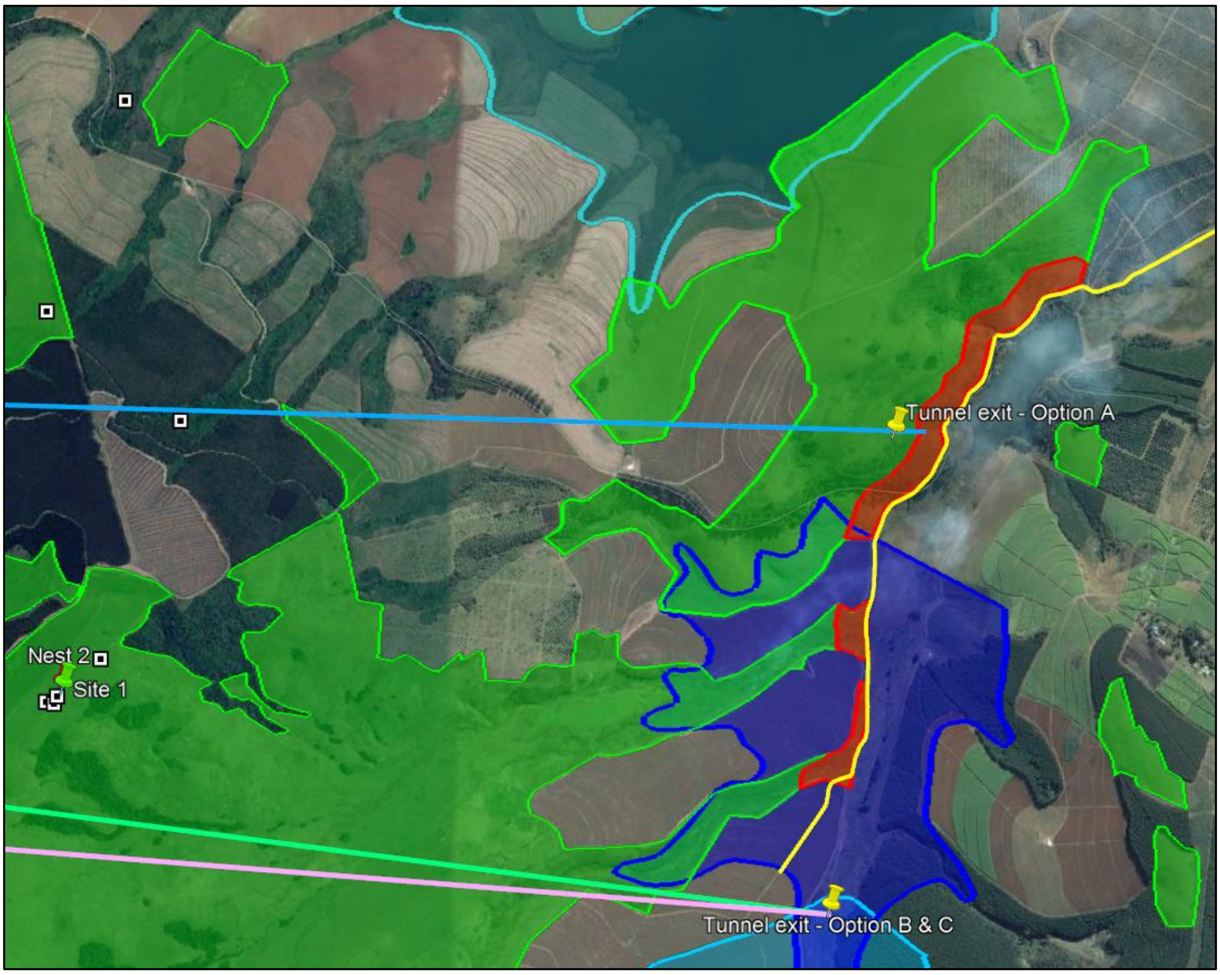


Figure 8-5: Area in Blue Swallow Habitat that will be Subjected to Ground Vibrations in Excess of the Steady State Threshold

8.3. Tunnelling Vibration

Ground vibration due to tunnelling has the potential to cause ground vibration environmental impacts as the TBMs approach the Blue Swallow nesting habitats, which could result in the local PPV within the habitat exceeding the recorded background steady-state PPV of 0.056 mm/s in the Blue Swallow nesting habitats.

It is acknowledged that the Blue Swallows might habituate to ground-borne vibration levels higher than which was observed during the field measurements. Therefore, it is proposed that the background vibration be compared to the ground vibrations generated by a Haul Truck at 50 m away from a receptor (0.1 mm/s PPV, as with construction vibrations).

In assessing the projected vibration levels, empirical data was considered from Hillar & Crabb (2000) in **Section 7.3** above. This data is represented in **Equation 7** above. Rahman & Orr (2011) also provides an upper and lower bounds for possible ground vibrations due to TBMs (refer to **Equation** 8 and **Equation 9** above). The predictions of **Equation 7** and **Equation 9** above correspond well, while differing from the prediction of **Equation 8** above by an order of magnitude. Respectively, these equations predict that the PPV generated by the TBMs will exceed that of the ambient PPV of 0.056 mm/s at distances of 95 m, 110 m and 920 m from a receptor. Due to the predominant soil type being soft, **Equation 7** above should be be used to predict stand-off distances less than 140 m, as this equation is the more conservative between **Equation 7** and **Equation 9** above at distances less than 140 m. Using **Figure 7-4**, the steady state vibration threshold of 0.1 mm/s will be exceeded from 70 m away from the TBMs.

The radius of influence (radius from the TBM at which the ambient PPV of 0.056 mm/s will be exceeded – 110 m in this Report) and the threshold radius (radius from TBM at which the threshold PPV of 0.1 mm/s will be exceeded – 70 m in this Report) can then be compared to the vertical distances between the Blue Swallow nesting habitat zones and the tunnelling paths of the TBMs.

It is therefore evident that there is a risk that the ground vibrations due to tunnelling may exceed the steady state threshold ground vibration level of 0.1 mm/s at some of the Blue Swallow habitat zones at distances to the TBM face of less than 70 m – notably at the tunnel exit at the balancing dam (see **Figure** 8-6 to **Figure 8-8**, below).

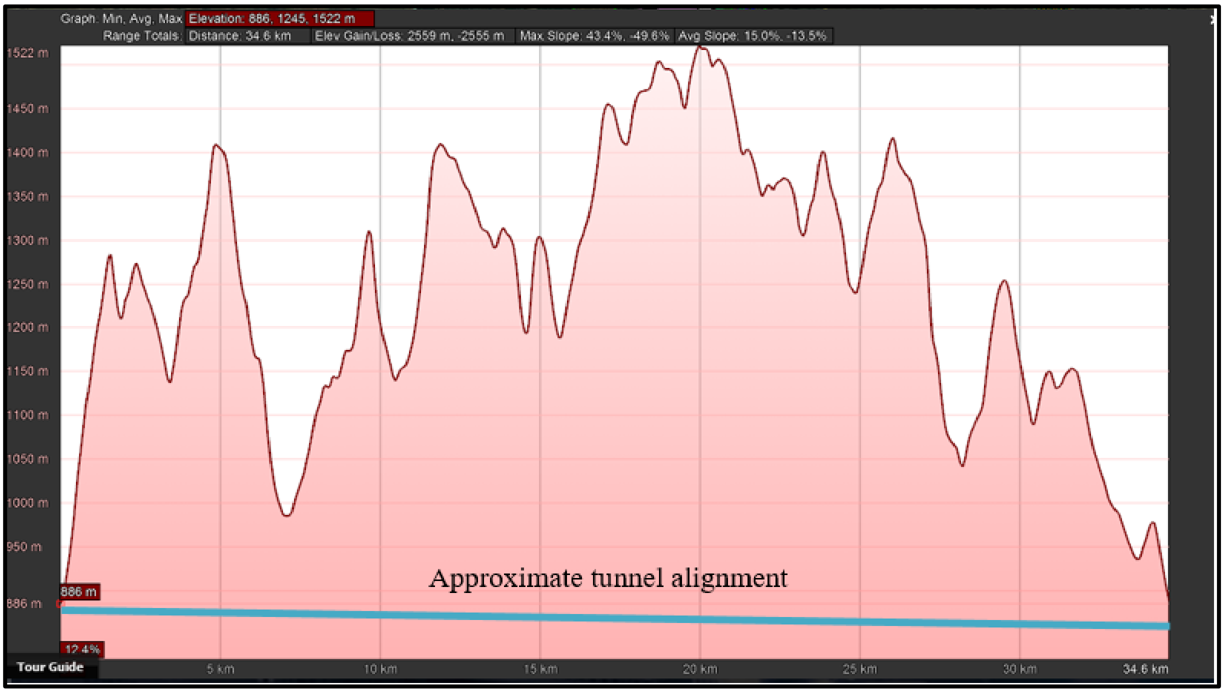


Figure 8-6: Tunnel Alignment Option A Relative to the Heights of the Ground Levels

Figure 8-7: Tunnel Alignment Option B Relative to the Heights of the Ground Levels

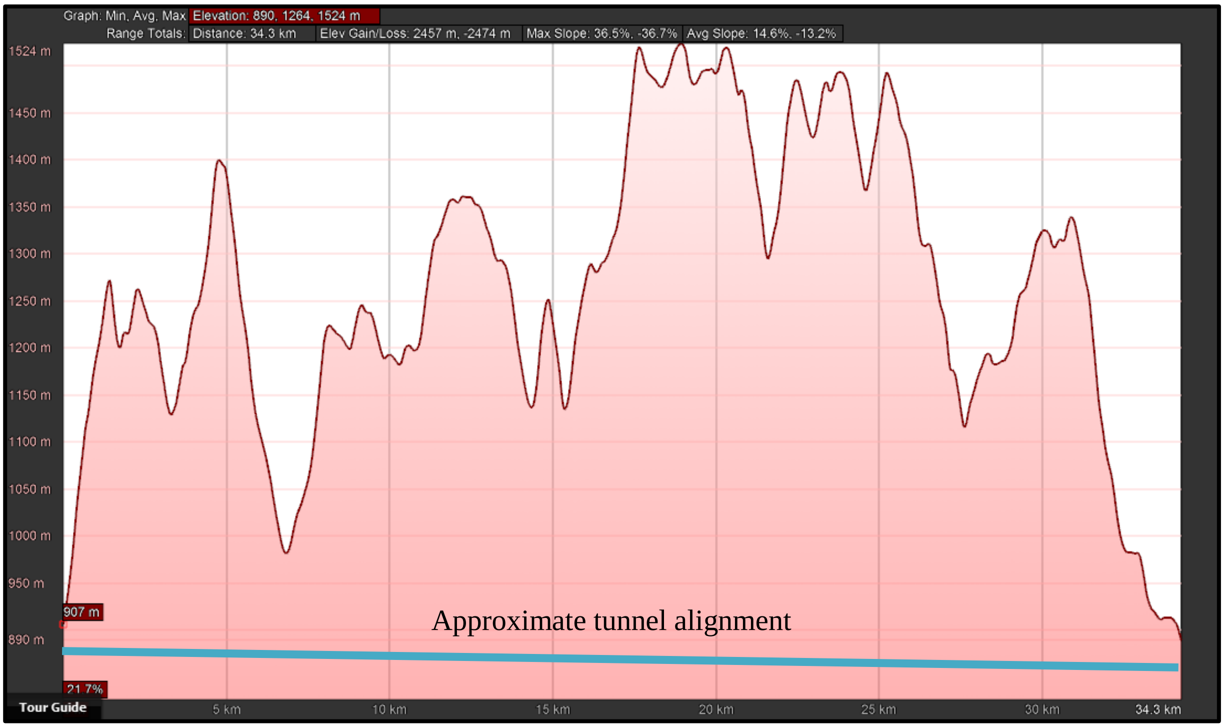


Figure 8-8: Tunnel Alignment Option C Relative to the Heights of the Ground Levels

It is necessary to define the horizontal range at which the TBMs may generate disturbances in excess of the ambient PPV of 0.056 mm/s. As there exists vertical separation between the TBMs and the ground level, the horizontal influence radii from TBM in **Table 8-4** below will apply, if it is assumed that the TBMs will generate PPVs exceeding the background vibration at a direct distance of 110 m and exceeding the threshold at a direct distance of 70 m (see **Figure 8-9** below). Note that as the tunnel depth increases, the influence- and threshold radii will decrease. However, for ease of reference and simplicity of comparison, the quoted radii are used for the entire vertical separation range given in **Table 8-4** below.

Table 8-4: TBM Vibration Influence Radii at Blue Swallow Nesting Habitats

Alignment option	Vertical Separation	Influence Radius (PPV > background)	Threshold Radius (PPV > threshold)
A	0 m >	110 m	70 m
B and C	29 m >	95 m	65 m

Therefore, within the horizontal radii quoted in **Table 8-4** above, it is expected that the TBMs will generate PPVs in excess of the background PPV level of 0.056 mm/s (within the influence radius) and the recommended threshold of 0.1 mm/s (within the threshold radius).

These radii are graphically illustrated in **Figure 8-9** below, and the direct vibration propagation path that runs between the TBM face and the surface is also illustrated in this figure. This corresponds to the horizontal propagation distance between the location of the TBM (projected on the ground level) to the location on the ground where the direct propagation path reaches the ground level.

Figure 8-10 below illustrates the positions along the proposed Tunnel Alignment Options that falls within the TBM's vibration radius of influence (PPV above background vibration of 0.056 mm/s, indicated by blue highlights on the alignment options) and threshold radius (PPV above the recommended threshold of 0.1 mm/s , indicated by red highlights on the alignment options).

As can be seen on **Figure 8-10** below, the area in the vicinity of the proposed tunnel exit of Tunnel Alignment Option A falls within the radius of influence (110 m) and the threshold radius (70 m). This area of influence (where the vibration generated by the TBMs will exceed the background vibration of 0.056 mm/s) and threshold area (where the vibration generated by the TBMs will exceed the threshold vibration of 0.1 mm/s) extends into the mountain side until the radius of influence and threshold radius falls below the ground level (when considered in the vertical plane) from the point of the TBM face. Tunnel Alignment Options B and C use the same tunnel exit portal. This shared exit portal is some distance away from the Blue Swallow nesting habitat (approximately 600 m along the length of Tunnel Alignment Options B and C). Nevertheless, as Tunnel Alignment Options B and C approach the Blue Swallow habitat area (from the the exit portal side), the area of influce and threshold area penetrates into the Blue Swallow habitat. See the blue and red shaded areas on **Figure 8-10** below, which represent the areas where the TBM generated vibrations exceed the background vibration (0.056 mm/s) and the steady state threshold vibration level (0.1 mm/s). For reference, see **Table 8-5** below for the legend of **Figure 8-10**.

The TBM generated ground vibration will also be above the measured background PPV of 0.056 mm/s and steady state threshold of 0.1 mm/s at the tunnel intake, but this location is too far from a Blue Swallow habitat to be of concern and is therefore not discussed further in this Report.

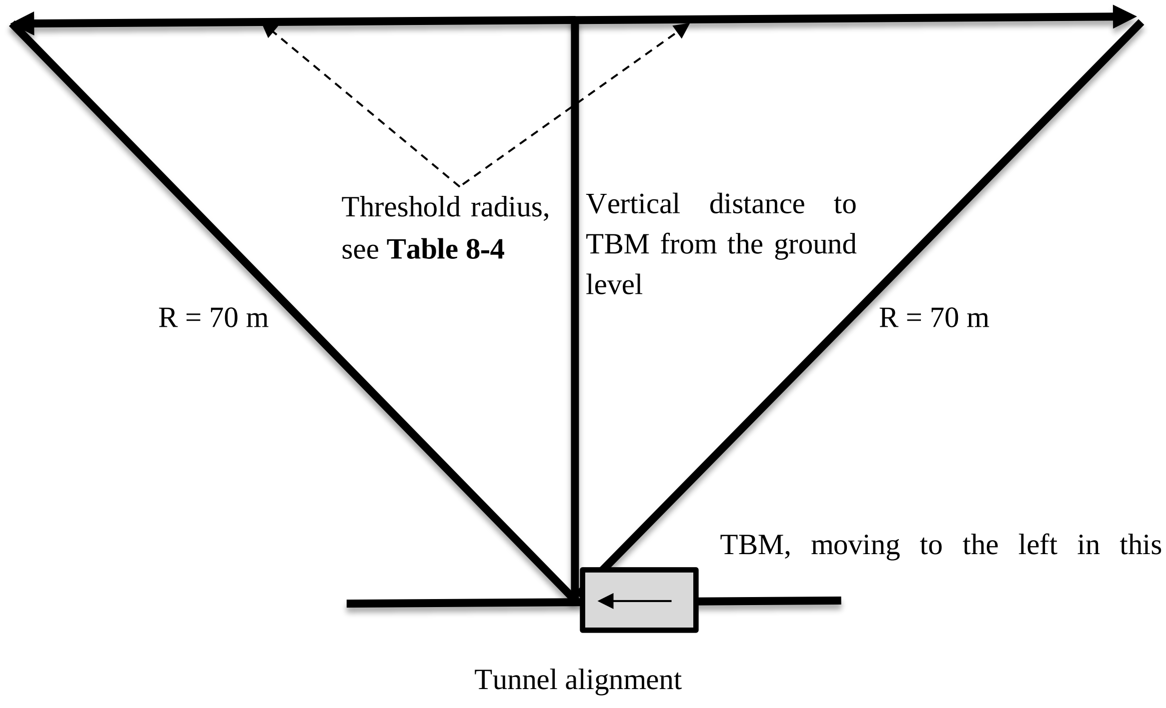


Figure 8-9: Geometric Relationship between Vertical Distance, Horizontal Distance and the TBM Vibration Influence Radius

Table 8-5: Legend for Figure 8-10

Map Object	Description
	Tunnel Alignment Option A.
	Tunnel Alignment Option B.
	Tunnel Alignment Option C.
	Baynesfield Balancing Dam (Northern balancing dam).
	Mbangwenni Balancing Dam (Central balancing dam).
	Langa Balancing Dam (Southern balancing dam).
	Baynesfield Estate Blue Swallow nesting habitat.
	Blue Swallow nesting habitat expected to be exposed to ground vibrations in excess of the steady state vibration threshold.
	Blue Swallow nesting habitat expected to be exposed to ground vibrations in excess of the background vibration.
	Historical Blue Swallow nesting sites from Ezemvelo KZN Wildlife.
	Confirmed active Blue Swallow Nest.
	Ground Vibration Measurement Location.
	Potential source of man-made ground vibrations.

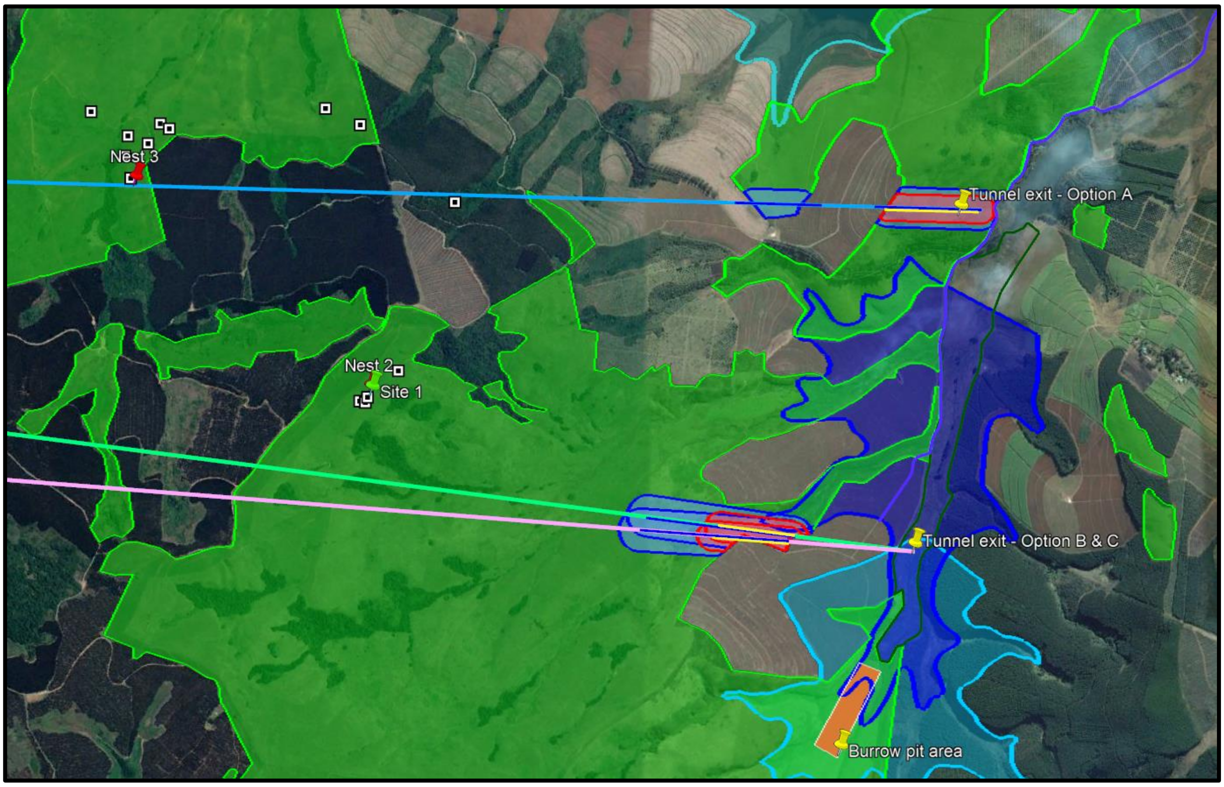


Figure 8-10: Positions along the Tunnelling Alignment Options located within the TBM Vibration Radius of Influence

The distances along each proposed tunnel option where the radius of influence and threshold radius is more than the depth of the tunnel are given in **Table 8-6** below. These distances are represented in **Figure 8-10** above by the blue lines (relating to the distance where the tunnel depth is smaller than the radius of influence), and yellow lines (relating to the distance where the tunnel depth is smaller than the threshold radius). This implies that for the distances in **Table 8-6** below, along the proposed tunnel option, the PPV generated on the surface by the TBMs will exceed the background vibration (Column 2 in **Table 8-6** below) or the steady state vibration threshold (Column 3 in **Table 8-6** below). Tunnel Alignment Option A has two (2) values for radius of influence associated with it, as it the tunnel depth is numerically smaller than the radius of influence at two sections along the alignment.

Table 8-6: Horizontal distances over the Blue Swallow Nesting Habitats including the Radius of TBM Influence

Tunnel Alignment Option	**Length along alignment where tunnel depth is shallower than the radius of influence [m] – Blue lines on Figure 8-10 above**	**Length along alignment where tunnel depth is shallower than the threshold radius [m] – Yellow lines on Figure 8-10** above
A	514 / 420	450 / -
B	720	380
C	725	370

The time (in weeks) to tunnel through the distances quoted in **Table 8-6** above are given in **Table** 8-7 below at a tunnelling rate of 130 m per week, as per the uMWP-1: Engineering Feasibility Design Deport (2012).

Table 8-7: Time Taken to Tunnel through the Distances Quoted in Table 8-6 above at a Tunneling Rate of 130 m per week

Tunnel Alignment Option	Tunnelling time through Influence Radius [weeks]	Tunnelling time through Threshold Radius [weeks]
A	4 / 3.2	3.5
B	5.5	3
C	5.6	2.8

8.4. Operational Impacts from Ground-Borne Vibration

No information regarding any negative environmental impacts in terms of ground-borne vibrations for the operational dam and water conveyance infrastructure, including hydropower, pumping stations and tunnels could be found in the open and scientific literature. As such, this aspect is not deemed to be of concern to this Study and therefore it was not assessed further.

9. GROUND-BORNE VIBRATION IMPACT ASSESSMENT

The ground-borne vibration impacts on the Blue Swallows have been rated by taking aspects of the occurrence- and severity of vibration impact into account. These factors are summarised and quantified in **Table 9-1** to **Table 9-4** below. The values in these rating tables were applied in **Equation 10** below to estimate the environmental significance before- and after mitigation.

Table 9-1: Rating Table of the Probabilities of Disturbing the Blue Swallows

Probability of Blue Swallow Disturbance	Definition	Rating
Definite	Disturbance near an active nest is such that nest damage is possible and disturbance to the Blue Swallows is definite.	5
Highly Probable	Disturbance at the nesting habitat is such the Blue Swallows will be subjected to vibration levels in excess of the threshold of 0.1 mm/s for steady-state ground vibrations and 0.57 mm/s for impulsive ground vibrations. They will therefore likely be disturbed beyond what vibrations they can tolerate.	4
Medium Probability	The disturbance at the Blue Swallow nesting habitat is such that they will be exposed to ground vibrations in excess of the background vibration of 0.1 mm/s for steady-state ground vibrations and 0.57 mm/s for impulsive ground vibrations They have a roughly equal chance to habituate to the generated ground vibrations.	3
Low Probability	Even though the nesting habitat may be subjected to ground vibrations in excess of the vibrations thresholds of 0.1 mm/s for steady-state ground vibrations and 0.57 mm/s for impulsive ground vibrations, the Blue Swallows are on migration and therefore not affected.	2
Improbable	The induced levels of ground vibration is less than the ambient vibration levels of 0.056 mm/s for steady-state ground vibrations and 0.57 mm/s for impulsive ground vibrations at the nesting habitat and the birds are highly unlikely to be affected by this.	1

Table 9-2: Rating Table of the Duration of Activities likely to cause Disturbance to the Blue Swallows

Duration of Disturbance	Definition	Rating
Permanent	The activity causing the disturbance will be present indefinitely.	5
Long-term	The activity causing the disturbance will be present for longer than 15 years.	4
Medium-term	The activity causing the disturbance will be present for between 5 and 15 years.	3
Short-term	The activity causing the disturbance will be present for longer between	2

Duration of Disturbance	Definition	Rating
	1 and 5 years.	
Immediate	The activity causing the disturbance will be present for less than one year.	1

Table 9-3: Rating Table of the Scale of the Impacts resulting from Disturbances causing Ground Vibration

Scale of the Impact	Definition	Rating
International	The impact has a global scale.	5
National	The impact has a scale extending to the boundaries of the country.	4
Regional	The impact has a scale extending roughly to the boundaries of the province.	3
Local	The impact has a scale extending roughly to the project site vicinity	2
Site only	The impact has a scale not exceeding the site.	1

Table 9-4: Rating Table of the Magnitude of the Impact that the Ground Vibration will have on the Blue Swallows

Magnitude of the Impact	Definition	Rating
Very high / don’t know	Nests (known or unknown) near the activity site are in severe danger due to the PPV generated by the activity being an order of magnitude more than the threshold for nest damage.	10
High	Nests (known or unknown) near the activity site are in danger due to the PPV generated by the activity reaching the threshold of nest damage.	8
Moderate	The PPV induced by the disturbing activities are in excess of the suggested thresholds, though no known nests are in danger.	6
Low	The PPV induced by the disturbing activities are less than the suggested thresholds.	4
Minor	The PPV induced by the disturbing activities are less than the background vibrations.	2

As already stated above, the environmental significance was calculated using **Equation 10** below, by utilising the scaling factors in **Table 9-1** to **Table 9-4** above:

$$SP = (M + D + S) \times P \qquad \textbf{Equation 10}$$

Where:

SP represents environmental effects;

M represents the magnitude of the environmental effects (see **Table 9-4** above);

D the duration of the environmental effects (see **Table 9-2** above);

S represents the scale of the environmental effects (see **Table 9-3** above), and

P represents the probability of the environmentals effect (see **Table 9-1** above).

The value of SP is rated according to the following assessment scale:

- More than 60 points indicate a high environmental significance [H]
- Between 30 and 60 points indicate moderate environmental significance [M]
- Lower than 30 points indicate a low environmental significance [L]

The environmental impact ranking scales used and the results from **Equation 10** above are summarised in **Table 9-5** and **Table 9-6** below for prior to and after mitigation respectively. Every considered source of ground-borne vibration is treated separately.

Table 9-5: Environmental Significance prior to Mitigation

Activity Disturbing the Birds' Nesting and Breeding Behaviour	Environmental Significance prior to Mitigation					
	M	D	S	P	SP	Rating
Blasting	10	3	2	4	60	H
Construction	8	3	2	4	52	M
Tunnelling	8	2	2	4	48	M

Table 9-6: Environmental Significance after Mitigation

Activity Disturbing the Birds' Nesting and Breeding Behaviour	Environmental Significance after Mitigation					
	M	D	S	P	TOT	Rating
Blasting	10	3	2	2	30	M
Construction	8	3	2	2	26	L
Tunnelling	8	2	2	2	24	L

10. RECOMMENDED MITIGATION AND MONITORING

10.1. Mitigation

The ground vibrations due to blasting are expected to infringe approximately 1200 m into the Blue Swallow habitat, at the Borrow Area A. Blue Swallow Nest 1 is expected to be affected, in addition to as yet undiscovered nests, or nests that may be established at this location in the future. Borrow Area A is located 740 m at its closest point to Blue Swallow Nest 1.

If blasting is required all year around at Borrow Area A, a maximum instantaneous blast charge of 35 kg per delay is advised when the Blue Swallows are present. If this is not feasible, a higher rate of excavation may be considered when the Blue Swallows are on migration in order to stockpile enough material for use during the time when the Blue Swallows are present and conventional blasting is too disruptive for the Blue Swallows. Alternative, non-explosive, methods of rock breaking may also be considered during the time when the Blue Swallows are present.

It is advised to schedule the blasting at the tunnel outlet portal during the times when the Blue Swallows are not present (away on migration).

However, tunnelling will occur beneath Blue Swallows nesting habitat near the tunnel exit for all three (3) the proposed tunnel alignment options. As the tunnel alignment emerge from the surface at the tunnel exit, it is necessarily close to the surface for all the tunnel alignment options. At these levels it is possible that the disturbances will register above the background- and threshold PPVs of 0.056 mm/s and 0.1 mm/s respectively.

Hiller (2011) noted that the ground vibrations due to TBM operations are primarily a function of the soil type. As such, there is little that can be done apart from scheduling the tunnelling so that the TBMs operates beneath the Blue Swallow habitat near the tunnel outlet portals during their migration times.

10.2. Monitoring

Due to the uncertainties in predicting the vibration levels generated by the TBMs and blasting work, a careful Ground-borne Vibration Monitoring Program is advised. Such a program will provide more certainty to the actual levels of vibration generated by the TBMs and blasting work and the reaction of the Blue Swallows to the ground vibration levels.

It is envisaged that information pertaining to the vibration propagation characteristics may be useful in future project planning. It is acknowledged if the vibrations measured as part of a Ground-borne Vibration Monitoring Program are equivalent to what is predicted (or higher), there is little that can be done at that stage. However, if it is found that the ground-borne vibration is less than predicted, the reduced level of ground-borne vibration may open possibilities in the scheduling of blasting, construction and tunnelling.

In addition, the behaviour of the Blue Swallows should be monitored as the TBMs approach their nesting zones.

The monitoring should therefore involve seismic recording equipment, but would also necessitate consulting an Avifaunal Specialist to closely monitor the behaviour of the Blue Swallows.

11. CONCLUSIONS

During this Ground-borne Vibration Impact Assessment, the current background vibration levels were measured at five (5) of the most vulnerable sites within the nesting habitat of the Blue Swallows. These sites included two locations in the Baynesfield Estate, as well as one location each at Trewirgie, Mount Shannon and the Impendle Nature Reserve.

The background vibrations were processed to yield the PPV for impulsive ground vibrations, as well as steady state ground vibrations, since the Blue Swallows may respond differently to each of these phenomena. The maximum steady-state and impulsive PPV values observed during the measurement exercise were found to be 0.056 mm/s and 0.57 mm/s respectively.

As the background vibration is at a very low level, due to the environment being free of human activities, it was anticipated that taking the observed levels as a threshold may yield overly conservative results. This was confirmed by the Avifaunal Specialist (see **Appendix A**, Communication of 24 January 2018) and more reasonable thresholds were estimated.

The thresholds used in this Ground-borne Vibration Impact Assessment were based on the expected ground vibrations at a known Blue Swallow nest caused by forestry vehicles driving on a forestry road 50 m away from a known nest. This threshold PPV is 0.1 mm/s, and is taken as the steady-state vibration threshold. The impulsive vibration threshold is taken to be 0.57 mm/s, which is equivalent to the impulsive background vibration. This figure was adopted after a field measurement campaign was undertaken to measure the vibrations of a bridge (see **Appendix C** for the details of this measurement exercise), as would typically be used be Blue Swallows to make a nest (personal communication by the Avifauna Specialist, Mr. David Allan on 16 February 2018, refer to **Appendix A)**. It was found during these tests that the maximum PPV measured on the bridge equated to 0.4 mm/s. As this was lower than the maximum ambient impulsive PPV of 0.57 mm/s measured in the Blue Swallow habitat zone, the ambient value of 0.57 mm/s was adopted.

The vibration threshold obtained, as described in **Sub-section 3.6** above, was compared to the expected vibration levels of blasting, general construction vibration and tunnelling. Regarding construction vibration, a section of the Blue Swallow habitat (a section with a radius of 100 m, see **Figure 8-3** above) is expected to be subjected to ground vibration levels exceeding the recommended steady state threshold of 0.1 mm/s. However, it is not known whether active Blue Swallow nests are located within this area of disturbance.

Blasting vibration is expected to have a more significant impact, as it is expected that the recommended impulsive vibration threshold of 0.57 mm/s will be exceeded within 1200 m of the blasting site (for a maximum instantaneous charge of 90 kg per delay). At the Borrow Area A, this would imply that Blue Swallow Nest 1 (see **Figure 8-1** above) will be disturbed as it is located 740 m away from the nearest point of Borrow Area A.

There still remains uncertainty as to the precise magnitude of vibrations that a TBM will cause. Sources in the open and scientific literature were consulted, with the predictions typically differing by an order of magnitude at the depths expected. The calculations in this Report are based on soil models most closely matching the soil characteristics described in the uMWP-1: Geotechnical Report (2014), which indicates that mostly soft soil will be encountered.

Due to some uncertainty still remaining, a comprehensive Ground-borne Vibration Monitoring Program is proposed to characterise the vibrations generated by the TBMs and blasts precisely. The result of this program would be used to improve the Soil Vibration Attenuation Model and thereby more accurately predict the expected ground-borne vibration. If it is found that the soil attenuates the vibration better than predicted by the soil models, the strict scheduling timeframes of blasting and tunnelling could be relaxed. The proposed Ground-borne Vibration Monitoring Program should also involve an Avifaunal Specialist in order to understand the effects that ground-borne vibration has on the behaviour of the Blue Swallows.

Based on the expected tunnelling- and blasting induced ground-borne vibrations, Tunnel Alignment Options B or C are slightly more favourable. The reason being that a marginally smaller section of the Blue Swallow habitat is expected to be affected by tunnelling than for Tunnel Alignment Option A. In support of this, the disturbance due to tunnelling through Tunnel Alignment Options A, B and C will last 3.5, 3 and 2.8 weeks in total respectively. The ground-borne vibration due to the blasting required for the exit of Tunnel Alignment Option A will, however, cause ground-borne vibration within a part of the Blue Swallow habitat to exceed the impulsive ground vibration threshold of 0.57 mm/s, a factor that is less of a concern for Tunnel Alignment Options B and C. However, if blasting activities are scheduled when the Blue Swallows are migrating, there is no preference.

The risks involved could likely be mitigated if tunnelling and blasting is undertaken during the Blue Swallow migration time, since they are only present from October to March. Borrow Area A represents the most serious concern with regard to blasting, as Blue Swallow Nest 1 is located 740 m away from this area. Mitigation measures proposed include blast design of less than 35 kg instantaneous charge per delay, or increased material extraction for stockpiling when the Blue Swallows are present from April to September (6 months of the year). If neither of these are possible, non-explosive techniques may need to be considered.

Therefore, with monitoring and mitigation measures in place, it is believed that Environmental Authorisation for the construction and operation of the uMWP-1 could be obtained.

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APPENDIX A: PERSONAL CORRESPONDENCE

A-1. 24 January 2018

The following communication was received by email from the Avifauna Specialist, Mr David Allan, to Rudi Kroch:

Hi Rudi

I agree your thinking is probably on the right track. Unfortunately we have to rely on some conjecture in the absence of empirical data on how the birds would respond to vibrations.

Following your reasoning, I would imagine similar options such as:

1 – The vibrations remain at all times undetectable by the birds.

2 – The vibrations at some point become detectable but remain so low that the birds ignore them or the birds gradually habituate and essentially ignore the increasing vibrations throughout.

3 - At some point the vibrations become so marked that the birds are no longer prepared to continue with the breeding attempt.

4 – The vibrations become so marked that the nest actually detaches from the supporting wall.

I also recognise the relevance of your point relevant to "steady or impulse" vibrations. Presumably the drilling would result in more steady vibrations. Blasting, for example, in more impulse vibrations.

As a general rule, breeding birds are fairly resilient to isolated instances of disturbance, even when quite severe, e.g. me scaring them off the nest and sticking my head down their breeding hole. But where these instances of disturbance increase in frequency, even when relatively quite minor, e.g. my walking past the nest three times a day close enough for them to hear and thus flush out of the nest hole, a threshold may be reached which is intolerable to the birds.

Continual 'moderate startle responses' can be more damaging than the occasional 'severe startle response'.

So it follows that least damage could be expected from steady low-level vibrations that don't worry the birds, followed by occasional impulse vibrations that are detected, followed by repeated impulse vibrations that are detected, with the worst case being steady (= constant) high-level vibrations that do worry the birds.

Of course, a level of disturbance that resulted in the birds actually deserting the territory would be worse than them just giving up on a single breeding attempt. But certainly causing breeding failure could be expected to possibly contribute to territory abandonment.

It is a pity there is not an operational drill somewhere working at the closest distances from the surface envisioned here that we could visit and gain a first-hand impression of how detectable the vibrations are just below the ground surface.

These are some ideas that come to mind from my side at this point.

Thanks.

A-2. 16 February 2018

The following communication was received by email from the Avifauna Specialist, Mr David Allan, to Rudi Kroch:

Hi Rudi

Sorry for the delay in responding.

I've phoned Brent Coverdale of Ezemvelo KZN Wildlife to get input on which nests he knows of may be close to busy roads. He is not in the office at present. Essentially though, none are really close to highways as such. A few are close to quite busy roads though and he mentioned a 'Good Hope' nest which sounds like it is about 200 m from the main Ixopo – Donnybrook road. He also mentioned a 'McKenzie' nest quite close to a busy road. He says he'll have a quick look at his nest database and get back to me in a day or so on this.

Tracked down Steven Evans in Oudtshoorn about it too. In Tanzania the Blue Swallows regularly nest under bridges and road culverts along roads (something they do not do in South Africa). Steven has seen several nests like this in Tanzania. He points out that one of the major reasons why Blue Swallow nests so regularly fall down in their natural holes is that the walls of the holes get wet when it rains heavily and that's why the nests detach and fall. Under the bridges and culverts in Tanzania they are attached to cement surfaces under the structures where they are kept dry and hence are better off than in natural holes in this regard. So any problems from vibration from traffic over these culverts and bridges is compensated for by the dryness of the attachment points.

I've also phoned Athol Marchant but could not get him and left a message.

From my side, it is worth noting that my Nesting Site 5 is only 40 m from a gravel district road. The Ezemvelo KZN Wildlife database of older nest records in the same area show two nests about 35 and 50 m from essentially the same road. I don't know of any other Blue Swallow nests this close to roads and can't imagine there can be many. But it's a quiet road with perhaps 10-20 vehicles per day (?). But some of that traffic will certainly be heavy forestry trucks.

As I've mentioned before, other swallow species in South Africa nest regularly under highway bridges and culverts. Some with nest structures very similar to Blue Swallows. Indeed, it seems that the majority of nesting pairs of these species now use these structures. This means that any such swallow likely was raised in such a locality and it hence is both habituated to it and actually imprinted as to that being the appropriate nest site to search out to build a nest. Again, the dryness of the attachment points under these structures may help counteract the vibration from the passing traffic relative to nest integrity.

I don't if any of this helps you. Important to keep both the problems of the birds being directly disturbed by the vibrations and potential damage to the attachment points of the nests from vibrations in mind.

Thanks.

Regards – David

A-3. 16 February 2018 (2) - Athol Marchant, via David Allan

The following communication was received by WhatsApp instant message from the Avifauna Specialist, Mr David Allan, to Rudi Kroch:

Hi Dave - Brent in Zululand. Difficult to say re BS - in Impendle there is a historical site quite close to edge of plateau/forest below which is the busy Bulwer road. At Sunnyvale (Harding area) there was nest site about 50m from the now busy Ingeli/Harding road. Highover was nest site about 100m from dirt road up Hella Hella. Most of other nest sites I think (Brent has all co-ords) are not all that close to busy roads. Is this because of disturbance/noise etc - its possible, but dont know. Maybe the BS were closer to current roads but moved away when roads built/upgraded - noise & vibration during construction, noise/vibration when roads then became busy? Who knows! Why is vibration specialist interested in busy roads - I would guess the noise/blasting/vibrations from building dams & the serious tunneling would be FAR greater than anything from busy roads! The BS nest sites I knew at Ngome were possibly abandoned when the new road was built & tarred next to the old dirt road.

APPENDIX B: BACKGROUND VIBRATION RESULTS

This Appendix provides the calibrated time-histories of the vibration signals measured in **Figure** B-1 to **Figure B-15** below. In addition, **Table B-1** below summarises the ambient conditions observed during the measurements.

Table B-1: Environmental Observations during Measurement Times

Measurement Location	Measurement No	Description
1	1	No human activity within sight. Noticeable animal life: Birds. Winds calm.
	2	No human activity within sight. Noticeable animal life: Birds. Winds calm.
	3	No human activity within sight. Noticeable animal life: Birds. Winds calm.
2	1	No human activity within sight. Noticeable animal life: Birds. Winds calm.
	2	No human activity within sight. Noticeable animal life: Birds. Winds calm.
	3	No human activity within sight. Noticeable animal life: Birds. Moderate wind.
3	1	No human activity within sight. Noticeable animal life: Birds. Winds calm.
	2	No human activity within sight. Noticeable animal life: Birds. Winds calm.
	3	No human activity within sight. Noticeable animal life: Birds. Mist with slight breeze.
4	1	Lingering vehicles and humans on foot approx. 600 m away. Noticeable animal life: cattle approximately 200 m away. Winds calm. Winds calm.
	2	Light forestry activity (petrol weed cutters) as well as personnel movement trucks approx. 100m away. Noticeable animal life: Cattle within 30 m of the sensors. Winds calm
5	1	Storehouse approx. 500 m away, homestead approx. 600 m away. No human activity seen. Noticeable animal life: Birds, reedbuck approx. 200 m from the measurement location. Winds calm.
	2	Storehouse approx. 500 m away, homestead approx. 600 m away. No human activity seen. Noticeable animal life: Birds. Winds calm.
	3	Storehouse approx. 500 m away, homestead approx. 600 m

Measurement Location	Measurement No	Description
		away. No human activity seen. Noticeable animal life: Birds. Winds calm.

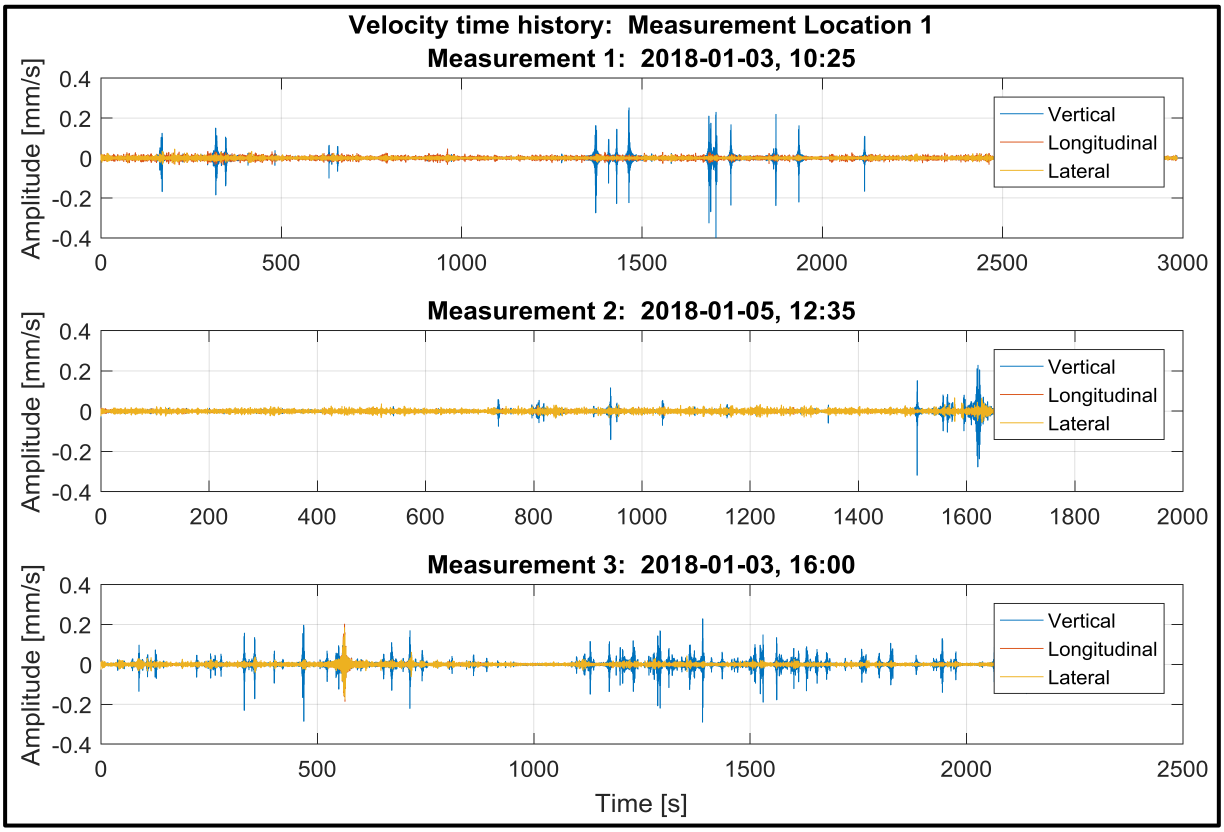

Figure B-1: Time History of Background Vibration Measured at Measurement Location 1

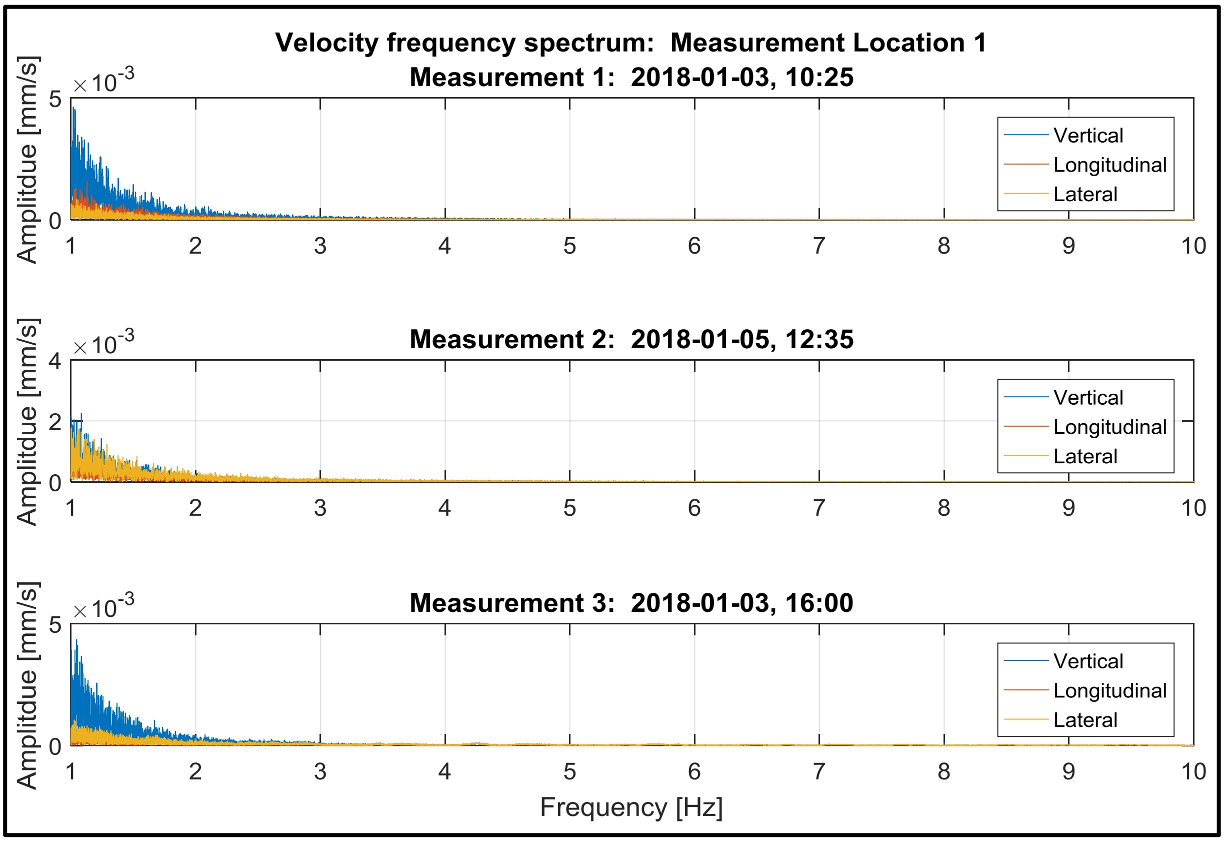

Figure B-2: Frequency Spectrum of Background Vibration Measured at Measurement Location 1

Figure B-3: Photo of Measurement Location 1

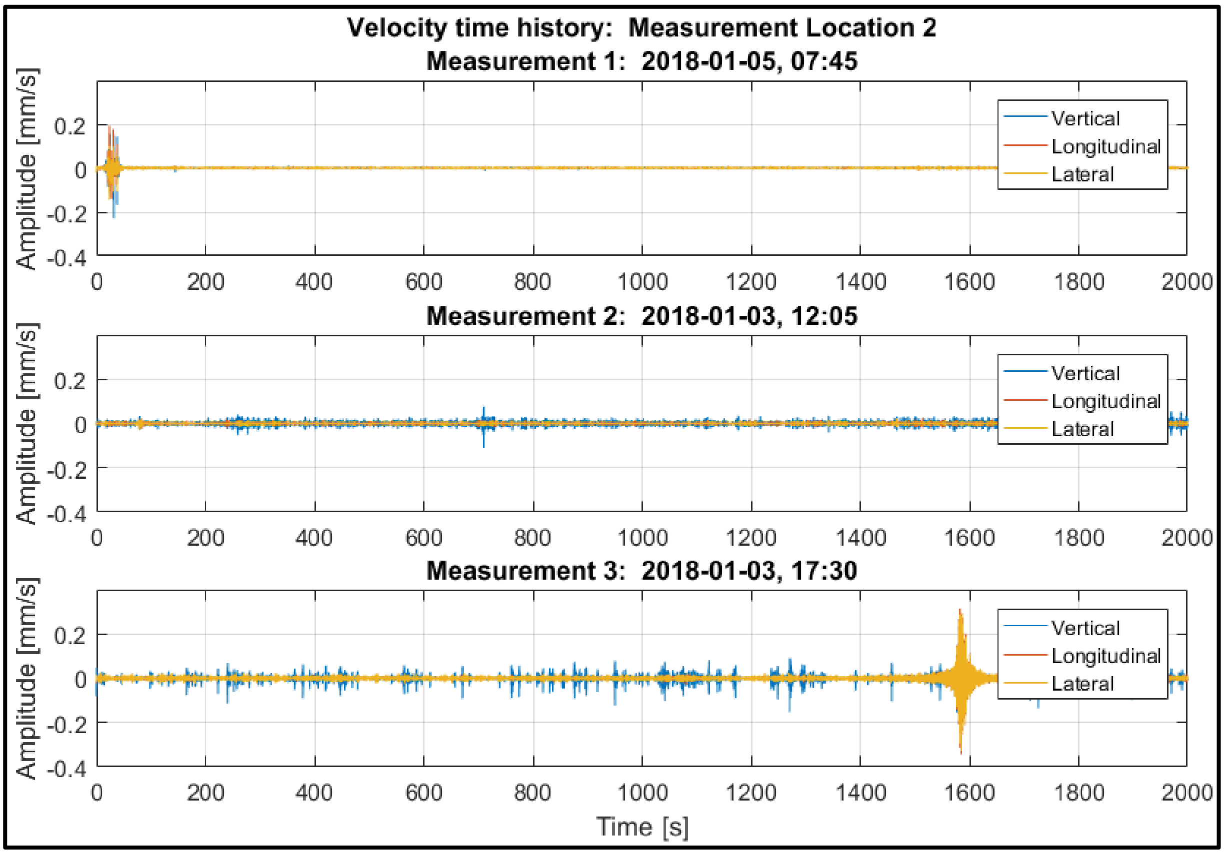

Figure B-4: Time History of Background Vibration Measured at Measurement Location 2

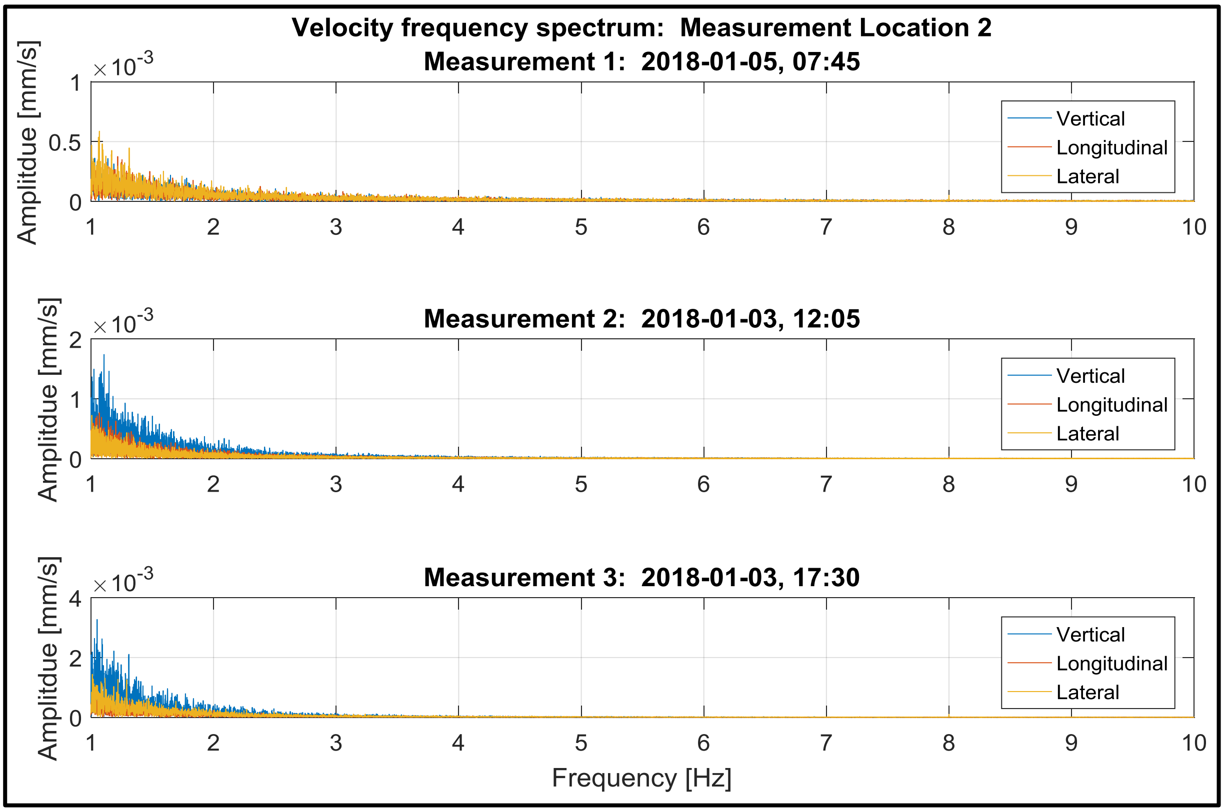

Figure B-5: Frequency Spectrum of Background Vibration Measured at Measurement Location 2

Figure B-6: Photo of Measurement Location 2

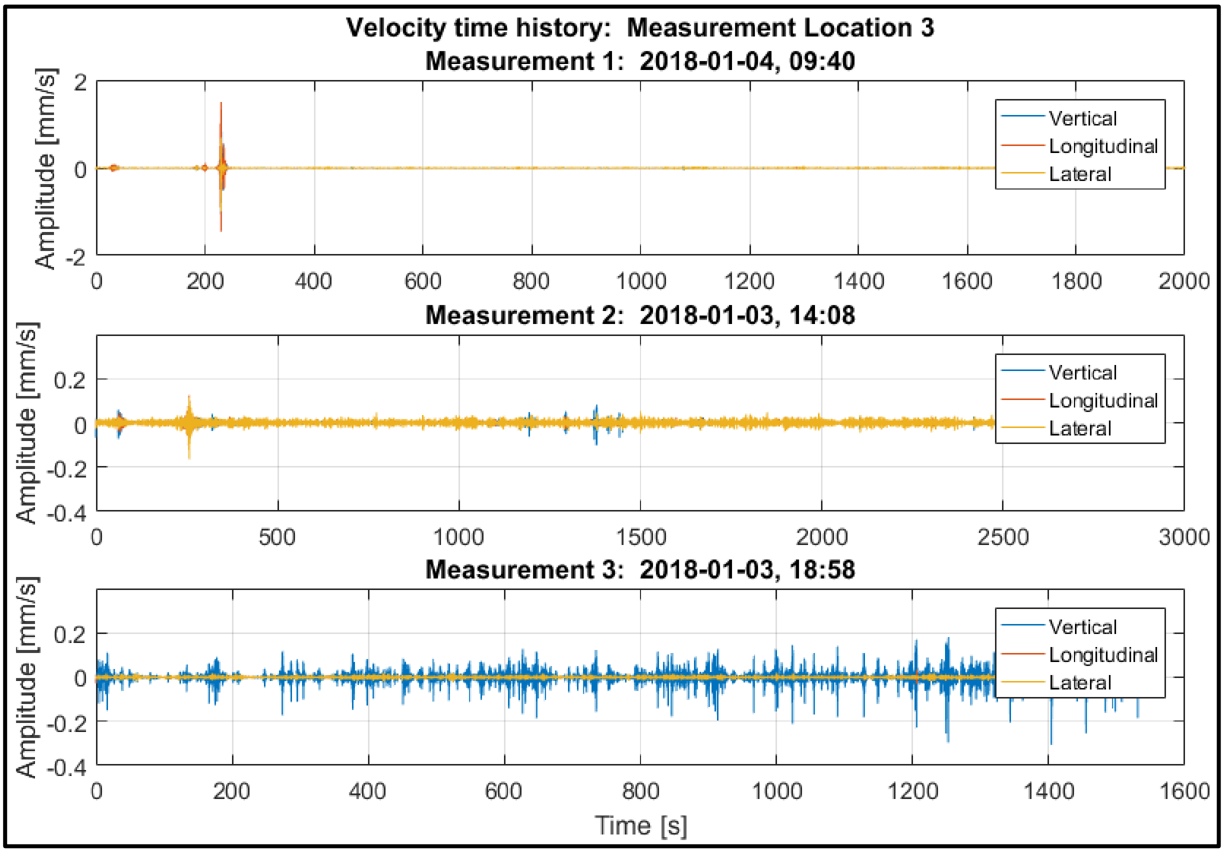

Figure B-7: Time History of Background Vibration Measured at Measurement Location 3

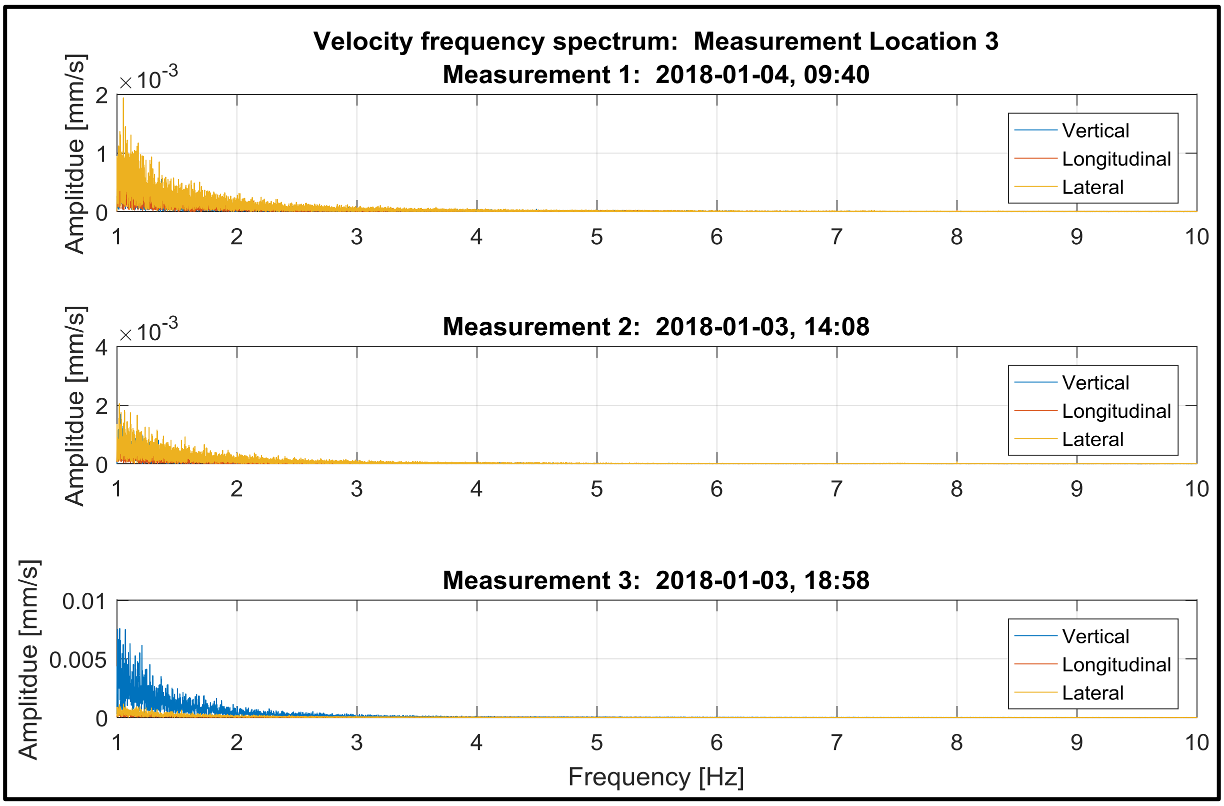

Figure B-8: Frequency Spectrum of Background Vibration Measured at Measurement Location 3

Figure B-9: Photo of Measurement Location 3

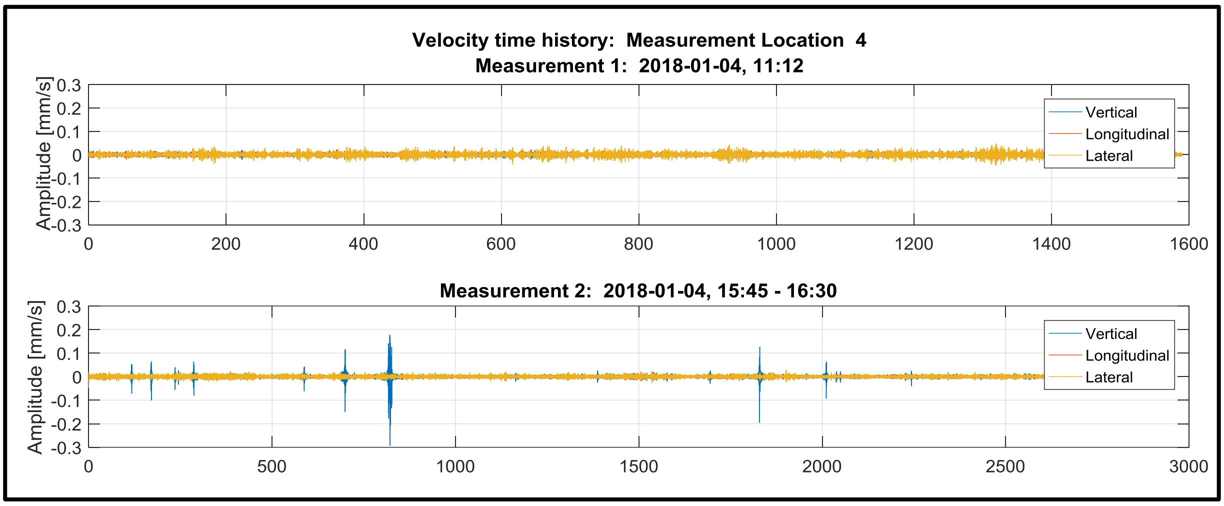

Figure B-10: Time History of Background Vibration Measured at Measurement Location 4

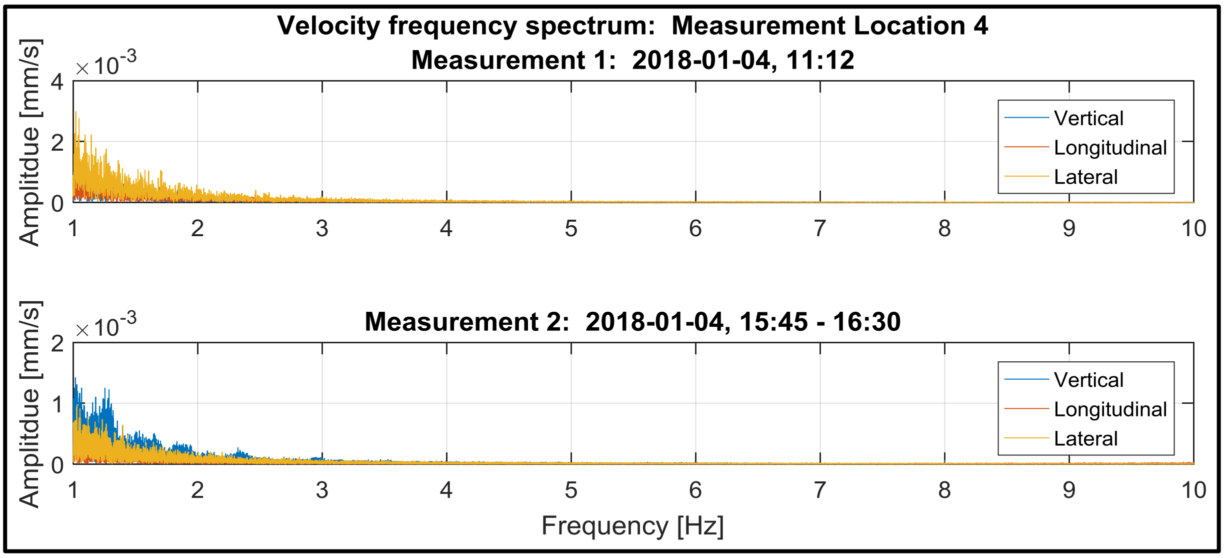

Figure B-11: Frequency Spectrum of Background Vibration Measured at Measurement Location 4

Note that only two measurements were taken at Measurement Location 4 due to the distances involved. See **Section 6** in this report for further details.

Figure B-12: Photo of Measurement Location 4

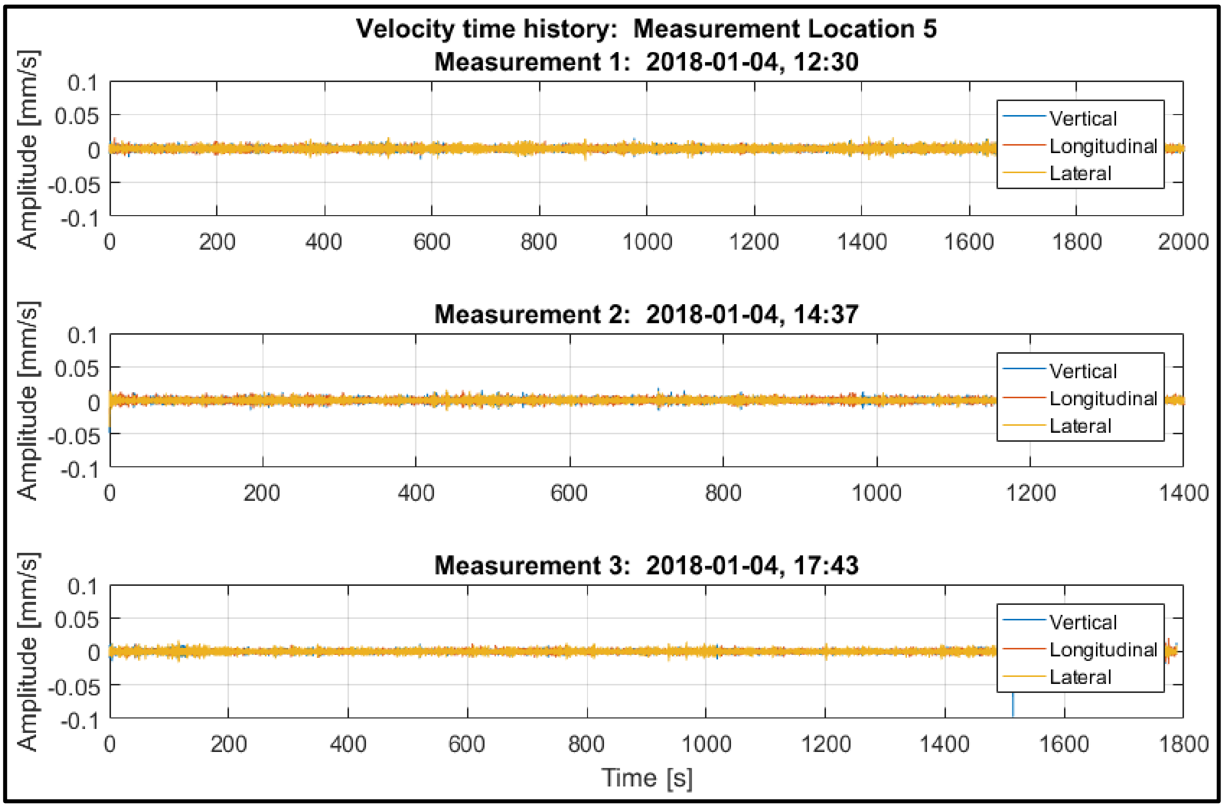

Figure B-13: Time History of Background Vibration Measured at Measurement Location 5

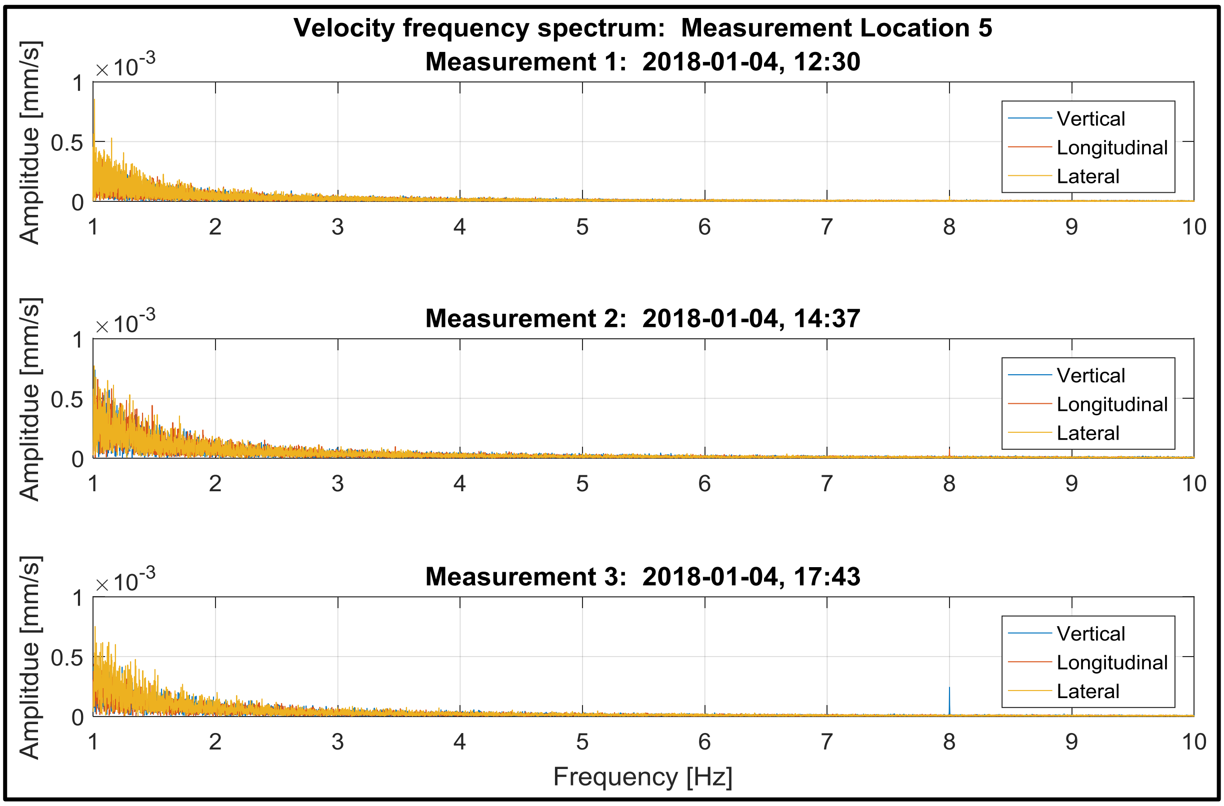

Figure B-14: Frequency Spectrum of Background Vibration Measured at Measurement Location 5

Figure B-15: Photo of Measurement Location 5

APPENDIX C: FOLLOW UP VIBRATION MEASUREMENTS ON A BRIDGE

In **Sub-section 3.6** of the Report, a suggestion is made that an appropriate threshold for impulsive vibration may be the response of a bridge as a vehicle is passing over it. This suggestion is based on personal communication with the Avifaunal Specialist, Mr. David Allan (see **Appendix A**, 16 February 2018), which indicated that this behaviour has been observed in Tanzania. In addition, other swallow species have been known to exhibit this behaviour in South Africa.

In order to obtain a quantitative value, a local bridge in Pretoria, similar in design to what Blue Swallows may use for nesting, was instrumented by using seismic accelerometers that was arranged orthogonally (as was done during the background vibration measurements in the study area). These accelerometers were mounted on an aluminium block and fastened the underside of the bridge.

The test setup was then turned on and recorded approximately 28 minutes of traffic in two measurements. During this time, the traffic on the bridge consisted of cars, pick-up trucks, motorcycles and heavy trucks.

The instrumentation used are described in **Table C-1**, below. In addition, a photograph of the accelerometers on the bridge is provided in **Figure C-1** below. The bridge itself is illustrated in **Figure C-2** below, and a satellite image of the bridge is provided in **Figure C-3** below.

The bridge itself is a small 2-lane bridge crossing the Hartebeesspruit in Pretoria and serves Lynette Street. The coordinates of the bridge are as follows:

Latitude: 25°43'14.3"S

Longitude: 28°15'42.5"E

Table C-1: Instrumentation used to Measure the Vibrations on the Bridge

Item	Serial Number	Details
Coco-80 logger		Resolution: 24 bit Sampling frequency: 2.05 kHz
Seismic Accelerometer (V)	SN 24742	1104 mV/g
Seismic Accelerometer (H)	SN 22590	1048 mV/g
Seismic Accelerometer (H)	SN 25045	1075 mV/g

Figure C-1: Photograph of the Three Seismic Accelerometers on the Measured Bridge (safety cord also visible)

Figure C-2: Photograph of the Bridge where Vibration was Measured

Figure C-3: Satellite Image of the Bridge on where Vibration was Measured

The time-domain results of the recorded data were processed exactly as described in **Sub-section 4.3** in the Report. The processed time-domain results are provided in **Figure C-4** below, and the computed PPV histories are provided in **Figure C-5** below.

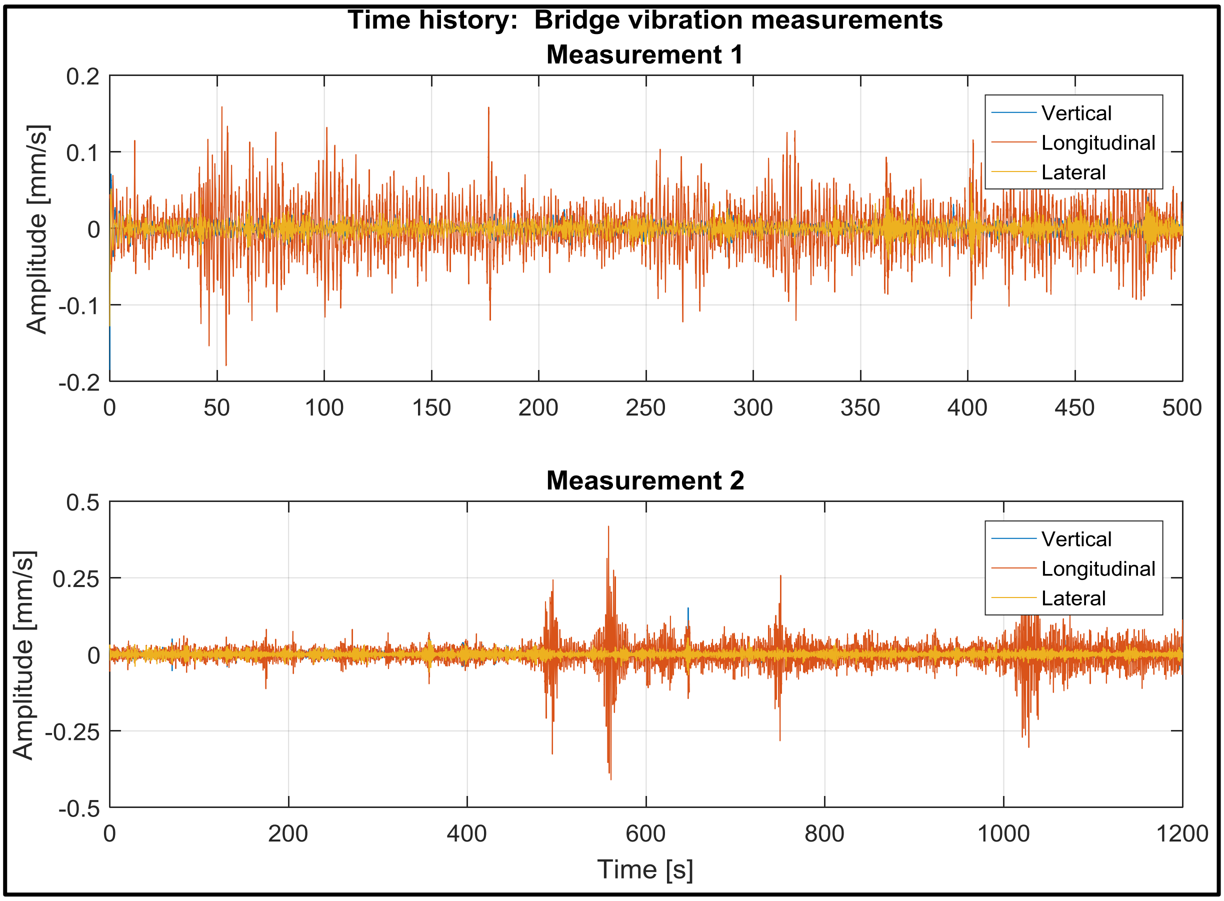

Figure C-4: Processed Time Domain Results of the Measurement Excercise

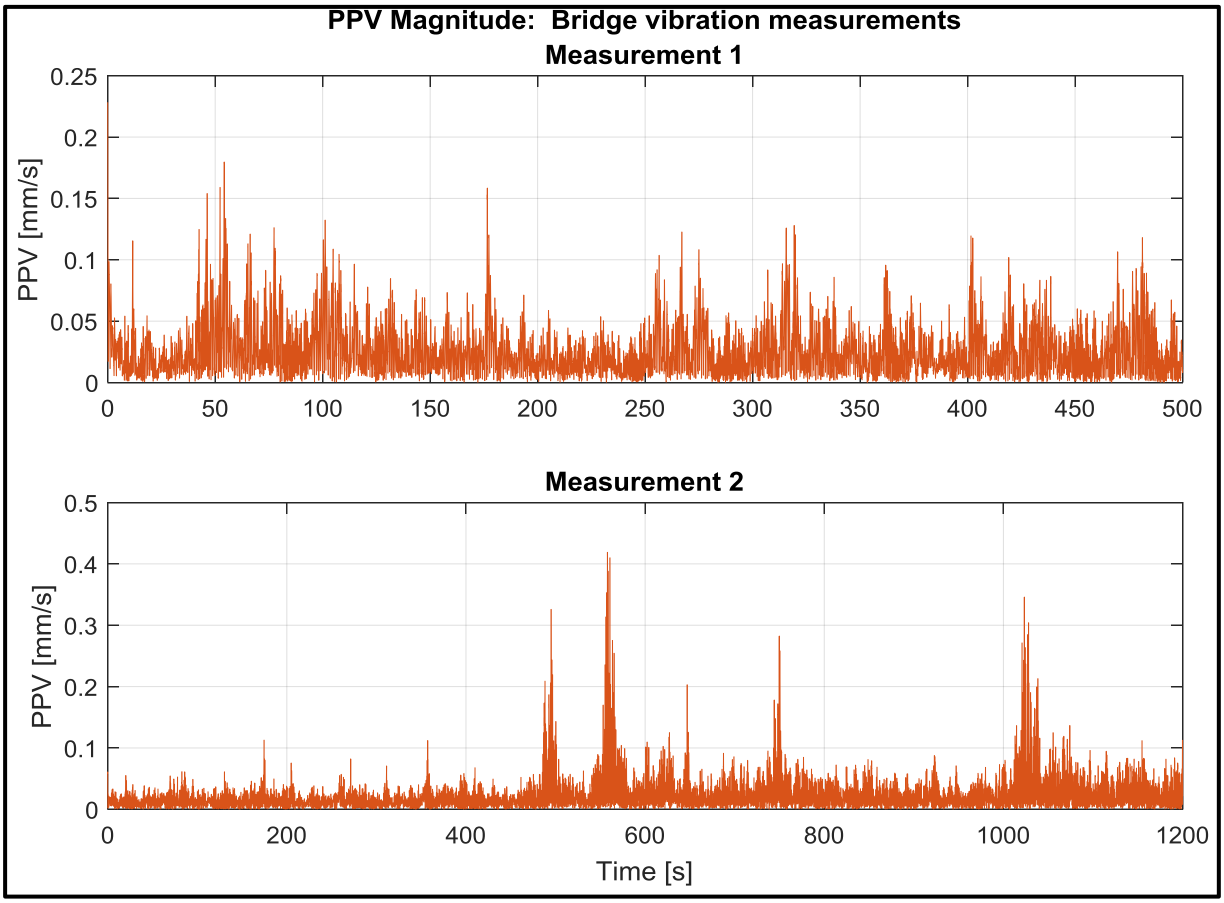

Figure C-5: Processed PPV Results from the Vibration Measurements on the Bridge

The measurements yielded a maximum PPV of 0.41 mm/s as a large refuge removal truck drove over the bridge. This value is, however, less than the maximum impulsive vibrations of 0.57 mm/s measured during the field measurement exercise. As such, the maximum impulsive vibrations during the field measurement exercise were used in the Report as a threshold for impulsive vibrations.

APPENDIX D: SPECIALIST DETAILS

D-1. Summary of Specialist Professional Background

The details of the specialists are summarised in **Table D-1** and **Table D-2** below.

Table D-1: Specialist Details - Prof PS Heyns

Name and Surname	Prof PS Heyns
Role in the Project	Supervisory
Citizenship	South African
Highest Qualification	PhD
Registration	Engineering Council of South Africa – PrEng Registration No. 860377
Experience in field of expertise	More than three (3) decades of experience in vibration and noise related research and specialist consulting projects. Prof Heyns has published more than 65 journal papers in the field as well as about 100 conference papers, most at international conferences. He has acted a project leader for hundreds of industrial projects in South Africa and Abroad. He leads a research team of about 70 people. He is fellow of various South African and international societies, and past president of the Southern African Acoustics Society.

Table D-2: Specialist Details - Mr Rudolph Kroch

Name and Surname	Mr Rudolph Kroch
Role in Project	Mechanical Engineer, specializing in noise and vibrations
Citizenship	South African
Highest Qualification	MEng (Mechanical Engineering)
Registration	Engineering Council of South Africa – PrEng Registration No. 160616
Experience in field of expertise	Nine (9) years' experience analysing noise and vibration problems usually encountered in industrial, mining and automotive applications. Typical projects include: human exposure to whole body vibrations, noise and vibration impact studies, noise and vibration characterisation of plants and machines, vibration-based fault diagnosis in machines, as well as finite element modelling of noise problems.

D-2. Specialist CVs

D-2.1 RUDOLPH KROCH

Education

2012 – 2015 University of Pretoria (UP) Master of Engineering [MEng] (Mechanical)

2009 – 2011 University of Pretoria (UP) Bachelor of Engineering Honours [BEng Hons] (Mechanical)

2005 – 2009 University of Pretoria (UP) Bachelor of Engineering [BEng] (Mechanical)

Professional Experience

Sep 2011 – Present Enterprises University of Pretoria (Pty) Ltd: Provides industry solutions through research and consulting Position: Project Engineer

Notable Commercial Projects

Human vibration survey on open cast mining machines

Several vehicles were evaluated according to the ISO 2631 Standard

Noise and vibration survey in a village near a mine

General noise and vibration root-cause analysis by investigating vibration sound and infrasound

Noise measurement and characterisation of a scrubber in an underground environment

Underground acoustic measurements following the principles of SABS 083

Aerodynamic and noise testing of a continuous miner with integrated scrubber

Two-dimensional mapping of the sound and airflow field around the machine

Finite Element prediction of noise in an underground mining environment

Using the sound power in conjunction with the measured direct field sound of a scrubber, the entire sound field in an underground environment was calculated

Human vibration survey and assessment on a diesel locomotive

Several locomotives were evaluated according to the ISO 2631 standard

Acoustic and vibration analysis on an armoured personnel carrier

In situ sound and vibration were measured on the vehicle in order to identify the source of spurious noise in the vehicle while on the Gerotek Test Track.

Surface miner vibration survey

Acceleration, sound, vehicle speed and rotor speed of a surface miner were recorded for the client

Roll over Protective Structure (ROPS) and Falling Object Protective Structure (FOPS) tests

Evaluated according to the ISO3471 (ROPS), ISO 3449 (FOPS) and Anglo American 264073 (ROPS and FOPS) Standards.

Environmental Impact Assessments

Ground vibration, noise and fly-rock assessments for envisioned industries such as mines, railways and pipelines. No south African legislation exists, therefore assessments are based on international best practices and scientific literature.

Graduate Projects

2011 – 2015: Development of a Low-Cost Vibration Monitoring System for Industrial Gearboxes

A continuation of the project “Development of a prototype vibration monitoring system for industrial gearboxes”, the objectives of the projects overlap. The difference is that the goal of the previous project was to develop a prototype, whereas this project aims to develop a production system. The hardware developed in this project seeks to rectify the deficiencies of the prototype and condenses the entire system in a user friendly, PC independent package and introduces several features. More attention is paid to the algorithms to enhance the speed of operation, by means of effort spent on optimising the signal processing techniques used.

2009 – 2011: Development of a Prototype Vibration Monitoring System for Industrial Gearboxes

Using basic signal processing techniques (Detrending, Windowing and FFT analysis) this project aimed to develop a low-cost, hand held, vibration tester for industrial gearboxes. The challenge in the project was detection of faults in the gearbox with very limited processing power. Starting with a vibration measurement campaign at the SASOL Plant in Secunda, representative signals were recorded and algorithms developed, tested and refined in the Matlab environment. Once satisfied, these were translated to C where they were further adapted for the embedded environment. In parallel the prototype specification was generated and component selection took place. Once the electronic hardware was designed (with the help of an electronic development firm) the prototype was tested, first in the SASOL laboratory and then on the SASOL Plant. The system worked, but several flaws were identified and corrected with a follow up project, which is the focus of the current project (see above).

Jan – Nov 2009: Wear and Tribological Investigation of a Transfer Case

This group project aimed to investigate the tribological aspects of the transfer case of a heavy-duty military vehicle, and to determine the general service intervals. During the project a transfer case was subjected to simulated loads representing normal operation of the vehicle. Oil samples were drawn as well as oil temperature, load and speed measured. After the test, the oil temperature, gearbox loading and gearbox speed were correlated to investigate the correspondence. Spectrographic oil analyses were performed on the oil samples and correlated with wear on specific transfer case components, such as the roller bearings, journal bearings, casing, shafts and gears.

Jan – Nov 2008: Vibration Monitoring and Lifetime Prediction on a Helical Gearbox

The objective of this project was condition monitoring on a small Helical Gearbox, where a gearbox was subjected to overloading conditions until failure. The life of the gears was monitored throughout the test with the use of data trending in the time and frequency domain. This was compared to theoretical life calculations of the gear.

D-2.2 STEPHAN HEYNS

Stephan Heyns is a professor of Mechanical Engineering at the University of Pretoria and holds a BSc (Eng Mech)(1977) degree, an MEng(Mech Eng)(1982) degree and a PhD degree (1987) in Mechanical Engineering. He is currently director of the Centre for Asset Integrity Management (C-AIM) at the University of Pretoria. The C-AIM focuses on aspects of the physical integrity of mechanical and civil engineering structures systems. His particular expertise is in the measurement and analysis of vibration of systems, the analysis of the vibration and noise signals and the interpretation of these signals on machine health as well as human health. Prof Heyns has been teaching various courses on undergraduate and post-graduate levels on vibration and noise analysis at the University of Pretoria since 1982. He is particularly knowledgeable on the diagnostics and prognostics of these vibration and noise disturbances in the context of machine health monitoring as well as human health monitoring. Prof Heyns has authored or co-authored more than 65 journal papers in internationally per reviewed journals, as well as more than 100 conference papers. He has also supervised ten (10) PhD students and about fifty (50) Masters Degree students in this general field. A full list of publications can be found at the following link:

http://web.up.ac.za/default.asp?ipkCategoryID=14193&sub=1&parentid=2163&subid=2164&ipklookid=7

He is a member of scientific committees of various international conferences. He is a C1 accredited researcher with the National Research Foundation (NRF) in South Africa, as well as a fellow of the South African Academy of Engineering, a fellow of the SA Institution of Mechanical Engineers and a fellow of the International Society of Engineering Asset Management.

He is also head of the Sasol Laboratory for Structural Mechanics, at the University of Pretoria. This laboratory does extensive vibration related analysis and testing work for numerous South African and international companies. He has done extensive environmental vibration related projects, which include numerous vibration environmental impact studies and continuous vibration monitoring studies for the Gautrain Project, the Coega-Hotazel Freight Train Expansion Project, as well as blasting impact studies on many projects in African countries.

APPENDIX E: SPECIALIST INDEPENDENCE DECLARATION

I, Rudolph Kroch, declare that –

- I act as the independent specialist;
- I will perform the work relating to the project in an objective manner, even if this results in views and findings that are not favourable to the project proponent;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this project, including knowledge of the National Environmental Management Act, 1998 (Act No. 107 of 1998; the Act), regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, regulations and all other applicable legislation;
- I will take into account, to the extent possible, the matters listed in Regulation 8 of the Act;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the project proponent and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the project; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority or project proponent;
- All the particulars furnished by me in this document are true and correct; and
- I realise that a false declaration is an offence in terms of Regulation 71 of the Act and is punishable in terms of Section 24F of the Act.

Signature of Specialist: RC Kroch

Company: Enterprises at University of Pretoria (Pty) Ltd: Research Solutions

Date: 15 July 2018