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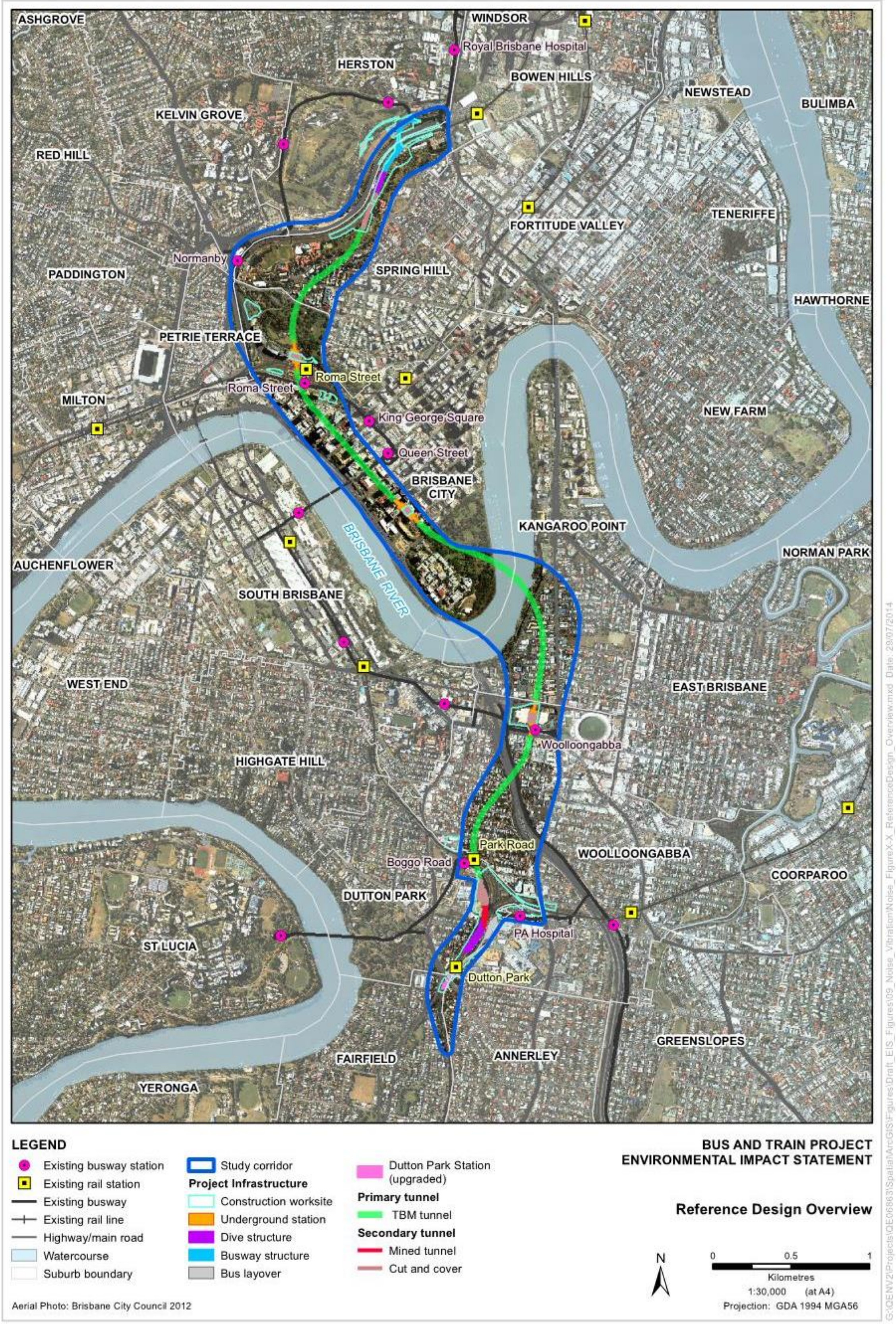
1 INTRODUCTION

SLR Consulting Australia Pty Ltd (SLR) has been commissioned by the SKM-AECOM Joint Venture (JV) to prepare an assessment of the noise and vibration aspects of the operational phase for Underground Bus and Train project (BaT) for inclusion in the Environmental Impact Statement (EIS).

BaT is a major project for the City of Brisbane, South East Queensland and the State of Queensland. It will provide a new north-south rail line in Brisbane's inner city that includes a new river crossing and inner city train stations. From the existing southern rail network, it will pass under the central business district (CBD) of Brisbane and connect with the existing northern rail network.

A project overview with the defined Reference Project alignment is shown in Figure 1**.**

Figure 1 BaT Reference Project



1.1 Terms of Reference

Objective: Development is planned, designed, constructed and operated to protect the environmental values of the acoustic environment.

- Fully describe the characteristics of the noise and vibration sources that would be emitted when carrying out the activity (point source and general emissions). Describe noise and vibration emissions (including fugitive sources) that may occur during construction, commissioning, upset conditions, and operation.
- Predict the impacts of the noise emissions and vibration from the construction and operation of the project on the environmental values of the receiving environment, with reference to sensitive receptors, using recognised quality assured methods. Discuss separately the key project components likely to present an impact on noise and vibration for the construction and operation phases of the project.
- Taking into account the practices and procedures that would be used to avoid or minimise impacts, the impact prediction must address the:
    - activity's consistency with the objectives
    - cumulative impact of the noise with other known emissions of noise associated with existing development and possible future development (as described by approved plans)
    - potential impacts of any low-frequency (<200 Hz) noise emissions
    - potential vibration impacts on sensitive receptors and transport-related infrastructure.
- Describe how the proposed activity, and in particular, the key project components described above, would be managed to be consistent with best practice environmental management for the activity. Where a government plan is relevant to the activity, or the site where the activity is proposed, describe the activity's consistency with that plan.
- Describe how the achievement of the objectives would be monitored and audited, and how corrective actions would be managed.

1.2 Objectives

The objectives of this report in relation to the project description are to:

- Address the acoustical requirements detailed in the project's Terms of Reference in relation to the operational phase of the project.
- Evaluate the operational noise and vibration impacts at sensitive locations in terms of planning levels identified in the EPP[Noise] and other Guidelines.
- Define noise and vibration goals by which operational noise and vibration impacts at sensitive locations may be evaluated.
- Evaluate the extent of resulting impacts and the scope for the reduction of these impacts through reasonable and feasible mitigation strategies.
- Recommend appropriate mitigation measures.

2 IMPACT ASSESSMENT GOALS

The noise and vibration associated with the operational phase of the Project can be divided into the following main categories:

- Noise and vibration generated by surface rail and bus operations.
- Ground-borne vibration generated by underground rail operations.
- Ground-borne noise generated by underground rail operations.
- Noise emission from mechanical ventilation plant at stations and portals.

The relevant noise and vibration goals for these categories are outlined in the following section. In addition to the noise and vibration goals discussed for the above main categories, **Section 2.1** gives a general discussion of the community values with regard to noise and vibration.

2.1 Community Values Relating to Noise and Vibration

The Queensland Environmental Protection (Noise) Policy 2008 (EPP[Noise]) defines the values to be protected as the qualities of the acoustic environment that are conducive to:

- The qualities of the acoustic environment that are conducive to protecting the health and biodiversity of ecosystems.
- The qualities of the acoustic environment that are conducive to human health and wellbeing, including by ensuring a suitable acoustic environment for individuals to do any of the following-
  a. Sleep
  b. Study or learn
  c. Be involved in recreation, including relaxation and conversation
- The qualities of the acoustic environment that are conducive to protecting the amenity of the community.

Sleep

A person's ability to sleep is perhaps the most important value that can be impacted by noise and/or vibration. Noise and vibration effects on sleep are generally referred to as sleep disturbance.

Education and Work

The needs for education and work in relation to the acoustic environment relate to the need to be able to communicate effectively either face-to-face or by telephone, and the ability to think or focus on auditory information without undue intrusion from other sources of noise.

Recreation

Recreation is an important aspect of a healthy lifestyle. Recreation may include time spent both indoors and outdoors. In terms of acoustic function, recreation may involve communication with others in verbal conversation or simple enjoyment of an outdoor or indoor soundscape.

2.1.1 Acoustic Quality Objectives

The EPP(Noise) includes long term acoustic quality objectives. It is intended that the acoustic quality objectives be progressively achieved as part of achieving the purpose of the EPP(Noise) policy over the long term. The EPP(Noise) states that it is not applicable for assessing noise mentioned in the reprint No 8 (2009) of the Environmental Protection Act 1994 (the Act), Schedule 1, Part 1 which refers to safety and transportation noise. Therefore, the acoustic quality objectives are not considered applicable for assessing the operational noise associated with rail or bus operations for this project. The acoustic quality objectives will be considered for assessing the ventilation and mechanical plant noise associated with the new rail and ventilation stations as these will be permanent long-term noise sources.

2.1.2 Evaluating Impacts

The impact of a project on community values relating to noise and vibration is normally evaluated using statutory regulations and policies which describe acceptable levels of noise and vibration from various sources.

For types of noise for which specific levels are not listed in statutory regulations or policies, it is common to refer to relevant Australian or internationally recognised standards that define acceptable levels of noise and vibration in various human and structural contexts. Such standards can serve an advisory function to regulatory organisations and may be adopted by statutory authorities for the purpose of defining regulatory levels.

2.2 Surface Rail Operations

The applicable noise criteria for the railway surface track airborne noise emissions are in accordance with Queensland Rail's *Code of Practice – Railway Noise Management* (Queensland Rail Code of Practice). The Queensland Rail Code of Practice refers to the following operational noise metrics and operational planning noise levels.

2.2.1 QR Noise Metrics

The two primary noise metrics used to describe railway noise emissions in accordance with the Queensland Rail Code of Practice are:

- **Single Event Maximum Level** Queensland DERM and Queensland Rail have reached agreement on the definition of single event maximum level as being the *"arithmetic average of the 15 highest maximum noise levels in the 24 hour period"*.
- **$L_{Aeq(24hour)}$** "Equivalent Continuous Noise Level", sometimes referred to as the "energy-averaged noise level". The $L_{Aeq(24hour)}$ may be likened to a "noise dose", representing the cumulative effect of all train noise events occurring in one day and is calculated from the sound exposure level (SEL)[1] of each individual train passby.

2.2.2 QR Planning Levels

Queensland Rail's Code of Practice outlines the operational "planning levels" applicable to this project.

The Planning Levels are:

- 65 dBA, assessed as the 24 hour average equivalent continuous A-weighted sound pressure level, $L_{Aeq(24hour)}$.
- 87 dBA, assessed as a Single Event Maximum sound pressure level.

The planning levels refer to an assessment location one metre in front of the facade of an affected noise sensitive building.

[1] SEL – Is the total sound energy for the train passby referenced to 1 second.

2.3 Surface Bus and Road Operations

The applicable noise criteria for the surface busway and road alignments are in accordance with the Department of Transport and Mains Roads (DTMR) *Transport Noise Management Code of Practice* (Code of Practice).

Categories and criteria for 'Busway' roads are applicable to the sections of carriageway which carry only buses, not other transport types. Categories and criteria for 'Multi-modal Corridor' roads are applicable to sections of carriageway which carry different types of vehicles (eg cars, motorcycles and buses).

The following DTMR Code of Practice Categories and Criteria (Table 1) are applicable to the BaT project.

Table 1 Road Categories and Criteria

Categories	**Criteria (dBA)**		
	Existing Residences	**Educations, Community and Health buildings**	**Outdoor Educational and Passive Recreational areas (Parks)**
Multi-Modal Corridor			
New Road – Access Controlled	63 LA10 (18hour) existing level > 55LA10 (18(hour) 60 LA10 (18hour) existing level ≤ 55LA10 (18(hour)	58 LA10 (1hour)	63 LA10 (12 hour)
Upgrading Existing Road	68 LA10 (18 hour)	65 LA10 (1hour)	
Busway			
New Busway	55 LAeq (1hour) day & evening 50 LAeq (1hour) night 64 LAmax night	55 LAeq (1hour) operation hours 64 LAmax night	57 LAeq (1hour) day 66 LAmax day
Upgrading Existing Busway	60 LAeq (1hour) day and evening 55 LAeq (1hour) night 69 LAmax night	60 LAeq (1hour) operation hours 69 LAmax night	

2.4 Ground-borne Vibration

The effects of vibration in buildings can be divided into four main categories:

- Human comfort.
- Effects of vibration on building contents.
- Safe vibration levels for common services.
- Structural damage.

A fifth effect is the noise generated within buildings as a result of the vibration. This is termed "ground-borne noise" and is discussed further in **Section 2.5**.

2.4.1 Human Comfort

Humans are far more sensitive to vibration than is commonly realised. They can detect and possibly even be annoyed at vibration levels which are well below those causing any risk of damage to a building or its contents.

2.4.2 Human Subjective Response to Vibration

The actual perception of motion or vibration may not, in itself, be disturbing or annoying. An individual's response to that perception, and whether the vibration is "normal" or "abnormal", depends very strongly on previous experience and expectations, and on other connotations associated with the perceived source of the vibration. For example, the vibration that a person responds to as "normal" in a car, bus or train is considerably higher than what is perceived as "normal" in a shop, office or dwelling.

Human tactile perception of random motion, as distinct from human comfort considerations, was investigated by Diekmann and subsequently updated in German Standard *DIN 4150 Part 2 1975*. On this basis, the resulting degrees of perception for humans are suggested by the continuous vibration level categories given in **Table 2**.

Table 2 Vibration Levels and Human Perception of Motion

Approximate Vibration Level	Degree of Perception
0.10 mm/s	Not felt
0.15 mm/s	Threshold of perception
0.35 mm/s	Barely noticeable
1 mm/s	Noticeable
2.2 mm/s	Easily noticeable
6 mm/s	Strongly noticeable
14 mm/s	Very strongly noticeable

Note: These approximate vibration levels (in floors of building) are for vibration having frequency content in the range of 8 Hz to 80 Hz.

Table 2 suggests that people will just be able to feel continuous floor vibration at levels of about 0.15 mm/s and that the motion becomes "noticeable" at a level of approximately 1 mm/s.

Although people are able to perceive relatively low vibration levels, it is not appropriate to set vibration emission limits requiring "no vibration", since there will always be some measurable vibration in any environment. Realistic design goals should therefore be set to minimise disturbance and adverse impacts on amenity. The recommended approach is discussed in the ground-borne vibration goals section below.

2.4.3 Effects of Vibration on Building Contents

People can perceive floor vibration at levels well below those likely to cause damage to building contents or affect the operation of typical equipment. As such, the controlling vibration design goals during operations will be the human comfort goals, and it is therefore not necessary to set separate design goals for the Project in relation to the effect of railway vibration on common building contents.

Some scientific equipment (eg electron microscopes and microelectronics manufacturing equipment) can however require more stringent design goals than those applicable to human comfort. In such cases, vibration design goals should be obtained from the specific equipment manufacturers. If specific vibration design goals are not available, recommended vibration levels are provided in the Association of Noise Consultants "Measurement and Assessment of Ground-Borne Noise & Vibration" (ANC Guidelines 2001) and Ungar et Al "Vibration Control Design of High Technology Facilities", Journal of S & V, (Ungar 1990). The vibration criterion curve BBN - C provided in the ANC Guidelines 2001 should be used as a trigger level for further investigation for identified receivers likely to have highly vibration sensitive equipment. The BBN – C curve (also referred to as the VC-C curve in other literature) specifies a limit of 0.013 mm/s (or expressed in decibels 82 dB_V re 10^{-9} m/s) per 1/3 Octave band for frequencies between 8 Hz and 80 Hz and is appropriate for most lithography and inspection equipment down to 1 micron detail size.

The most sensitive equipment adjacent to the Project alignment is a Transmission Electron Microscope (TEM) located in the basement of the Eco-Science Precinct. A technical paper received from the tenant for this specific TEM (JEOL type JEM-1400) gives a vibration deflection tolerance as presented in **Table 3**. Also included in **Table 3** are the estimated equivalent vibration velocity criteria, based on evenly distributed vibration energy within each of the specified frequency ranges.

Table 3 Floor Vibration Tolerance for JEM-1400

Frequency Range	Vibration Displacement (μm)		Vibration Velocity (mm/s)	
	Vertical	Horizontal	Vertical	Horizontal
3 Hz or less	2	0.6	0.019 mm/s	0.006
3 Hz to 10 Hz	0.5	0.5	0.02	0.02
10 Hz or higher	1	0.2	0.3	0.06

Note: It should be noted that normally the horizontal vibration is significantly lower in buildings than the vertical vibration, especially at basement and lower floor levels. The very strict horizontal vibration criteria indicate that the JEOL vibration criteria could be based on actually measured floor vibrations at a successful installation site rather than based on forced vibrations until disturbances are noticed in the equipment.

2.4.4 Safe Vibration Levels for Common Services

The levels of vibration required to cause damage or disruption to common services are at an order of magnitude (10 times) higher than those at which people may consider the vibration to be intrusive. Therefore, it is not necessary to set separate assessment goals for this project in relation to vibration induced effects on common services for the operational phase.

2.4.5 Effects of Vibration on Structures

As for common services above, the levels of vibration required to cause damage to buildings (including sensitive heritage buildings) tend to be at least an order of magnitude (10 times) higher than those at which people may consider the vibration to be intrusive. Therefore, it is not necessary to set separate assessment goals for the operational phase of this project in relation to building damage from railway vibration.

2.4.6 Ground-borne Vibration Goals

On the basis of the above discussion, the vibration goals adopted for this project are based on human comfort considerations, rather than the less stringent building damage risk criteria or potential effects on building contents, except at the Eco-science precinct TEM facility.

There are several sources from which relevant vibration criteria may be drawn. These include:

- Australian Standard AS 2670.2 1990 “Evaluation of Human Exposure to Whole Body Vibration - Part 2: Continuous and Shock Induced Vibration in Buildings (1 Hz to 80 Hz)”.
- The United States Federal Transit Administration (FTA) guideline “Transit Noise and Vibration Impact Assessment”.
- British Standard BS 6472-1:2008 “Guide to evaluation of human exposure to vibration in buildings Part 1: Vibration sources other than blasting”.
- The NSW Department of Environment, Climate Change and Water (now Environment Protection Authority) document “Assessing Vibration: A Technical Guideline”.

The following discussion expresses vibration levels in terms of both vibration velocity in mm/s and decibels (dB_V re 10^{-9} m/s). A level of 100 dB corresponds to 0.1 mm/s (rms) and a level of 120 dB corresponds to 1 mm/s (rms). They are both included below since many of the International references in relation to vibration from railways give the vibration limits in decibels, however, in Queensland it is most common to express vibration limits in mm/s. All values are in root mean square (rms) averaged values.

AS 2670.2 provides recommended vibration levels corresponding to 106 dB_V (0.2 mm/s) to 112 dB_V (0.4 mm/s) for residential buildings during the daytime, reducing to 103 dB_V (0.14 mm/s) during the night-time. These levels apply to both continuous and intermittent vibration. For office and industrial buildings, the recommended vibration levels are 112 dB_V (0.4 mm/s) and 118 dB_V (0.8 mm/s) respectively, independent of the time of day. Much higher vibration levels are permitted for transient events with only a few occurrences per day.

For residential buildings, the US FTA guideline recommends a vibration level of 100 dB_V (0.1 mm/s) for frequent events (ie more than 70 per day), 103 dB_V (0.14 mm/s) for occasional events (ie between 30 and 70 per day) and 108 dB_V (0.25 mm/s) for infrequent events (ie less than 30 per day). For schools, churches, quiet offices, etc, the recommended vibration levels are 3 dB higher than residential receivers.

BS 6472 includes a vibration dose relationship for intermittent events such as trains, which for a “low probability of adverse comment” would permit vibration levels of up to approximately 110 dB_V (0.32 mm/s) on the basis of the frequent nature of the rail operations in the proposed Underground Bus and Train tunnel.

The Environment Protection Authority (EPA) “*Assessing Vibration: A Technical Guideline*” is based on the guidelines contained in BS 6472. The acceptable values for intermittent vibration are the same as detailed above (namely 110 dB_V).

The proposed vibration goal for residential receivers is based on the lower daytime value in AS 2670, namely 106 dB_V (0.2 mm/s). This level is recommended for both the daytime and night-time periods, recognising that the intermittent nature of train vibration events and that the frequency of train passby events will be lower during the night-time period.

The recommended level of 106 dB_V for residential receivers is 3 dB_V higher than the 103 dB_V night-time level (for continuous vibration) in AS 2670, but 4 dB_V lower than the BS 6472 and DECCW guidelines.

For other sensitive receiver categories, the proposed vibration goals are listed in **Table 4**. For assessment purposes, these goals may be regarded as applicable to the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.

Table 4 Ground-borne Vibration Goals

Receiver Type	Period	Vibration Goal[1,2] (Vibration Velocity)
Residential	Day/Night	0.2 mm/s (106 dB_V)
Commercial (including schools and places of worship)	When in use	0.4 mm/s (112 dB_V)
Industrial	When in use	0.8 mm/s (118 dB_V)
Sensitive equipment within medical or research facilities	When in use	0.013 mm/s (82 dB_V) [3]

Note 1: The vibration goals are based on the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.
2: dB_V re 10^{-9} m/s
3: Unless actual equipment manufacturer data are available.

In the case of railway tunnels, the ground-borne noise goals, presented in **Section 2.5**, almost always dictate lower vibration levels than the vibration goals indicated in **Table 4**. Hence other than at specific facilities with equipment with particularly high sensitivity to vibration, compliance with the ground-borne noise goals should ensure that the vibration goals will also be achieved.

2.5 Ground-borne Noise

The fact that ground-borne train noise may be audible does not necessarily indicate that it is offensive or disturbing. In many cases, the train noise may pass unnoticed due to the “masking” effect of other ambient noise sources, activities or distractions.

Some especially sensitive spaces and activities, such as theatres, cinemas, studios and sleeping areas are more prone to disturbance from ground–borne noise than others, such as shopping areas, office spaces or industrial premises.

There are no Australian Standards specifically addressing the issue of ground-borne noise from railway operations. Guidance can be obtained, however, from the following International and Australian references.

- International Standard ISO 14837-1:2005(E) Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General Guidance, First Edition 2005
- American Public Transit Association (APTA), Guidelines for Design of Rapid Transit Facilities, 1991
- Federal Transit Administration (FTA), US Department of Transport, Transit Noise and Vibration Impact Assessment, May 2006.
- The Association of Noise Consultants Measurements & Assessment of Groundborne Noise & Vibration, 2001.
- Harris Miller Miller and Hanson Inc. Transit Noise and Vibration Impact Assessment, 1995 (a guideline prepared for the United States Department of Transportation).
- NSW EPA Rail Infrastructure Noise Guideline (RING), May 2013.

All the above standards and guidelines acknowledge and are specifically designed to take into account the intermittent and low frequency character of ground-borne noise and subjective characteristics of underground rail operations as part of the assessment criteria. Therefore, these guidelines have been deemed more relevant than the more general (ie not specific to ground-borne noise from underground rail operations) Ecoaccess Draft Guideline *Assessment of Low Frequency Noise*.

Currently, ISO 14837 only provides guidance in relation to the prediction of ground-borne noise levels and factors that need to be considered in the prediction process. Acceptability criteria are currently not included in ISO 14837.

The APTA Guidelines recommend a ground-borne noise goal of 40 dBA for multi-family dwellings in average to high-density residential areas and a design goal of 35 dBA for single family dwellings in these areas. For hospital buildings, schools, libraries and university buildings, the Guidelines recommend a ground-borne noise design goal of 35-40 dBA. For auditoriums and music rooms a design goal of 30 dBA is recommended, while for churches and theatres the design goal is 30-35 dBA.

The FTA Guideline presents ground-borne noise impact criteria for residential (sleeping area) between 35 dBA and 43 dBA (maximum passby levels) for infrequent (less than 30) events and frequent (more than 70) events. The FTA Guideline also presents ground-borne noise and vibration criteria for special buildings (concert halls, TV studios, recording studios, auditoriums and theatres) ranging from 25 dBA to 35 dBA for frequent events.

The noise criteria contained within the RING guideline are expressed as non-mandatory “trigger levels”, which if exceeded will trigger the need to consider feasible and reasonable mitigation measures. A summary of the ground-borne noise trigger levels provided in RING guideline is presented in **Table 5**.

Table 5 RING Ground-borne Noise Trigger Levels for Sensitive Receivers

Receiver	Time of day	Noise trigger levels dB(A)
		Development increases existing rail noise levels by 3 dB(A) or more ***and*** resulting rail noise levels exceed:
Residential	Day (7 am–10 pm)	40 L_{Amax} (slow)
	Night (10 pm–7 am)	35 L_{Amax} (slow)
Schools, educational institutions, places of worship	When in use	40–45 L_{Amax} (slow)

The ground-borne noise levels in **Table 5** refer to noise contributed from the proposed rail operations only and do not include ambient noise from other sources such as major roads and industry. The train noise levels are evaluated inside buildings at the centre of the most affected habitable room.

“Residential” typically means any residential premises located in a zone as defined in a planning instrument that permits new residential land use as a primary use. The LAmax noise level refers to the 95th percentile train passby event (ie 5% of train passbys are permitted to exceed the trigger levels). The absolute maximum event is not used for design, as it cannot be precisely defined and would be a highly infrequent event. The ground-borne noise level of the “average” or median train event would typically be approximately 3 dB lower than the 95th percentile event.

For new rail projects, the noise trigger levels apply immediately after operations commence and for projected traffic volumes over an indicative period into the future that represents the expected typical level of rail traffic usage (eg 10 years or a similar period into the future).

For schools, educational institutions and places of worship, the lower value of the range is most applicable where low internal noise levels are expected, such as in areas assigned to studying, listening and praying.

The RING guideline also states:

> *"It appears reasonable to conclude that ground-borne noise at or below 30 dB LAmax will not result in adverse reactions, even where the source of noise is new and occurs in areas with low ambient noise levels. Levels of 35–40 dB LAmax are more typically applied and likely to be sufficient for most urban residential situations, even where there are large numbers of noisy events.*
>
> *When assessing the impact of ground-borne noise, the noise trigger levels … are necessarily set to the lower end of the range of possible trigger values so that potential impacts on quieter suburban locations are addressed. In practice, higher levels of ground-borne noise than the trigger level for assessing impacts may be appropriate for urban areas where background noise levels are relatively high."*

For commercial receivers, shopping centres and industrial buildings, RING does not provide guidance on acceptable levels. On other projects, SLR has applied ground-borne noise goals of 45 dBA for general office areas and 50 dBA to 55 dBA for retail areas depending on the particular sensitivity of the receiver. A ground-borne noise design goal of 40 dBA is desirable for commercial receivers with private offices or conference rooms.

Based on the above, **Table 6** provides a summary of the proposed ground-borne noise goals for the Project.

Table 6 Ground-borne Noise Goals

Receiver	Time of Day	Noise Trigger Level (dBA)[1]
Residential	Day (7.00 am to 10.00 pm)	40 dBA
	Night (10.00 pm to 7.00 am)	35 dBA
Schools, educational institutions, places of worship[2]	When in use	40 dBA to 45 dBA
Retail Areas	When in use	50 dBA to 55 dBA
General Office Areas	When in use	45 dBA
Private Offices and Conference Rooms	When in use	40 dBA
Theatres	When in use	35 dBA

Note 1: Evaluated as the L_{Amax} "Slow" response noise level (interpreted as applicable to the 95th percentile train passby event ie typically the highest 1 in 20 event).

Note 2: The lower value of the range is primarily applicable where low internal noise levels are expected, such as in areas assigned to studying, listening, quiet contemplation and praying.

2.6 Mechanical Plant and Ventilation

Relevant assessment criteria for operational mechanical plant noise can be found in the following:

EPP(Noise)

- Minimising Background Creep – Existing L_{A90} + 0 dBA
- Acoustic Quality Objectives – Refer to Schedule 1 in EPP(Noise)

DERM Ecoaccess Guideline Planning for Noise Control (Ecoaccess PNC)

- Minimising Background Creep – Refer to Table 1 and Table 2 of Ecoaccess PNC
- Planning Noise Levels (PNL) – Refer to Table 3 and Table 4 of Ecoaccess PNC
- Specific (Intrusive) Noise Levels (SNL) – Existing Rating Background Level (RBL[2]) + 3 dBA (assessed as L_{Aeq})

DERM Draft Ecoaccess Guideline Assessment of Low Frequency Noise (Ecoaccess ALFN)

- Refer to Table 3 of the draft Ecoaccess ALFN.

Brisbane City Council (BCC) Noise Impact Assessment Planning Scheme Policy (NIAPSP)

- Minimising Background Creep – Existing L_{A90} + 0 dBA (for noise categories R3 to R6 as per Appendix A of AS 1055.2)
- Comparison of Like Parameters – Existing LA90 + 0 dBA
- AS/NZS 2107: 2000 Acoustics – Recommended design sound levels and reverberation times for building interiors (AS 2107) internal noise levels – Refer to Table 1 in AS 2107

The applicable statutory requirement for noise emissions associated with fixed mechanical plant is the EPP(Noise). The EPP(Noise) nominates long term acoustic quality objectives and a background creep criteria applicable to stationary mechanical plant.

The background creep criteria according to the EPP(Noise) is identical with the background creep criteria according to BCC's NIAPSP. The Ecoaccess PNC includes more complex background noise criteria. In determining the appropriate background creep goals for the BaT Project, the statutory and Brisbane City Council criteria have been adopted.

Mechanical ventilation noise is generally steady state (ie the noise emission varies very little with time in the short term) and therefore the difference between the L_{A90} the L_{Aeq} will be small. As a result, based on the criteria/limits discussed above, the L_{A90} based background creep criteria will be stricter than the L_{Aeq} based intrusive noise criterion. In determining the appropriate goal, a conservative approach has been adopted and thus only a background creep goal has been recommended.

The Ecoaccess ALFN guideline gives advice regarding assessment of infrasound and low frequency noise. However, the mechanical ventilation and/or emergency ventilation noise associated with the Project is not anticipated to generate any infrasound or distinctly low frequency noise and therefore will not require a specific assessment.

On the basis of the above references and discussion, the proposed noise goals for mechanical plant are presented in **Table 7**.

[2] The RBL is the median of the 90th percentile background (L_{A90}) noise levels in each assessment period (day, evening and night) over the duration of the monitoring (as defined in the Queensland Department of Environmental Resources Management (DERM) *Ecoaccess Guideline Planning for Noise Control*)

Table 7 Operational Mechanical Plant Noise Goals

Receiver	Time of Day	Background Noise Creep[1], dBA LA90(1hour)	Acoustic Quality Objectives[2], dBA LAeq(1hour)
Residential (for outdoors)	7am to 10pm	b/g + 0 [3]	50 [3]
	10pm to 7am	b/g + 0	-
Residential (for indoors)	7am to 10pm	-	35
	10pm to 7am	-	30
Library and educational institution (including a school, college and university) (for indoors)	when open for business or when classes are being offered	-	35
Commercial and retail activity (for indoors)	when the activity is open for business	-	45

Note 1: Background creep criteria in accordance with the EPP(Noise) and BCC NIAPSP for continuous noise sources, adopting the Rating Background Level in accordance with the DERM Ecoaccess PNC. Applicable for noise contribution from the source only.

2: Long term acoustic quality objectives according to EPP(Noise).

3: The lower of the background creep $L_{A90(1hour)}$ and Acoustic Quality Objectives $L_{Aeq(1hour)}$ is applicable.

3 NOISE AND VIBRATION TERMINOLOGY

3.1 Noise

The terms “sound” and “noise” are almost interchangeable, except that in common usage “noise” is often used to refer to unwanted sound. Sound (or noise) consists of minute fluctuations in atmospheric pressure capable of evoking the sense of hearing. The human ear responds to changes in sound pressure over a very wide range. The loudest sound pressure to which the human ear responds is ten million times greater than the softest. The decibel (abbreviated as dB) scale reduces this ratio to a more manageable size by the use of logarithms.

The symbols SPL, L or L_P are commonly used to represent Sound Pressure Level. The symbol L_A represents A-weighted Sound Pressure Level. The noise level descriptors that have been utilised within this report are illustrated in **Figure 2** and described below**.**

L_{Amax} The maximum A-weighted noise level associated with a sampling period.

L_{A1} The A-weighted noise level exceeded for 1% of a given measurement period. This parameter is often used to represent the typical maximum noise level in a given period.

L_{A10} The A-weighted noise level exceeded 10% of a given measurement period and is utilised normally to characterise average maximum noise levels.

L_{Aeq} The A-weighted average noise level. It is defined as the steady noise level that contains the same amount of acoustical energy as a given time-varying noise over the same measurement period.

L_{A90} The A-weighted noise level exceeded 90% of a given measurement period and is representative of the average minimum background noise level (in the absence of the source under consideration), or simply the “background” level.

Figure 2 Graphical Display of Typical Noise Indices

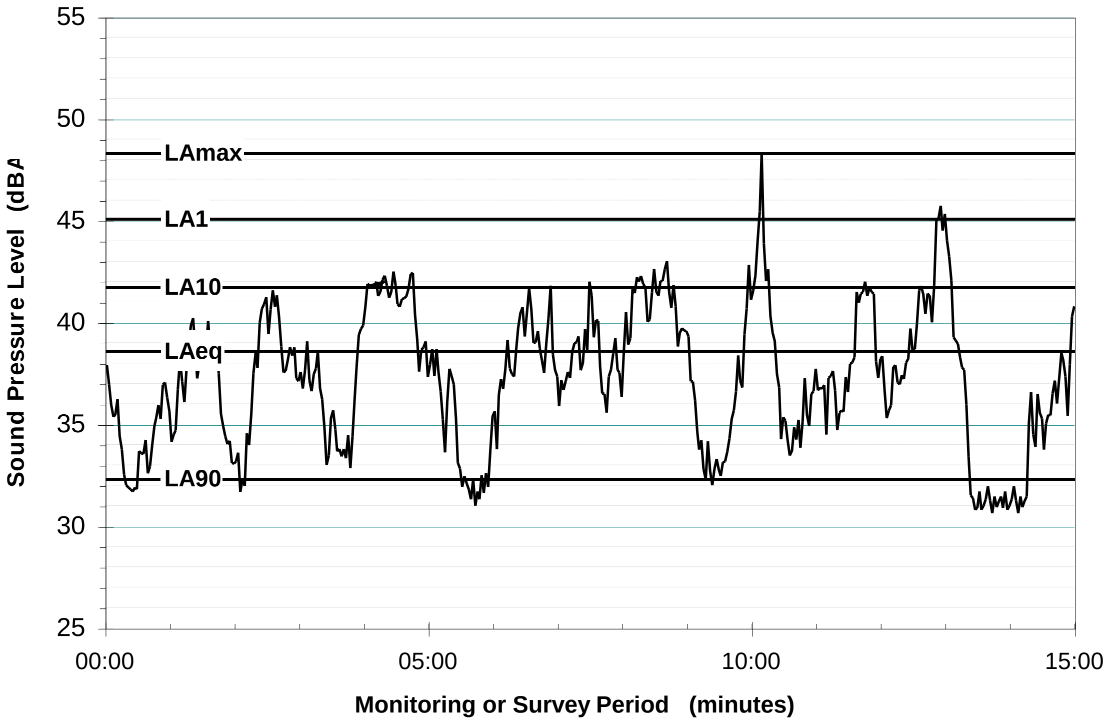


Table 8 presents examples of typical noise levels.

Table 8 Typical Noise Levels

Sound Pressure Level (dBA)	Typical Source	Subjective Evaluation
130 120 110	Threshold of pain Heavy rock concert Grinding on steel	Intolerable Extremely noisy
100 90	Loud car horn at 3 m Construction site with pneumatic hammering	Very noisy
80 70	Kerb side of busy street Loud radio or television	Loud
60 50	Department store General Office	Moderate to Quiet
40 30	Inside private office Inside bedroom	Quiet to Very quiet
20	Unoccupied recording studio	Almost silent

When dealing with numerous days of statistical noise data, it is sometimes necessary to define the typical noise levels at a given location for a particular time of day. A standardised method is available for determining these representative levels. This method produces a level representing the “average minimum” background (LA90) noise level over the relevant daytime, evening and night-time periods, and is referred to as the Rating Background Level (RBL).

A change of up to 3 dBA in the level of a sound is difficult for most people to detect, whilst a 3 dBA to 5 dBA change corresponds to a small but noticeable change in loudness. A 10 dBA change corresponds to an approximate doubling or halving in loudness.

3.2 Vibration

Vibration is the term used to describe the oscillating or transient motions in physical bodies. This motion can be described in terms of vibration displacement, vibration velocity or vibration acceleration. Most assessments of human response to vibration or the risk of damage to buildings use measurements of vibration velocity. These may be expressed in terms of “peak” velocity or “rms” velocity. The former is the maximum instantaneous velocity, without any averaging, and is sometimes referred to as “peak particle velocity”, or PPV. The latter incorporates “root mean squared” averaging over some defined time period.

Vibration measurements may be carried out in a single axis or alternatively as triaxial measurements. Where triaxial measurements are used, the axes are commonly designated vertical, longitudinal (aligned toward the source) and transverse. The common units for velocity are millimetres per second (mm/s).

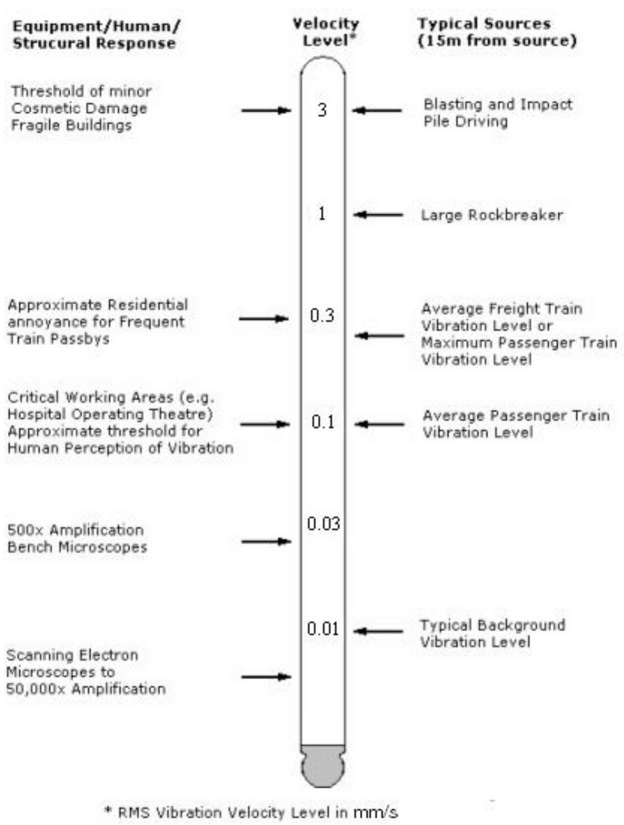
As with noise, decibel units can also be used, in which case the reference level should always be stated. Usually, the vibration velocity level is expressed in dB_V (ref 10^{-9} m/s). The character of vibration emissions can be continuous, intermittent or impulsive.

As for noise, the vibration can be described with the same level descriptors as presented and explained in **Section 3.1**. The corresponding vibration descriptors are V_{max}, V_1, V_{10}, V_{eq}, V_{90}.

Figure 3 gives examples of typical vibration levels associated with surface and underground railway projects together with the approximate sensitivities of buildings, people and precision equipment. The vibration levels are expressed in terms of the vibration velocity (in mm/s).

Vibration and sound are intimately related. Vibrating objects can generate (radiate) sound and, conversely, sound waves (particularly lower frequencies) can also cause objects to vibrate.

Figure 3 Typical Vibration Levels



3.3 Ground-borne Noise

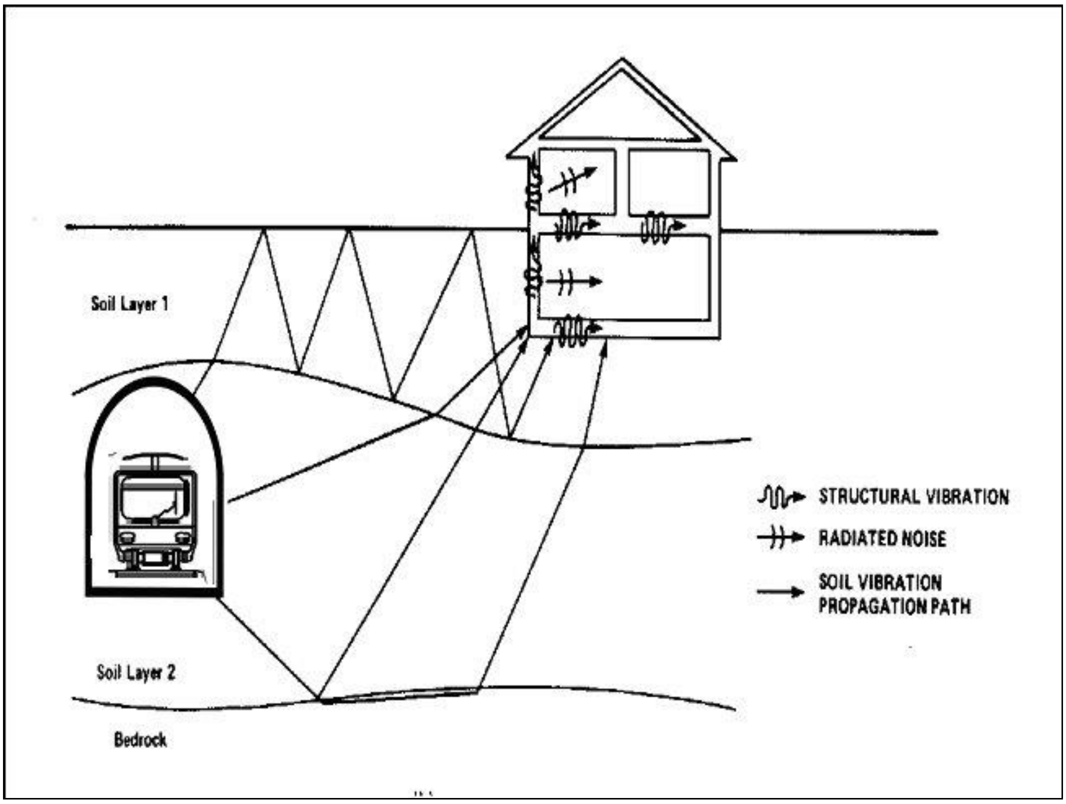
Noise that propagates through a structure as vibration and is radiated by vibrating wall, ceiling and floor surfaces is termed “ground-borne noise”, “regenerated noise”, or sometimes “structure-borne noise”. Ground-borne noise originates as vibration and propagates between the source and receiver through the ground and/or building structural elements, rather than through the air.

Typical sources of ground-borne noise include underground railway operation, tunnelling construction works, excavation plant (eg rockbreakers) and building services plant (eg fans, compressors and generators).

For surface rail operations, the airborne noise will be significantly higher than the ground-borne noise for most situations. It is only if the airborne noise is highly attenuated by very effective noise barriers that the ground-borne noise component may become dominant. This rare situation has not been identified next to the existing surface rail tracks throughout the study corridor.

Figure 4 presents the various paths by which vibration and ground-borne noise may be transmitted to a receiver for underground railway operation occurring within a tunnel.

Figure 4 Vibration and Ground-borne Noise Transmission Paths



4 EXISTING ENVIRONMENT

4.1 Noise

This section presents the results of the ambient monitoring surveys carried out for the BaT project. Ambient noise monitoring was conducted at 18 residential and special use (ie educational or medical) locations evenly spaced along the study corridor. The data for 11 of these locations were taken from a previous project where monitoring was conducted in May 2010. These locations were considered representative of the current BaT project. Both attended and unattended ambient noise measurements have been conducted at an additional seven (7) locations in order to accurately document the existing noise environment. The measured ambient noise levels have been used in part to determine applicable project noise goals.

4.1.1 Noise Monitoring Methodology

In order to determine the existing ambient noise environment along the study corridor, information about the existing ambient noise environment has been obtained from the following sources:

- Unattended continuous noise measurement of sound pressure levels at the selected monitoring locations over a seven (7) day period. The only exceptions to this program were:
    - Location 9 (803 Stanley Street) where only one (1) full day was possible due to logger malfunction and access restrictions.
    - Location 17 (Parkland Boulevard Building 3) and Location 18 (Floor 27, 21 Mary Street) where monitoring was carried out over a 48 hour period for the purpose of quantifying facade noise reductions of the nearest residential buildings to the Roma Street Station and George Street Station worksites respectively.
- Attended 15 minute noise measurements of sound pressure levels at the selected monitoring locations during the daytime (7 am to 6 pm), evening (6 pm to 10 pm) and night-time (10 pm to 7 am) periods.

The noise monitoring undertaken in 2010, was performed between 7 May and 28 May 2010 for at least seven (7) days at each monitoring location. These locations are highlighted green in **Figure 5**.

Noise monitoring at the additional seven (7) locations was undertaken between 11 March and 1 May 2014. These locations are highlighted orange in **Figure 5**.

4.1.2 Instrumentation

The ambient noise monitoring was undertaken using Acoustic Research Laboratories Type EL-316 and SVAN Type 957 Environmental Noise Loggers programmed to record various statistical noise levels over consecutive 15 minute intervals.

Each logger was checked for calibration before and after the survey with a SVAN Sound Level Calibrator and no significant drift (greater than 0.5 dBA) in calibration was detected.

ARL EL-316 and SVAN 957 Noise Loggers are NATA certified Type 1 meters. It is common practice to use Type 1 (or 2) noise loggers for measuring ambient noise levels in accordance with the Australian Standard AS 1055.1 *Acoustics – Description and measurement of environmental noise*. The noise floor of EL-316 loggers is approximately 20 - 22 dBA and the SVAN 957 loggers are approximately 10 - 15 dBA.

Attended measurements were undertaken using Precision Sound Level Meters (SLM); a Rion NA-27, a SVAN Type 948 and a Brüel & Kjær Type 2250. All the SLMs were Type 1 Sound Level Meters. The noise floors of the SLMs are approximately 10 dBA. The SLM’s were checked for calibration before and after each set of noise measurements using a Brüel & Kjær Sound Level Calibrator and no significant drift (greater than 0.5 dBA) in calibration signal level was observed.

All items of acoustic instrumentation employed during the noise monitoring were set to 'Fast' response in accordance with the relevant Australian Standards and the Queensland Department of Environment and Resource Management (DERM) *Noise Measurement Manual*. All items of acoustic instrumentation employed during the noise measurement surveys were designed to comply with AS IEC 61672.2-2004 *Electroacoustics-Sound level meters–Specifications* and carry current calibration certificates.

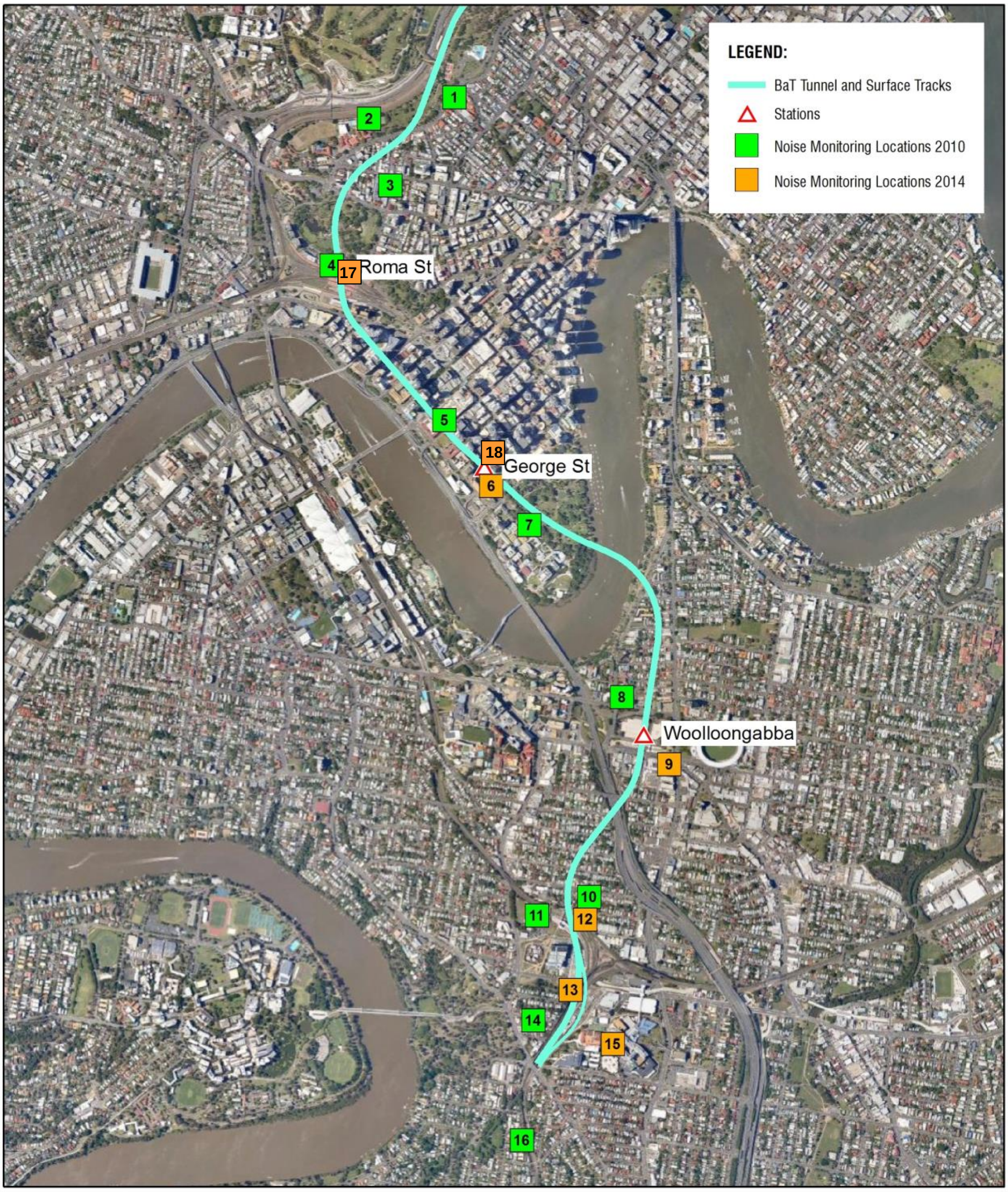
4.1.3 Noise Monitoring Locations

Noise monitoring locations have been selected to be representative of residential areas as well as special receivers (ie Educational and Health Care Facilities) along the corridor that may be potentially affected by the BaT project. Noise monitoring locations have been selected to provide spatial coverage of the areas with sensitive receivers along the length of the study corridor.

An overview of the selected monitoring locations is shown in **Figure 5**.

The details of the selected noise monitoring locations are summarised in **Appendix A**.

Figure 5 Overview of Noise Monitoring Locations



4.1.4 Noise Monitoring Results

Unattended Logging

The unattended ambient noise measurements were used to determine the Rating Background Levels (RBL) for the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location. The RBL is the median of the 90th percentile background (L_{A90}) noise levels in each assessment period (day, evening and night) over the duration of the monitoring (as defined in the *Ecoaccess PNC*). **Table 9** contains the determined RBL for each measurement location.

Table 9 Measured Rating Background Levels

Monitoring Location		Rating Background Levels (RBL), LA90 (dBA)		
		Day	**Evening**	**Night**
1	St Josephs College	50	48	40
2	Brisbane Girls Grammar	61	60	46
3	St Andrews War Memorial Hospital	55	53	51
4	Parkland Cres	54	50	47
5	191 George St	58	57	54
6	40 George Street, The Mansions	59	55	51
7	QUT Gardens Point	49	48	46
8	58 Leopard St	53	50	46
9	803 Stanley St [1]	58	57	51
10	143 Park Rd	43	39	34
11	Dutton Park State School	44	40	35
12	26 Elliot St	46	44	40
13	68 Railway Tce, Leukaemia Foundation	47	45	41
14	19 Dutton St	43	42	37
15	Princess Alexandra Hospital	54	54	53
16	4 Fenton St	39	38	34
17	Parkland Boulevard (Level 3 conference meeting room, Building 3) [2]	RBL: 53 (30) L_{Aeq}: 61 (37)	RBL: 50 (27) L_{Aeq}: 58 (35)	RBL: 44 (<24)[3] L_{Aeq}: 55 (31)
18	21 Mary Street (Level 27 unit 1) [2]	RBL: 56 (33 – Living room) L_{Aeq}: 58 (34)	RBL: 55 (-)[4] L_{Aeq}: 56 (-)[4]	RBL: 53 (27 - Bedroom) L_{Aeq}: 56 (30)

Note 1: RBL based on only one (1) full day of data due to logger malfunction and access restrictions.
Note 2: Levels in brackets were measured inside the building.
Note 3: Actual noise level was below the instrument noise floor of 24 dBA.
Note 4: Evening period data not available due to logger malfunction at 21 Mary Street.

Graphs showing the statistical noise levels measured at the monitoring locations over the whole monitoring period are presented in **Appendix B** for each 24-hour period. The graphs show various statistical noise levels, including the background (L_{A90}) noise level at each site.

15 minute weather data during noise monitoring periods was sourced from the Bureau of Meteorology, Brisbane Station. The weather conditions during the monitoring periods were generally fine. Some rainfall was recorded during the monitoring period and these periods have been excluded from the measurement results. The weather conditions during the remainder of the monitoring period are considered to be suitable for obtaining ambient noise measurements.

On review of the measured ambient noise levels, the statistical noise plots (**Appendix B**), the 1/3 octave attended measurements and operator notes in **Table 10**, only one location (143 Park Rd) showed the presence of atypical insect noise. The short periods (around 6.00 pm) dominated by insect noise at 143 Park Rd were excluded when determining the RBL in **Table 9** to generate a conservatively low (ie no insects present) background noise level.

It is expected that there would be periods during the year when ambient noise levels along the BaT project could be higher than those shown in **Table 9** due to the presence of insect noise.

It should be noted that the Brisbane Girls Grammar school has high ambient noise levels and is representative of a location close to a Motorway (Inner City Bypass) with no existing noise barriers.

High noise levels have also been monitored at St Andrew Hospital, Parkland Boulevard, 21 Mary Street, 191 George Street, 40 George Street, 803 Stanley Street and PA Hospital. These are representative of typical inner city locations with high density of road and rail traffic, pedestrian activity and nearby mechanical noise. Noise levels measured on the balcony of 21 Mary Street were primarily dominated by rooftop mechanical plant from surrounding buildings.

Monitoring locations 10 through to 16 (with the exception of 15, the PA Hospital) show lower ambient noise levels, representative of locations with more suburban characteristics - ie larger distances from receivers to dominant noise sources. For most locations, including these suburban locations (somewhat) distant to major roads, road and rail traffic noise still dominates background noise levels.

Attended Ambient Noise Measurements

Attended ambient noise measurements were also conducted at each site to confirm background noise levels and to observe typical noise sources associated with the ambient noise environment during the daytime, evening and night-time periods. The attended ambient noise measurements were conducted for one (1) 15 minute period during each of the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location (ie three (3) 15 minute attended measurements were taken at each location). The results of these measurements are summarised in **Table 10.**

Table 10 Attended Ambient Measurement Results – Day, Evening and Night-Time Periods

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
1.	19/05/10	15:20	54	63	66	71	Road traffic noise dominant. Children talking nearby.
	20/05/10	18:30	51	62	66	69	Road traffic noise dominant. Distant railway noise.
	21/05/10	01:20	38	49	50	63	Intermittent road traffic noise dominant.
2.	17/05/10	17:35	65	67	68	73	Road traffic noise dominant. Train passby noise.
	20/05/10	18:55	63	68	68	81	Road traffic noise dominant. Train passby noise. Occasional siren from inside the gymnasium just audible.
	21/05/10	00:55	47	58	61	67	Road traffic noise dominant, though intermittent. Distant low level ventilation/construction noise. Some low level insect noise.
3.	10/05/10	17:20	57	60	63	67	Road traffic noise dominant. Various city noises.
	12/05/10	18:40	54	57	59	79	Road traffic noise dominant. Low level noise from ventilation at car park some distance away.
	13/05/10	00:35	51	53	54	60	Road traffic noise dominant. Ventilation noise. Road cleaner passed by.
4.	18/05/10	15:30	55	63	66	74	Road traffic noise. Some low level noise from ventilation. Train passby noise including warning horn and wheel squeal. Ambulance siren.
	20/05/10	21:20	51	62	65	73	Train passby noise including warning horn and wheel squeal. Some road traffic noise and ventilation noise.
	21/05/10	00:30	48	51	54	58	Low noise levels from distant road cleaner, ventilation and insects. One distant low level train passby including some wheel squeal. Some bird noise and road traffic noise.
5.	25/05/10	11:49	68	69	70	71	Ventilation noise constant. Some clangs and bangs from alley-way. Road traffic noise just audible in background.
	20/05/10	20:50	58	60	62	65	Ventilation noise dominant. Live music started playing at the Irish Murphy's at 9.00 pm. Plane pass-over. Patron noises. Intermittent road traffic noise.
	26/05/10	01:30	54	55	56	58	Ventilation noise constant and dominant noise source. Road traffic noise intermittent. Pedestrians talking occasionally.
6.	14/03/14	11:27	51	53	55	60	Traffic from George street dominant. Pedestrian crossing noise intermittent with occasional heavy vehicle passby.
	20/03/14	18:34	56	62	65	70	Traffic from George street dominant. Pedestrian crossing noise intermittent.
	21/03/14	00:04	49	58	50	68	Humming from air conditioning vents dominant with intermittent car passbys.

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
7.	07/05/10	15:55	51	56	57	64	Distant road traffic noise. People talking loudly most of the time.
	13/05/10	18:45	50	56	58	66	Pedestrian noise dominant most of the time. Some low level insect noise. Distant road traffic noise. Occasionally bird noise. Ambulance siren.
	13/05/10	01:15	47	48	48	50	Distant ventilation noise. Some low level insect noise and road traffic noise.
8.	25/05/10	08:13	54	57	59	75	Noises from children playing dominant ~57-64 dBA. Hum from road traffic noise constant ~ 54 dBA. Various vehicle and domestic noises intermittent.
	18/05/10	18:10	52	56	58	70	Road traffic noise dominant. Domestic noises intermittent. Ambulance siren.
	26/05/10	00:55	46	49	51	55	Road traffic noise dominant. Low level ventilation noise.
9.	21/03/14	14:09	65	71	73	76	Road traffic noise dominant. A/C units in neighbouring apartments audible.
	20/03/14	19:05	61	68	71	73	Road traffic noise dominant. Pedestrian crossing alarms. A/C units in neighbouring apartments audible.
	21/03/14	00:45	54	57	61	65	Intermittent road traffic, dominant when present. A/C units in neighbouring apartments audible. A TV set from neighbouring apartment just audible.
10.	25/05/10	08:49	44	57	61	67	Road traffic noise dominant. Plane pass-over intermittent. Train passby noise ~ 48-55 dBA. Some bird noise.
	25/05/10	18:55	42	52	56	60	Road traffic noise dominant most of the time. Significant contribution from insect noise. Train passby noise.
	26/05/10	00:20	37`	44	48	55	Distant road traffic noise dominant. Sporadic local road traffic. Freight train passby.
11.	18/05/10	14:10	45	57	61	70	Distant road traffic noise. Train passby noise including warning horn and wheel squeal. Plane pass-over. Occasional bird noise. Some noises from children playing/talking.
	20/05/10	20:15	42	51	52	63	Distant road traffic noise. Plane pass-over. Train passby noise. Pedestrians occasionally passing by.
	20/05/10	22:20	37	49	43	66	Stationary train with auxiliary units operating at station for a few minutes and train passby noise dominant. Plane pass-over.

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
12.	01/04/14	15:30	50	64	67	80	Train squeal intermittent; train horn = max; frequent train pass-bys; train movements (pass-bys on various tracks, accelerating and decelerating) dominant; intermittent local traffic; neighbour mowing and people talking nearby for few min up to 59dB; motorway noise audible
	26/03/14	20:10	47	64	68	77	Passenger and freight train passby dominant noise source. Distant road traffic, insect noise.
	27/03/14	00:15	42	60	58	74	Insect noise and distant road traffic noise dominant. Intermittent rail passbys.
13.	11/03/14	15:00	55	62	66	73	Road traffic noise dominant most of the time. Plane flyover, train passby, intermittent bird chipping, intermittent nearby construction generator.
	20/03/14	20:42	47	57	57	70	Road traffic and rail traffic noise dominant. Insect noise clearly audible.
	21/03/14	2:00	47	49	50	56	Insect noise dominant
14.	25/05/10	09:17	44	54	56	66	Plane pass-over. Birds intermittent ~ 54-58 dBA. Constant low level road traffic noise. Some domestic noises. Train passby noise ~ 48-54 dBA
	20/05/10	21:29	39	47	45	61	Road traffic noise intermittent. Insect noise (low noise level) constant in background. Occasional domestic noises. Train passby noise including warning horn and pass-bys ~46-49 dBA. Plane pass-over.
	20:/05/10	23:50	39	42	43	51	Distant road traffic noise. Train passby noise. Distant low-level ventilation/industrial and construction noise.
15.	14/03/14	11:27	51	53	55	60	Humming of air-conditioning vents dominant, intermittent banging noise and hospital traffic audible.
	26/03/14	19:41	52	53	54	55	Humming of air-conditioning vents dominant, distant aircraft, train passby and noise from a nearby closing roller door.
	26/03/14	23:53	51	51	51	52	Humming of air-conditioning vents dominant, distant road traffic just audible and train passby.

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
16.	07/05/10	16:53	45	55	58	64	Road traffic noise dominant. Train passby noise ~ 55-65 dBA. Some bird noise. Plane pass-over. Some domestic noises.
	17/05/10	20:55	39	50	52	62	Train passby noise ~ 48-64 dBA. Insects just audible. Road traffic noise intermittent. Plane pass-over. Occasional domestic noises/wildlife in trees.
	18/05/10	00:01	34	49	51	62	Road traffic noise intermittent. Insects just audible in background. Train passby noise ~ 40-66 dBA. Wildlife in trees occasionally. Helicopter pass-over.
17[1].	29/04/14	13:06	55 (31)	59 (35)	61 (36)	81 (50)	Noise environment dominated by rail operations at Roma Street Station
	29/04/14	19:45	51 (31)	59 (36)	61 (39)	69 (45)	Noise environment dominated by rail operations at Roma Street Station
	29/04/14	22:03	(26)	(30)	(33)	(38)	Noise environment dominated by rail operations at Roma Street Station
18[1].	29/04/14	15:30	63 (33)	63 (40)	64 (40)	66 (44)	Noise environment dominated by rooftop mechanical plant and traffic noise
	29/04/14	20:30	61 (31)	62 (32)	62 (33)	64 (36)	Noise environment dominated by rooftop mechanical plant and traffic noise
	29/04/14	23:15	(30)	(31)	(32)	(34)	Noise environment dominated by rooftop mechanical plant

Note: Daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am)

Note 1: Levels in brackets were measured inside the building.

The attended measurements and observations summarised in **Table 10**, show that railway noise and/or road traffic noise is dominant at the majority of monitoring locations during daytime and evenings. The night-time period was dominated by road traffic noise at most locations, though it was mostly a distant traffic noise.

Only one (1) monitoring location (Location 10, 143 Park Rd) had the ambient background environment dominated by insect noise during the evening period. Insect noise has been adjusted for where necessary at 143 Park Rd.

Monitoring location 5 (191 George Street) was located in an alley next to Irish Murphy's and was more representative of a commercial location than a residential location. The noise environment was dominated by ventilation noise, patron noise and music. As such, noise levels obtained at this location are assumed to be slightly higher than expected for the city residential area (where ventilation noise, music and patron noise is less prevalent), but never-the-less is representative of CBD living.

4.2 Vibration

Unlike noise, existing ambient vibration levels at residences and other sensitive buildings are not significant in the assessment of potential vibration issues. This is primarily because vibration impacts are assessed based on absolute criteria rather than criteria that are expressed relative to an existing ambient level. Existing vibration levels along the study corridor were measured to (if required) compare with future vibration levels with the BaT project in operation.

This section presents the results of the ambient vibration monitoring surveys carried out for the project. The data for eight (8) of these locations were taken from a previous project where monitoring was conducted in May 2010. These locations were considered representative of the current project. Ambient vibration measurements have been conducted at an additional two (2) locations in order to accurately document the existing vibration environment.

4.2.1 Vibration Monitoring Methodology

In order to determine the existing ambient vibration environment along the study corridor, 24 hour unattended vibration measurements were conducted at each selected site.

The vibration monitoring was performed between 7 and 25 May 2010 and 12 and 20 March 2014, for a period of at least 24 hours at each monitoring location.

4.2.2 Instrumentation

The vibration measurements were conducted using Instantel Minimate Plus vibration loggers with one triaxial (transverse, vertical and longitudinal) geophone installed inside the building at the monitoring locations. The vibration loggers were programmed to record Peak Particle Velocity (PPV) in mm/s every 60 seconds over the monitoring period.

The vibration instrumentation employed during the vibration measurement surveys carry current calibration certificates by an ISO 17025 accredited laboratory.

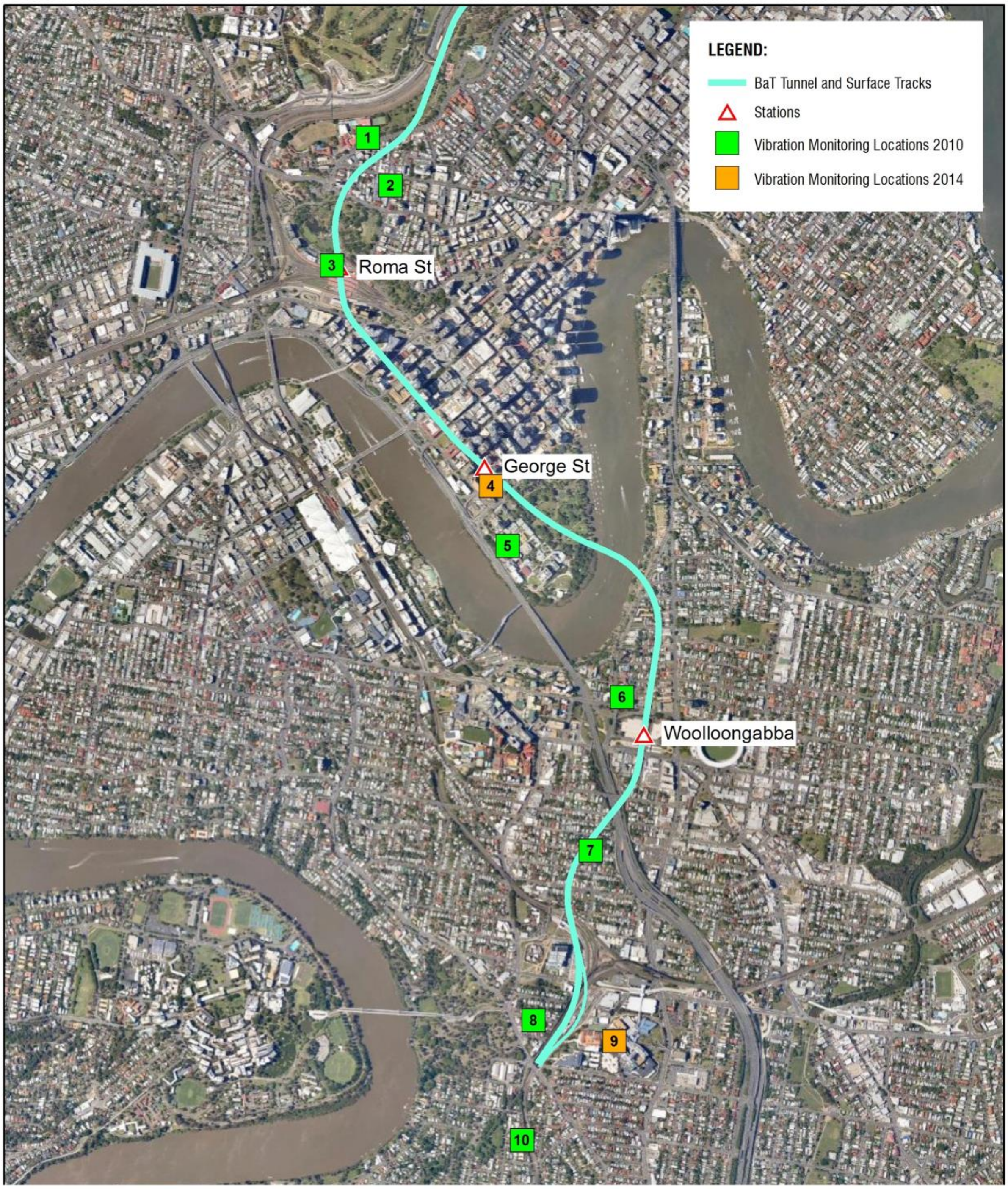
4.2.3 Vibration Monitoring Locations

Vibration monitoring locations have been selected to be representative of residential areas as well as special receivers (ie educational/research or health care facilities) along the corridor that may be potentially affected by the BaT project. Vibration monitoring locations have been selected to provide spatial coverage of the areas having sensitive receivers within the whole study corridor.

An overview of the selected vibration monitoring locations is shown in **Figure 6**, with locations monitored in 2010 highlighted green and locations monitored in 2014 highlighted orange.

The details of the selected vibration monitoring locations are summarised in **Appendix C**.

Figure 6 Overview of Vibration Monitoring Locations



4.2.4 Vibration Monitoring Results

The unattended ambient vibration measurements were used to determine the Average Minimum Background Level (V_{90}), Average Maximum Level (V_{10}) and Maximum Level (V_1) for the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location. **Table 11** contains the determined vibration levels for each measurement location. Graphs showing the peak particle velocity (mm/s) measured at each monitoring location during the monitoring period are presented in **Appendix D**.

Table 11 Measured Existing Ambient Vibration

Monitoring Location[1]	Average Minimum Background Vibration V_{90} (mm/s) [2]			Average Maximum Vibration V_{10} (mm/s) [3]			Maximum Vibration V_1 (mm/s) [4]		
	Day	Evening	Night	Day	Evening	Night	Day	Evening	Night
1	0.04	0.04	0.04	0.05	0.05	0.05	0.08	0.05	0.05
2	0.03	0.03	0.02	0.08	0.05	0.04	0.17	0.08	0.06
3	0.04	0.04	0.03	0.06	0.05	0.04	0.07	0.07	0.06
4	0.08	-	-	0.09	-	-	0.10	-	-
5	0.02	-	-	0.02	-	-	0.03	-	-
6	0.01	0.01	0.01	0.04	0.14	0.02	0.16	0.57	0.16
7	0.04	0.04	0.04	0.06	0.10	0.05	0.19	0.49	0.10
8	0.03	0.03	0.03	0.04	0.04	0.03	0.31	0.04	0.04
9	0.13	0.11	0.11	0.79	0.53	0.13	2.50	1.53	0.36
10	0.04	0.06	0.04	0.70	0.84	0.23	2.69	1.61	0.71

Note 1: All monitoring locations are residential excluding locations 2 to 5.

Note 2: The V90 is the vibration velocity exceeded 90% of a given measurement period and is representative of the average minimum background vibration.

Note 3: The V10 is the vibration velocity exceeded 10% of a given measurement period and is utilised normally to characterise average maximum vibration.

Note 4: The V1 is the vibration velocity exceeded for 1% of a given measurement period. This parameter is sometimes used to represent the maximum vibration in a given period. The absolute maximum peak particle velocity is higher than this V1 as can be seen in **Appendix D**.

The background vibration level (V_{90}) for all sites varies between 0.01 mm/s to 0.13 mm/s during daytime and evening. During the night-time, the background vibration level (V_{90}) varies between 0.01 mm/s to 0.11 mm/s. Maximum vibration levels (V_1) for the residential monitoring locations were in the range of 0.11 mm/s to 2.69 mm/s during daytime and evening. During night-time, vibration levels (V_1) of 0.04 mm/s to 0.71 were measured. The average maximum levels (V_{10}) for the residential monitoring locations ranged 0.04 mm/s to 0.84 mm/s during daytime and evening.

It can be noted that high vibration levels have been monitored at locations 6, 7 and 10 which are on floors in a residential dwellings. This shows that normal activities (ie closing doors, drawers and cupboards, walking, moving and sitting on furniture etc) in this residential dwelling generated vibration levels above the vibration goals presented in **Section 2.3**.

For receivers with vibration sensitive equipment locations 3 (St Andrews Hospital), location 5 (QUT) and location 9 (PA Hospital), background vibration levels (V_{90}) of 0.02 mm/s to 0.06 mm/s and maximum vibration levels (V_1) of 0.03 mm/s to 2.69 mm/s, were measured. It can be noted that the monitoring location just outside the MRI room at the PA Hospital registered significantly higher vibration levels than at QUT and St Andrews Hospital.

5 IDENTIFICATION OF NOISE AND VIBRATION SENSITIVE RECEIVERS

The sensitivity of occupants to noise and vibration varies according to the nature of the occupancy and the activities performed within the affected premises. For example, recording studios are more sensitive to vibration and ground-borne noise than residential premises, which in turn are more sensitive than typical commercial premises.

The sensitivity may also depend on the existing noise and vibration environment. For example, the AS/NZS 2107:2000 *"Recommended Design Sound Levels and Reverberation Times for Building Interiors"* recommend higher acceptable noise levels in urban areas compared with suburban areas.

Following receipt of the Reference Design, SLR has classified all buildings within a corridor extending approximately 100 m either side of the nearest BaT alignment or any construction site. Each building was classified into the following receiver categories:

- Residential
- Commercial
- Educational
- Health Care
- Place of Worship
- Heritage Item
- Industrial

In the noise and vibration modelling presented in this report, all residential receivers are considered to be of a sensitive nature. Commercial receivers are generally less sensitive to noise and vibration compared to residential receivers.

Appendix E presents details of non-residential noise and vibration sensitive receivers that are situated along the length of the alignment.

6 GROUND-BORNE VIBRATION ASSESSMENT - TRAIN OPERATIONS

6.1 Introduction

Railway vibration is generated by dynamic forces at the wheel-rail interface and occurs, to some degree, even with continuously welded rail and smooth wheel and rail surfaces (due to the moving loads, finite roughness and elastic deformation of the surfaces). Higher vibration levels occur in the presence of rail and wheel surface irregularities.

This vibration propagates via the rail mounts into the ground or track support structures. It then travels through the ground or structures and in some circumstances may sometimes be felt as tactile vibration by the occupants of buildings. If the levels of vibration are sufficiently high (ie in buildings very close to rail tracks), then rattling or visible movement of loose objects (crockery, plants, etc) may also sometimes occur.

The effects of vibration in buildings can be divided into four main categories:

- Those in which the occupants or users of the building are inconvenienced or possibly disturbed (human perception or human comfort vibration).
- Those where the building contents may be affected.
- Those where common services may be affected.
- Those in which the integrity of the building or the structure itself may be prejudiced.

A fifth effect is the noise generated within buildings as a result of the vibration. This is termed "ground-borne noise" and is discussed further in **Section 7**.

For this project, the potential ground-borne vibration impacts would be limited to receivers located within an approximate 50 m wide corridor above the centreline of the proposed tunnels. The applicable ground-borne vibration goals are discussed in **Section 2.4.6**.

6.2 Ground-borne Vibration Modelling Methodology

International Standard ISO 14837-1 2005 "*Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General Guidance*" provides useful guidance in relation to the extent of assessment that is normally required for new rail systems including:

- **Scoping Model** at the very earliest stages
- **Environmental Assessment Model** during planning process and preliminary design
- **Detailed Design Model** to finalise extent and form of mitigation for construction

At this stage of the detailed feasibility phase of BaT, a combined Environmental Assessment/Detailed Design Model has been adopted to assess the potential impact of ground-borne noise and vibration levels and identify, in-principle, the extent of likely mitigation measures. A brief description of the modelling options is provided in **Figure 7.**

Figure 7 Ground-borne Vibration/Noise Modelling Approaches (from ISO 14837-1:2005(E))

A single model may be used for all stages with appropriate selection of input parameters (e.g. worst case for scoping assessment). Otherwise, three types of ground-borne vibration and/or ground-borne noise prediction model should be considered, as follows.

a) **Scoping model**: to be used at the very earliest stages of development of a rail system to identify whether ground-borne vibration and/or ground-borne noise is an issue and, if so, where the "hot spots" along the length of the system's alignment are located. This type of model should be used to generate input to either environmental comparative frameworks (as part of the selection of a mode of transport) or the scoping stage of an environmental assessment.

b) **Environmental assessment model**: to be used to quantify more accurately the location and severity of ground-borne vibration and/or ground-borne noise effects for a rail system and the generic form and extent of mitigation required to reduce or to remove the effects. This type of model should form part of the planning process for a scheme, developing the environmental statement where required and supporting preliminary design.

c) **Detailed design model**: to be used to support the detailed design and specification of the generic mitigation identified as being required by the environmental assessment model. This type of model should form part of the design and construction stages of a scheme, with particular focus on the rolling stock and permanent-way design.

In accordance with the ISO standard, the ground-borne noise and vibration modelling considers all of the parameters that are critical in determining the absolute levels of ground-borne noise and vibration, and the benefits (or otherwise) of different design and mitigation options. The key parameters are listed under the following headings:

- **Source** - route alignment, rolling stock design, rail type, trackform design, tunnel design, construction tolerances, operations and maintenance.
- **Propagation Path** - ground type and vibration propagation wave types
- **Receiver** - Building construction

The following sections provide a brief summary of the modelling algorithms that have been adopted for this assessment.

6.2.1 Modelling Approach

The prediction of ground-borne vibration from rail systems is a complex and developing technical field. Whilst much research has been undertaken into various aspects associated with ground-borne noise and vibration from underground rail systems, there are currently no widely accepted modelling software packages available, and several different modelling approaches are currently in use (including empirical methods, finite element methods, boundary element methods and combinations of these). Whilst a number of possible calculation methods are available, each method needs to take into account the key parameters identified in the ISO standard.

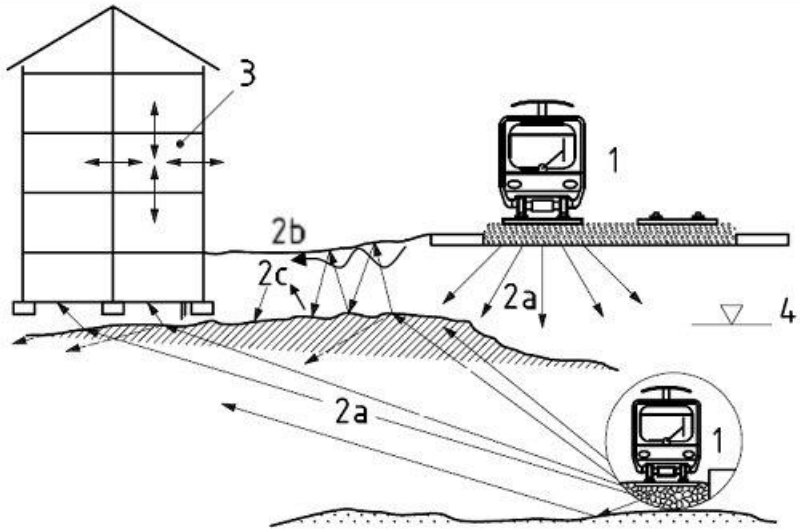
The modelling for this project was therefore carried out using an SLR-developed modelling process for the core calculations. The algorithms incorporated into the in-house model are well documented in authoritative references and are widely used within the acoustical consulting profession, both in Australia and internationally.

Furthermore, as part of the Epping to Chatswood Railway Line (ECRL) project in Sydney, ground-borne noise and vibration measurements have been undertaken by SLR whilst a test train was operated in the tunnel under controlled conditions. As part of this testing, SLR undertook ground-borne noise and vibration measurements on the surface and within the tunnel at a number of locations. The results from this testing have been used to validate and refine the ground-borne noise and vibration modelling algorithms for this assessment.

The ECRL and the Project share similar design characteristics in relation to a circular tunnel cross-section embedded in rock and similar slab track design. Where differences exist between the ECRL and the Project (eg tunnel dimensions, ground conditions, rolling stock and track/rolling stock maintenance practices), these have been accounted for in the ground-borne noise and vibration predictions.

The modelling approach is illustrated in **Figure 8** and takes into account the source vibration levels, the vibration propagation between the tunnel and nearby building foundations, and the propagation of vibration within the building elements. A summary of the key modelling assumptions are provided in the following sections.

Figure 8 Example of Source, Propagation and Receiver System (ISO 14837)



Key

1 source

2 propagation:
- 2 a body waves (compression, shear)
- 2 b surface waves (e.g. Rayleigh, Love)
- 2 c interface waves (e.g. Stoneley)

3 receiver (vibration, re-radiated noise)

4 water table

NOTE The components of the system comprising source, propagation and receiver are interdependent.

6.2.2 Source Vibration Levels

Source vibration levels within tunnels are dependent on a number of factors including the track design, train type, train speed, wheel condition, ground conditions and tunnel design.

Only single-deck passenger trains are proposed to operate in the Project. Ultimately there will be a captive fleet of 7 car (approximately 170 m) single-deck passenger trains operating in the Project.

A desktop assessment of similar rail projects was performed to determine the typical source vibration levels to be used as a starting point for the modelling. Vibration measurements in relation to the ECRL project in Sydney were used to further validate and refine the source vibration level.

Standards are also proposed to be adopted to ensure that the condition of the train wheels and rails are maintained within specified roughness limits in Annex C of ISO 3095:2005(E) "*Railway Applications - Acoustics - Measurement of noise emitted by railbound vehicles*" (ISO 3095).

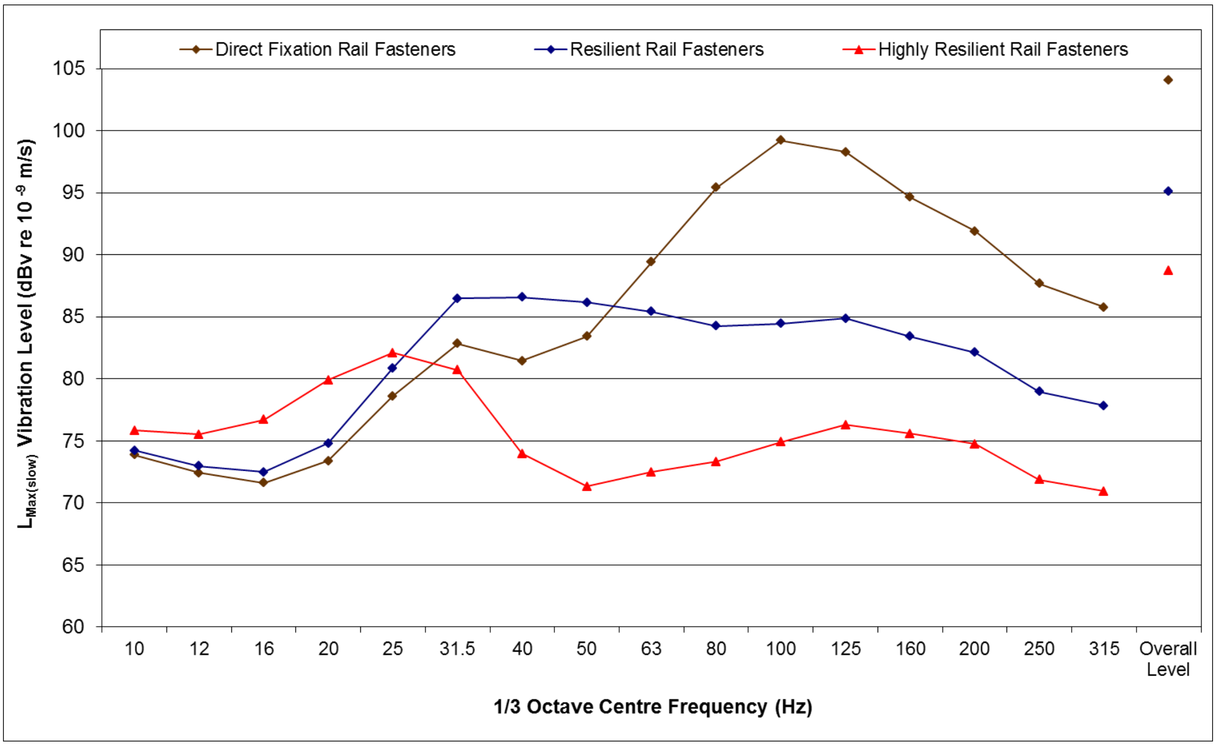
A summary of the reference vibration levels for three forms of track systems are provided in **Table 12** and **Figure 9**. These trackform source vibration levels take into account the relevant design factors of the Project and are described further below under the "trackform design" heading.

Table 12 Reference Source Vibration Levels for the Project Trains (Tunnel Wall Vibration Levels at Reference Speed of 80 km/h) – Lmax,Slow

Track Type	1/3 Octave Vibration Levels (dB_V re 10^{-9} m/s)																Overall Level
	10 Hz	12 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	
Direct Fixation Rail Fasteners	74	72	72	73	79	83	81	83	89	95	99	98	95	92	88	86	104
Resilient Rail Fasteners	74	73	72	75	81	86	87	86	85	84	84	85	83	82	79	78	95
Highly Resilient Rail Fasteners	76	76	77	80	82	81	74	71	72	73	75	76	76	75	72	71	89

Note: The LAmax,Slow noise level are for the 95th percentile train passby event. The absolute maximum event is not used for predictions, as it cannot be precisely defined and would be a highly infrequent event. The source vibration levels assume wheel and rail roughness within the limit spectrum in Annex C of ISO 3095.

Figure 9 Reference Source Vibration Levels for BaT Trains (Tunnel Wall Vibration Levels at Reference Speed of 80 km/h) – Lmax,Slow



Note: The LAmax noise level are for the 95th percentile train passby event. The absolute maximum event is not used for predictions, as it cannot be precisely defined and would be a highly infrequent event. The source vibration levels assume wheel and rail roughness within the limit spectrum in Annex C of ISO 3095.

Route Alignment

For as much as possible, the Project alignment has been located below major roads or existing railway lines including Dutton Park and Roma Stations and along George Street. From a ground-borne noise and vibration perspective, this is advantageous because in many areas next to major roads or railways, the nearest receptors may be of a commercial or industrial nature and are therefore not highly susceptible to ground-borne noise and vibration. In other sections, the proposed alignment runs beneath suburban residential areas where the ambient noise environment is quieter and the potential sensitivity to underground train passbys is increased.

On curved track, wear patterns on the rail and vehicle steering characteristics can affect the source vibration emissions at the wheel rail interface. The risk of poor rail condition (such as corrugation) is also greater on curves than on straights, as is the risk of other effects, such as wheel flanging.

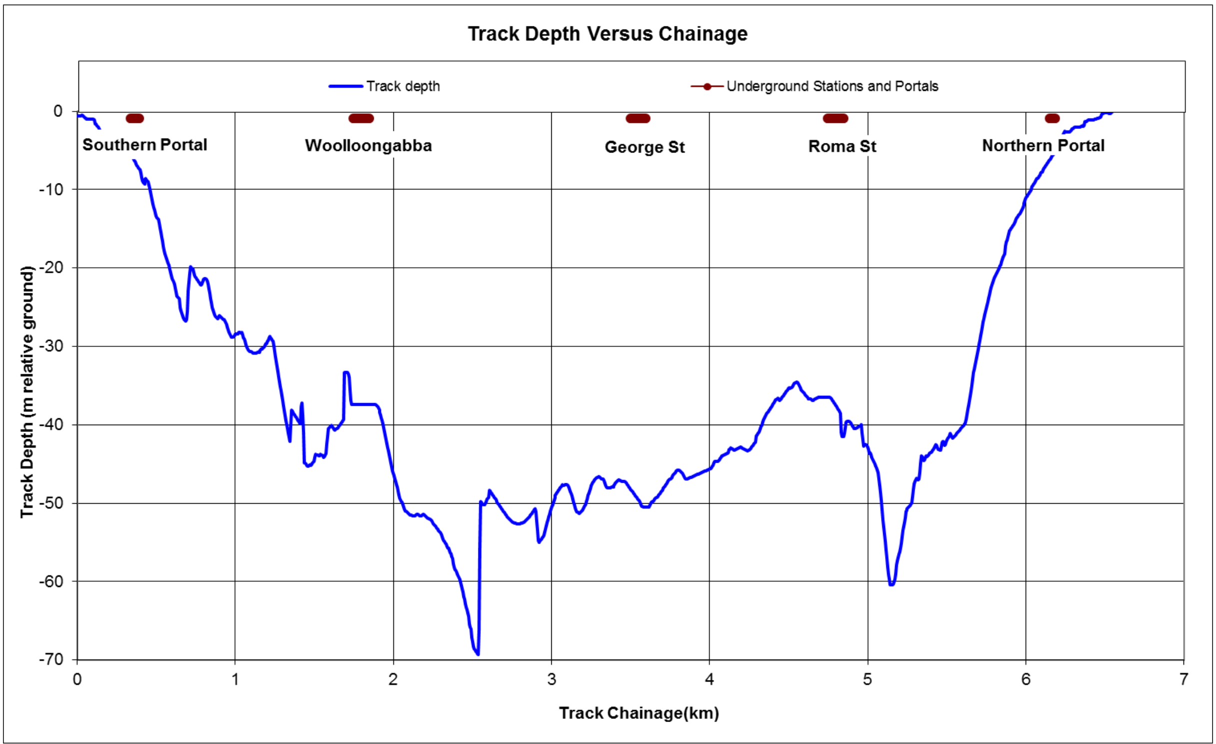
For track radii less than approximately 600 m, measurements undertaken by SLR on the Singapore Circle Line indicated that there is a general increase in source vibration levels of approximately 5 dB. On this basis, 5 dB has been added to the source vibration levels at the locations identified in **Table 13**.

Table 13 Location of Curve Radii Less than 600 m

Down Track			Up Track		
Chainage (km)		Curve Radius (m)	Chainage (km)		Curve Radius (m)
Start of Curve	End of Curve		Start of Curve	End of Curve	
0.300	0.510	300	0.260	0.500	300
0.790	1.115	406	0.810	1.130	400
1.450	1.640	400	1.465	1.635	406
4.465	4.665	406	4.490	4.700	400
4.950	5.340	406	4.970	5.350	400
5.535	5.730	400	5.550	5.745	406
6.180	6.465	400	6.195	6.480	400

The tunnel depth (i.e. rail track level) along the Reference Project alignment is shown in **Figure 10**. It can be seen that the rail tracks under the CBD (chainage 3.2 km to 4.7 km) is between 35m and 50m underground.

Figure 10 The Project Tunnel Depth vs Chainage



Rolling Stock Design

The proposed trains are approximately 170 m long in a 7-car configuration. They comprise single deck Electric Multiple Units (EMU) with an assumed maximum axle load of approximately 15 tonnes.

The ground-borne noise modelling assumes an unsprung axle load of 1941 kg/axle. The model has been adjusted to incorporate the length of the proposed 7 car Project trains.

At this stage of the Project, more detailed information on other rolling stock variables such as wheel diameter, wheel tread profile, axle spacing, bogie spacing, suspension stiffness and the modal properties of the train body have not been included in the modelling. This may have to be considered in more detail at a later stage when information on the proposed rolling stock is available. At this stage in the assessment process, these variables are not considered to be significant.

Rail Type

The proposed rail type for the Project is a 60 kg/m rail.

Trackform Design

The trackform design and its interaction with the rolling stock under consideration is one of the primary ways in which ground-borne noise and vibration can be minimised on new underground railway lines.

The broad principles of vibration isolation of railways consist of the reduction of the dynamic stiffness of the track support, and further, the introduction of (or increase in the mass of) elements of the track support, plus adjustments to damping. In general, the lower the natural frequency of the track support system, the better the vibration isolation. Low natural frequency is achieved by increased mass and reduced dynamic stiffness.[3]

A ballastless (concrete slab) trackform is proposed for the tunnels. For the Project, three different rail fastening systems (Direct Fixation, Resilient and Highly Resilient rail fasteners) have been proposed to achieve the ground-borne noise and vibration goals. Generic performance data has been obtained for the Delkor, Pandrol and Sonneville rail fastening systems. A summary of the dynamic stiffness properties of the Delkor, Pandrol and Sonneville rail fastening systems is provided in **Table 14**.

For the current assessment, it is assumed that the vibration attenuation provided by the different systems are in direct proportion to their dynamic stiffness values. In practice, the vibration attenuation performance will also be affected by other parameters including the loss factor (damping), mass and dynamic interaction with the tunnel and rolling stock. Furthermore, various testing methods are employed in order to calculate the static and dynamic stiffness values of different systems which makes a direct “like for like” comparison difficult. These other factors will need to be investigated as part of the detailed design.

Care also needs to be exercised during the detailed design stage to ensure that a low stiffness track design does not give rise to excessive passenger discomfort vibration levels or unacceptable reliability, availability, maintainability and safety (RAMS) implications.

For the ground-borne vibration modelling undertaken for this assessment, the source vibration levels with ECRL Delkor Egg fasteners have been adopted as a reference, on the basis of attended measurements undertaken by SLR on the ECRL.

For the Pandrol HDPE, Pandrol VIPA and Pandrol Vanguard fastening system, the relative performance (compared with the ECRL installed Delkor Egg) has been evaluated using a Single Degree of Freedom (SDoF) analysis including the unsprung axle mass of the proposed rolling stock and rail fastening stiffness per track metre. For the Project, a rail fastener spacing of 700 mm has been assumed for all trackform options.

3 Association of Noise Consultants (ANC Guidelines), 2001, “*Measurement and Assessment of Groundborne Noise & Vibration”*, Page132

In the ground-borne vibration assessment, the following three trackform options have been evaluated:

- **Direct Fixation Rail Fasteners -** Ground-borne noise performance equivalent to Pandrol HDPE stiff rail foot pads - or equivalent from other suppliers/systems. Assumed dynamic stiffness of 120 kN/mm.
- **Resilient Rail Fasteners** - Ground-borne noise performance equivalent to Pandrol VIPA, Delkor Alt 1 Systems - or equivalent from other suppliers/systems. Assumed dynamic stiffness of 28 kN/mm.
- **Highly Resilient Rail Fasteners -** Ground-borne noise performance equivalent to the Pandrol Vanguard System - or equivalent from other suppliers/systems. Assumed dynamic stiffness of 6 kN/mm.

The source vibration levels for the above trackforms are provided in **Table 14** and photos/sketches of the rail fastening systems are provided in **Figure 11**.

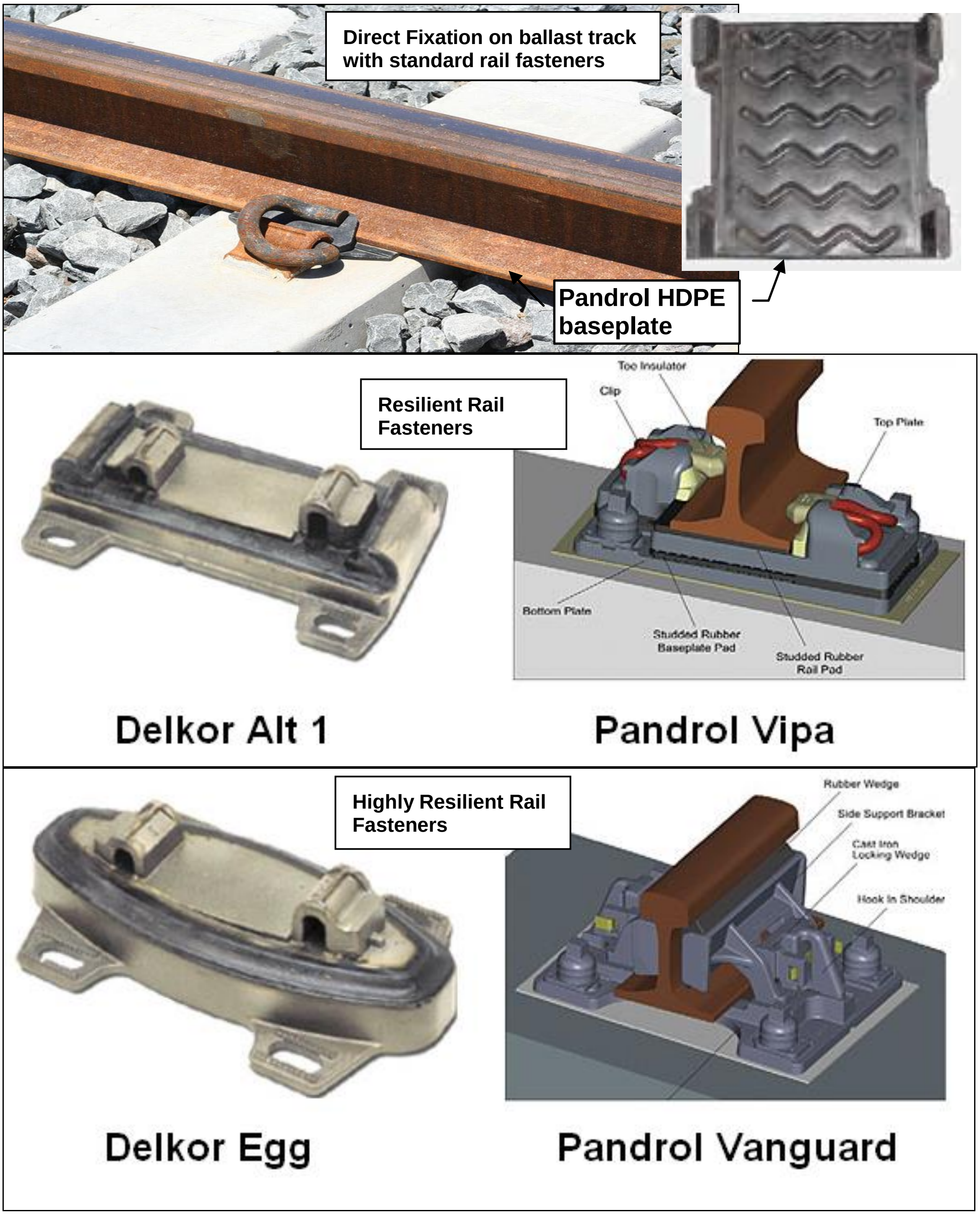
Table 14 Properties of Pandrol, Delkor and Sonneville Rail Fasteners

Fastener Type	Static Stiffness[1,2]	Dynamic Stiffness[1,2]	Dyn/Stat Ratio	Comments
Direct Fixation with Standard Rail Fasteners				
Pandrol HDPE	> 100 kN/mm	> 100 kN/mm	-	Normal “stiff” rail pads usually only used on surface tracks
Resilient Rail Fasteners				
Pandrol Vipa	17 - 20 kN/mm	17-21 kN/mm	1.05	-
ECRL Delkor Alt 1	20 kN/mm	28 kN/mm	1.4	As installed on ECRL
Delkor Alt 1	12 - 30 kN/mm	17-42 kN/mm	1.4	Stiffness options can be varied to suit
Sonneville Standard	18 kN/mm	27 kN/mm	1.5	Mass of Block 100 kg
Highly Resilient Rail Fasteners				
Pandrol Vanguard	3 - 5 kN/mm	5 - 7.5 kN/mm	1.5	Assume Dynamic Stiffness of 6 kN/mm for Modelling
Low Profile Delkor Egg	6 kN/mm	7.2 kN/mm	1.2	Stiffness options can be varied to suit

Note 1: The Static and Dynamic stiffness values have been obtained from product brochures (for Delkor and Pandrol products), from the ECRL 100% Design Report (for the ECRL Alt 1 product) and via e-mail correspondence with the manufacturer (for the Sonneville products).

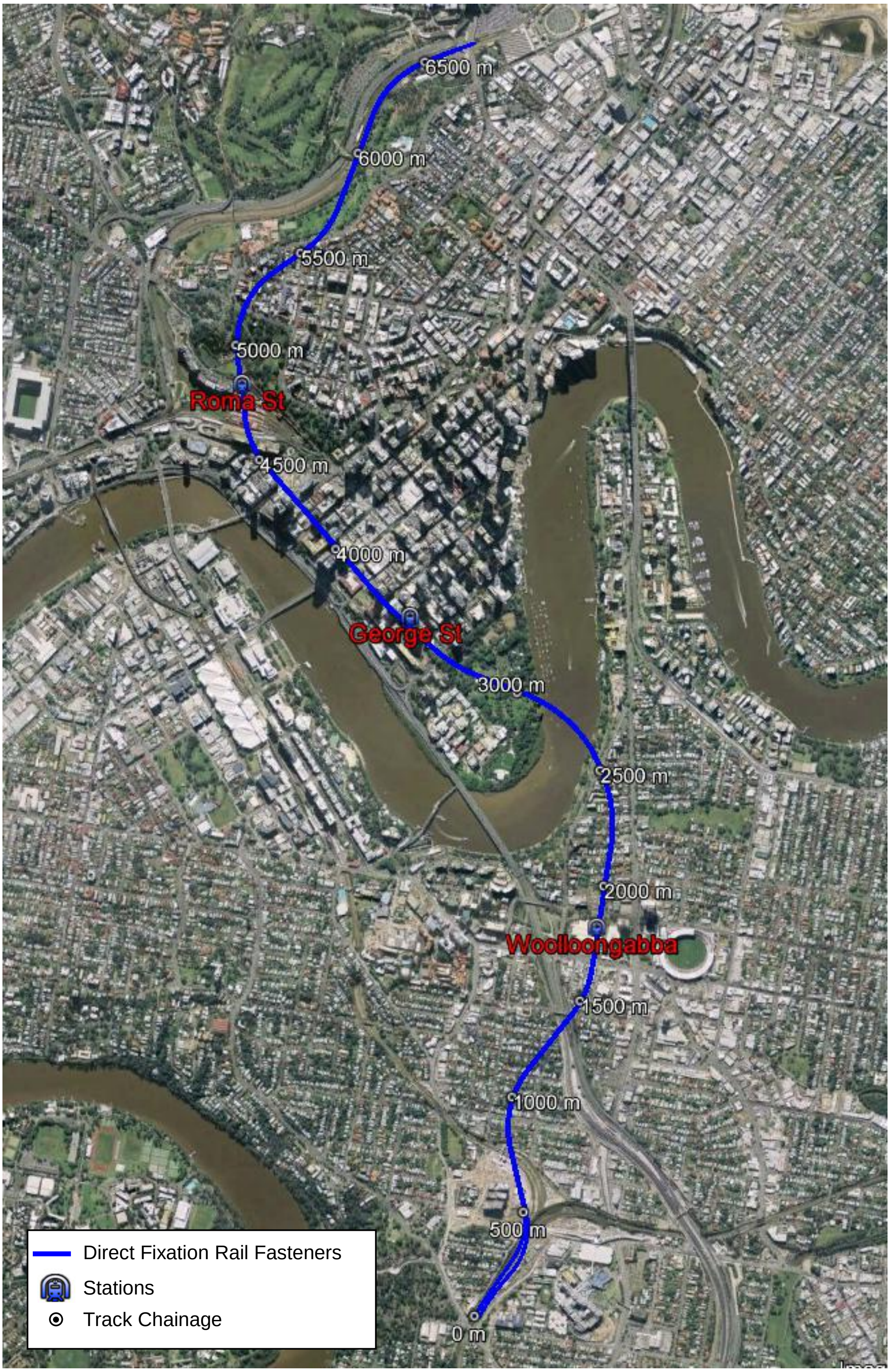
Note 2: Various testing methods are employed in order to calculate the static and dynamic stiffness values of different systems. This makes a direct like for like comparison of the different systems difficult.

Figure 11 Reference Project Proposed Trackforms



For the Project, initial modelling was undertaken assuming an unmitigated Direct Fixation trackform configuration along the whole alignment. The Project alignment and underground station locations are presented in **Figure 12**.

Figure 12 The Project Tunnel Alignment and Stations



Turnouts

References such as the US FTA "*Transit Noise and Vibration Impact Assessment*" indicate that vibration levels are typically 10 dB higher adjacent to turnouts, which is in accordance with SLR's experience on similar projects. There are, however, no proposed turnouts throughout the Project tunnels.

Construction Tolerances

Construction tolerances refer to factors such as the variation in stiffness values between rail fasteners, the quality of the track construction and any change in stiffness values with time.

The potential effect of construction tolerances has not been evaluated as part of this assessment and should be addressed in detailed design. These effects are not anticipated to be significant.

Operations

The main factors associated with operational patterns are the train speeds and timetabling. The speed profile used for the modelling are provided in **Table 15**.

Table 15 Speed Profile

Down Track			Up Track		
Chainage (km)		Speed (km/h)	Chainage (km)		Speed (km/h)
From	To		From	To	
0.00	0.151	50	0.00	0.181	50
0.151	0.568	60	0.181	0.579	60
0.568	6.507	80	0.579	6.540	80
6.507	6.742	50	6.540	6.775	50

For train operations in tunnels, the vibration levels typically increase by 6 dB for each doubling of train speed. This relationship has been observed by SLR on other projects (including ECRL) and has therefore been adopted for this assessment.

The reference vibration levels adopted in the modelling process are for a train speed of 80 km/h (refer **Table 12**). **Table 15** shows that for the Project, train speeds are expected to be between 50 and 80 km/h. Speed adjustment of the 80 km/h reference vibration level has therefore been made using the following formula on a 1/3 octave frequency basis:

$$V(speed\_adjusted) = V(reference) + 20\log_{10}\left(\frac{speed}{80}\right)$$

It is possible that trains could be timetabled to cross in separate directions below the same receiver location on a regular basis. The maximum increase in ground-borne noise and vibration levels would be up to 3 dB in the worst case situation. In most cases, the increase in ground-borne noise levels would only be 1 dB or 2 dB.

The potential impact of passing trains at particular receiver locations on a regular basis has not been evaluated as part of this assessment. Should such events occur during operations and the resulting ground-borne noise or vibration levels exceed the goals, consideration will need to be given to scheduling trains to cross at less sensitive locations.

As the Project will ultimately incorporate a captive fleet of 7 car single deck EMUs, the variation in source vibration levels from train to train is anticipated to be much smaller than an equivalent system with a variety of different rolling stock. As such, the ground-borne vibration modelling assumes that the source vibration levels of the rolling stock will vary in accordance with a normal distribution having a standard deviation of 2 dB. This results in a 95th percentile vibration level approximately 3 dB higher than the mean or 50th percentile level. This factor is included in the source vibration levels in **Table 12**.

Maintenance

The maintenance of the track and rolling stock can have a significant influence on the ground-borne noise and vibration levels. For modelling purposes, a correction of 3 dB has been applied to account for progressive deterioration in wheel and track condition between maintenance activities. This is included in the source vibration levels in **Table 12**.

In the case of poor track condition, it is assumed that rail grinding would be undertaken if the surface roughness values of the track are outside the permitted tolerances. Furthermore, it is also assumed that the condition of the track would be monitored on a regular basis using on-car or hand-held monitoring equipment.

In the case of poor wheel condition, it is assumed that the potential for wheel flats would be minimised through design. If wheel flats or other wheel defects do occur however, it is assumed that these would be identified by a permanent monitoring station and rectified using a wheel lathe or other measures to return the wheel condition to an acceptable degree of smoothness.

6.2.3 Propagation Path

The propagation of vibration through the ground is a complex phenomenon. Even for a simple source, the received vibration at any point includes the combined effects of several different wave types, plus reflections and other effects caused by changes in ground conditions along the propagation path.

Attenuation with distance occurs due to the geometric spreading of the wave front and due to other losses within the ground material, known as “damping”. The attenuation due to geometric spreading occurs equally for all frequencies, whereas the damping component is frequency dependent, with greater loss per metre occurring at high frequencies than at low frequencies.

In the modelling process, the various vibration wave contributions are not sufficiently defined to allow them to be calculated separately. Analytical techniques such as finite element analysis and boundary element analysis would require the ground and buildings to be modelled in great detail to represent the propagation path over the required frequency range. Otherwise, the modelling process could introduce large inaccuracies that may be difficult to trace.

Given the extensive land area along the proposed alignment, such an approach at this stage of the assessment is not feasible (and would only be undertaken at critical locations during detailed design). As such, the modelling was carried out using a combination of theoretical and empirical relationships to determine the attenuation and/or amplification of the ground-borne vibration levels.

Vibration Attenuation due to Geometric Spreading

For geometric spreading, the 170 m long train was modelled as a cylindrical line source based on the estimated tunnel wall vibration levels at a distance of 2 m from the track centreline. For this project, the trains were represented by point sources spaced at 5 m intervals, with the distance attenuation from each point calculated according to the following formula:

$$V(spreading) = 10\log_{10}\left(\frac{2}{\text{Distance}}\right)$$

where;

> *V(spreading)* is the change in vibration level (in dB), distance is the slant distance between the point source and the receiver location and 2 m is the reference distance of the source vibration spectrum.

Vibration Attenuation due to Material Damping

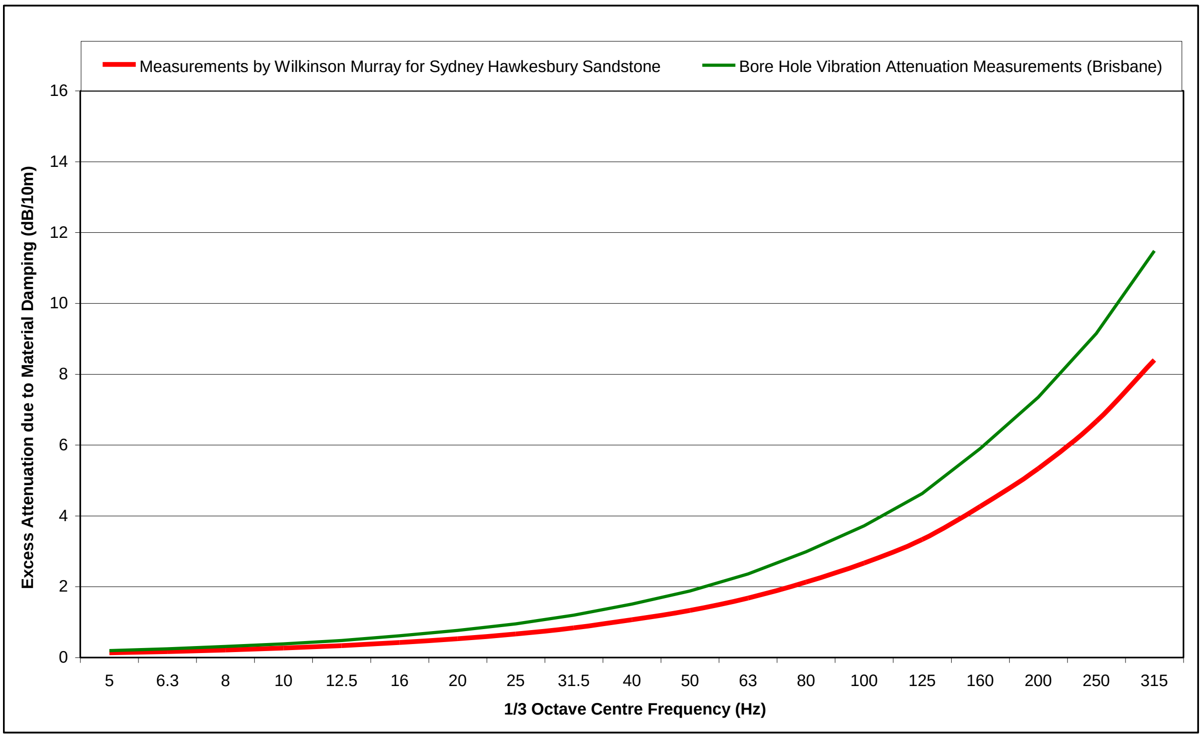
The excess attenuation due to material damping used for recent underground rail tunnel projects in Sydney was based on force transmissibility measurements undertaken by Wilkinson Murray Pty Ltd for the ECRL. The excess attenuation levels (refer to red curve in **Figure 13**) are representative of a conservative estimate for Hawkesbury Sandstone.

Vibration testing has been performed by SLR on three bore holes between Albert Street in the CBD and Boggo Road Jail adjacent to the Southern Connection using a special vibration sensor lowered to different depths in the bore holes and measuring the vibration attenuation. The tested bore holes had ground types consisting of Neranleigh-Fernvale Beds, Brisbane Tuff and at Boggo Road Jail a combination of Brisbane Tuff with Mudstone and Tingalpa Formation under.

The measured excess attenuation due to material damping was found to vary between the tested sites (having different ground types and local effects from cracks and layers in the stone). The lowest measured excess attenuation for the Brisbane tested sites has therefore been implemented as a conservative estimate of the excess attenuation (see green curve in **Figure 13**).

This conservative estimate for the excess attenuation due to material damping may result in a slight over-prediction of the ground-borne noise and vibration levels at some locations. However, since it is not possible to know exactly what ground conditions exist at all locations, this conservative approach is required at this stage in the assessment process to provide confidence that the ground-borne noise and vibration goals are achievable at all locations.

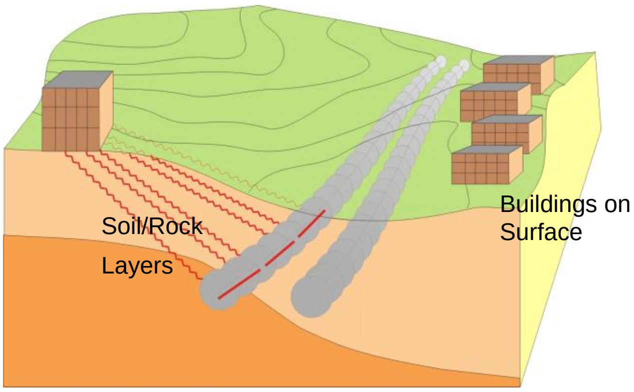
Figure 13 Excess Attenuation Due to Material Damping



Three-Dimensional Modelling

The importance of undertaking three-dimensional modelling is illustrated using the graphical representation in **Figure 14**. For a 170 m long vibration source, changes in trackform or train speed, curves and other local characteristics can result in variations in vibration emissions within the zone of influence of a given building. Hence, it is desirable for modelling to represent the train over its full length. In other words, it is necessary to model the tunnel in three dimensions, rather than as a simple cross section as illustrated in **Figure 8**.

Figure 14 Graphical Representation Indicating Possible Propagation Paths from a Train in a Tunnel



6.2.4 Receivers

Propagation of Vibration into Buildings

With many types of building, a coupling loss occurs at the ground/footing interface, resulting in lower levels of vibration in the building's footings than in the surrounding ground. The model permits assessment with a variety of coupling loss categories, or, alternatively, zero coupling loss can be specified. Typical coupling loss data for common building structures are presented in **Table 16**.

Within the Brisbane CBD, it is likely that most building footings will be founded directly on the underlying bedrock. On this basis, a conservative zero coupling loss has been assumed in the ground-borne noise and vibration modelling for all buildings within the CBD. This conservative zero coupling loss has also been assumed for some larger buildings outside of the CBD such as for the Land Centre building adjacent to Woolloongabba Station and the new Leukemia and Eco-science Precinct buildings at Boggo Road. For all smaller commercial and residential buildings outside the CBD, the "Single Residential" building type according to **Table 16** has been adopted.

Table 16 Coupling Loss Values (dB)

Building Type	**Coupling Loss (dB) in 1/3 Octave Bands**																		
	5 Hz	**6.3 Hz**	**8 Hz**	**10 Hz**	**12 Hz**	**16 Hz**	**20 Hz**	**25 Hz**	**31.5 Hz**	**40 Hz**	**50 Hz**	**63 Hz**	**80 Hz**	**100 Hz**	**125 Hz**	**160 Hz**	**200 Hz**	**250 Hz**	**315 Hz**
Large Masonry on Piles	*6*	*6*	*6*	*6*	*7*	*7*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*13*	*14*	*14*	*15*	*15*	*15*
Large Masonry on Spread Footings	*11*	*11*	*11*	*11*	*12*	*13*	*14*	*14*	*15*	*15*	*15*	*15*	*14*	*14*	*14*	*14*	*13*	*12*	*11*
2-4 Storey Masonry on Spread Footings	*5*	*6*	*6*	*7*	*9*	*11*	*11*	*12*	*13*	*13*	*13*	*13*	*13*	*12*	*12*	*11*	*10*	*9*	*8*
1-2 Storey Commercial	*4*	*5*	*5*	*6*	*7*	*8*	*8*	*9*	*9*	*9*	*9*	*9*	*9*	*8*	*8*	*8*	*7*	*6*	*5*
Single Residential	*3*	*3*	*4*	*4*	*5*	*5*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*5*	*5*	*5*	*4*	*4*	*4*

Note: Coupling loss values have been obtained from Nelson[4] and have been extrapolated to include frequency bands below 16 Hz.

Propagation of Vibration within Buildings

Losses also occur with the transfer of vibration from floor-to-floor within buildings. The model incorporates the losses listed in **Table 17**, which are based on data presented by Nelson (1987), extrapolated to include frequency bands below 16 Hz. The ground-borne noise and vibration levels attenuate by approximately 2 dB per floor for the first 4 floors and by approximately 1 dB per floor thereafter.

Table 17 Floor-to-Floor Loss Values

Floor Level Above Grade	**Floor to Floor Loss (dB) in 1/3 Octave Bands**																		
	5 Hz	**6.3 Hz**	**8 Hz**	**10 Hz**	**12 Hz**	**16 Hz**	**20 Hz**	**25 Hz**	**31.5 Hz**	**40 Hz**	**50 Hz**	**63 Hz**	**80 Hz**	**100 Hz**	**125 Hz**	**160 Hz**	**200 Hz**	**250 Hz**	**315 Hz**
1	*1*	*1*	*1*	*1*	*1.5*	*1.5*	*1.5*	*2*	*2*	*2*	*3*	*3*	*3*	*2*	*2*	*2*	*3*	*3*	*3*
2	*1*	*1*	*1*	*1*	*1.5*	*1.5*	*1.5*	*2*	*2*	*2*	*2*	*2*	*2*	*3*	*3*	*3*	*3*	*3*	*3*

Note: The floor to floor losses in this table are additive (ie for assessment on the second level above ground, the loss at 50 Hz would be 5 dB).

[4] Nelson, J. - Transportation Noise Reference Book (1987)

Low frequency vibration can be amplified within buildings by resonances in floors and walls. On the basis of data presented by Nelson (1987), the amplification spectrum presented in **Table 18** has been adopted. Nelson indicates that amplification values found in practice are typically within ±3 dB of these values. Slightly lower values are assumed for the ground-borne noise calculations as the ANC Guidelines indicate that using the full floor amplification values can result in over-estimation of the resultant noise.

The values in **Table 18** have been adopted in the BaT model for all receivers.

Table 18 Amplification within Buildings

Calculation Type	Amplification (dB) in 1/3 Octave Bands																		
	5 Hz	6.3 Hz	8 Hz	10 Hz	12 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz
Floor Vibration	10	10	10	10	10	10	10	11	11	11	10	9	9	-	-	-	-	-	-
Ground-borne Noise	-	-	-	-	-	-	6	7	7	7	6	6	5	5	4	3	2	1	1

Note: The frequency range used for vibration assessment is 5 Hz to 80 Hz and the frequency range for ground-borne noise assessment is 20 Hz to 315 Hz.

6.3 Ground-borne Vibration Predictions

On the basis of the ground-borne vibration modelling assumptions discussed above, **Table 19** presents a summary of the predicted ground-borne vibration levels for buildings located above or near the proposed rail tunnel alignment.

At this stage in the assessment process, it has been necessary to undertake a best estimate of several parameters that form part of the ground-borne noise and vibration modelling. These parameters include the source vibration levels of the proposed rolling stock, vehicle/track interaction, speed profile and ground conditions. For these reasons, it is considered prudent to incorporate a 5 dBA safety factor on the predicted ground-borne noise and vibration levels.

The predicted ground-borne vibration levels represent the maximum mid-floor vibration levels within multi-storey buildings. For a building with a slab on ground construction, the highest vibration levels would be expected to occur on Level 2, due to the amplification resulting from the suspended slab. The calculations in **Table 19** are based on Direct Fixation trackform configuration (refer to **Figure 12**).

Table 19 Summary of Predicted Ground-borne Vibration Levels (Reference Project Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Vibration Level (mm/s)[1]	Residential Night-time Vibration Goal (mm/s)[1,2]	Reference Design
0.37 – 1.8 Southern Connection to Woolloongabba Station	Residential Commercial Educational Worship Hotel	23 m – 134 m 40 m – 234 m 98 m – 176 m 116 m – 154 m 79 m	0.002 to 0.048 mm/s 0.001 to 0.018 mm/s 0.002 to 0.002 mm/s 0.001 to 0.002 mm/s 0.005 mm/s	0.2 mm/s	Direct Fixation Rail Fasteners
1.8 – 3.55 Woolloongabba Station to George Street Station	Residential Commercial Educational Worship Medical Hotel	43 m – 310 m 42 m – 293 m 103 m – 173 m 39 m – 312 m 311 m 54 m – 251 m	0.00 to 0.019 mm/s 0.00 to 0.012 mm/s 0.001 to 0.003 mm/s 0.00 to 0.015 mm/s 0.00 mm/s 0.00 to 0.008 mm/s	0.2 mm/s	Direct Fixation Rail Fasteners
3.55 – 4.8 George Street Station to Roma Street Station	Residential Commercial Educational Worship Medical Hotel	37 m – 97 m 33 m – 311 m 67 m – 267 m 241 m – 278 m 232 m – 249 m 35 m – 304 m	0.003 to 0.043 mm/s 0.00 to 0.041 mm/s 0.00 to 0.003 mm/s 0.001 to 0.001 mm/s 0.001 to 0.001 mm/s 0.00 to 0.050 mm/s	0.2 mm/s	Direct Fixation Rail Fasteners
4.8 – 6.05 Roma Street Station to Northern Connection	Residential Commercial Educational Medical Hotel	41 m – 124 m 40 m – 131 m 41 m – 161 m 88 m 58 m – 119 m	0.001 to 0.020 mm/s 0.002 to 0.015 mm/s 0.002 to 0.020 mm/s 0.005 mm/s 0.003 to 0.012 mm/s	0.2 mm/s	Direct Fixation Rail Fasteners

Note 1: The predicted vibration levels and vibration goal are based on the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.

Note 2: The residential night-time vibration goal is the most stringent operational vibration goal, except at a few special receivers with potentially highly vibration sensitive equipment (refer to **Section 6.4.1**).

6.4 Ground-borne Vibration Assessment

As discussed in **Section 2.4.6**, the human comfort (perception) limits for ground-borne vibration tend to be more stringent than other possible design limits relating to building damage risk or the potential effects on building contents. The most stringent ground-borne vibration goal is 0.2 mm/s (103 dB_V) for residential buildings during the night-time period (refer **Table 4**).

On the basis of the speed profile for the BAT project (refer **Table 15**) and on the proposed vertical alignment and modelling assumptions described in the previous sections, compliance with the ground-borne vibration limits is predicted for all sensitive receiver locations above or near the proposed alignments.

6.4.1 Special Receivers Which May Contain Highly Vibration Sensitive Equipment

The Eco-science precinct, Princess Alexandra Hospital, QUT at 2 George Street and St Andrews Hospital have been identified as having special vibration sensitive equipment (i.e. electron microscope or Magnetic Resonance Imaging (MRI) systems).

At this stage in the assessment, no other commercial facilities have been identified which contain any highly sensitive measurement equipment. For the Reference Project assessment purposes, it is assumed that all nearby research and medical facilities may contain highly sensitive equipment such as lithography and inspection equipment with high resolution. **Table 20** presents predicted ground-borne vibration levels and vibration goals for the facilities that are located in close proximity of the proposed Reference Project alignment.

For the electron microscope at the basement of the Eco-science precinct, an equipment specific vibration criterion has been supplied and included in **Table 20**. It can be seen that the predicted vibration levels are achieving the supplied vibration criteria.

All identified special receivers have predicted ground-borne vibration velocity below the limit of 0.013 mm/s (82 dB_V) per octave band.

Table 20 Special Receivers Which May Contain Highly Vibration Sensitive Equipment

Receiver	Location	Chainage (km)	Maximum 1/3 Octave Band Vibration Velocity (mm/s)[1]	
			Predicted	Vibration Goal
Princess Alexandra Hospital	Ipswich Road, Woolloongabba	0.345	<0.005	0.013
Eco-Science Precinct	Boggo Rd, Dutton Park	0.585	0.004 <10Hz [2] 0.006 >10 Hz [3]	0.02 <10Hz [2] 0.3 >10 Hz [3]
Abardeen Medical Clinic	470 Main Street, Kangaroo Point	2.675	<0.001	0.013
Queensland University of Technology	2 George Street, Brisbane	3.2	<0.001	0.013
CBD 7 Day Medical Centre	245 Albert Street, Brisbane	4.0	0.001	0.013
Brisbane Dental Hospital and College	168 Turbot Street, Brisbane	4.275	0.001	0.013
St Andrews Hospital	457 Wickham Tce, Spring Hill	5.355	0.002	0.013

Note 1: The predicted vibration levels are based on the Reference Project trackform of direct fixation.

Note 2: Vibration velocity within frequency range 3 Hz to 10 Hz as specified for the TEM equipment at the Eco-science precinct (i.e. not maximum 1/3 Octave band as the generic vibration criterion is specified).

Note 3: Vibration velocity for frequencies above 10 Hz as specified for the TEM equipment at the Eco-science precinct (i.e. not maximum 1/3 Octave band as the generic vibration criterion is specified).

6.4.2 Heritage Structures

As discussed in **Section 2.4**, the levels of vibration required to cause damage to sensitive heritage buildings (2 mm/s according to Department of Transport and Main Roads Technical Standard MRTS51) are an order of magnitude (10 times) higher than those at which people may consider the vibration to be intrusive (0.2 mm/s refer to **Table 4**).

The predicted vibration levels associated with train operations in the tunnels are less than 0.144 mm/s at any buildings near the tunnels and therefore the risk to any heritage buildings is negligible. Similarly, the potential for damage to other key utilities/ infrastructure is also negligible on the basis that the tunnel wall vibration levels are anticipated to be approximately 0.1 mm/s (100 dB_V).

6.4.3 Ground-borne Vibration Impacts on Rodents

Medical and specialist research facilities holding rodents are sensitive to noise and vibration, however specific industry guidelines on these aspects is limited within Australia. Following a review of the literature, SLR believes a floor vibration criteria of 0.1 mm/s PPV is likely to be acceptable in line with Section 3.3.4 of the Victorian Government Department of Primary Industries Code of Practice for the Housing and Care of Laboratory Mice, Rats, Guinea Pigs and Rabbits and the 2008 US National Institutes of Health (NIH) Design Requirements Manual for Biomedical Laboratories and Animal Research Facilities.

Excessive noise and vibration can create a range of issues in mice (and rats) including but not limited to disturbance of natural sleep-wake cycles and breeding / reproduction rates, induction of an array of behavioural and physiological changes, and physical injuries from startle reactions.

For basement locations (as is the case for the Translational Research Institute (TRI) laboratory), airborne noise from the operation of the BaT project is unlikely to be an issue, however ground vibration and regenerated noise may be of concern.

At the TRI facility within the PA Hospital grounds, ground-borne vibration is predicted to be below the above criteria of 0.1 mm/s.

Additionally, we note that vibration levels experienced by the rodents within TRI facility are (and will continue to be) typically higher than the above values during normal activities, and they generally include general footfall / walking, doorstrikes and manual handling of cages, feedstock and heavy items within the building floorplate.

On this basis, we expect ground-borne vibration emissions from the BaT project to be acceptable to the mice holding facilities at the TRI facilities. Regardless, it is recommended that vibration monitoring is undertaken at commencement of operation to ensure ongoing vibration levels are compliant with the criteria recommended.

7 GROUND-BORNE NOISE ASSESSMENT – TRAIN OPERATIONS

7.1 Introduction

Train noise in buildings adjacent to rail tunnels is predominantly caused by the transmission of ground-borne vibration rather than the direct transmission of noise through the air. The vibration is initially generated by wheel/rail interaction (by the mechanisms described in **Section 6.2**) and is transmitted from the trackbed, through the tunnel structure, via the ground and into the adjacent building structures (as illustrated in **Figure 8**). After entering a building, this vibration causes the walls and floors to vibrate faintly and hence to radiate noise (commonly termed “ground-borne noise”).

If it is of sufficient magnitude to be audible, this noise has a low frequency rumbling character, which increases and decreases in level as a train approaches and departs the site. This type of noise can be experienced in buildings adjacent to many urban underground rail systems.

In some CBD buildings, the rumbling noise can sometimes be heard several storeys above ground level where no precautions have been taken in the tunnel or building design to limit ground-borne noise and vibration effects. For most new underground railway lines, the standard track design usually incorporates resilient rail fasteners to reduce the transmission of dynamic forces that occur at the wheel-rail interface. This resilience serves to provide isolation of ground-borne vibration, which in turn reduces the ground-borne noise levels in buildings near the railway tunnel.

The fact that ground-borne train noise may be audible does not necessarily indicate that it is offensive or disturbing. In many cases, the train noise may pass unnoticed due to the “masking” effect of other ambient noise sources, activities or distractions.

Some especially sensitive spaces and activities, such as theatres, cinemas and sleeping areas are more prone to disturbance from ground–borne noise than others, such as shopping areas, office spaces or industrial premises.

The applicable ground-borne noise goals are discussed in **Section 2.5**.

7.2 Ground-borne Noise Modelling Methodology

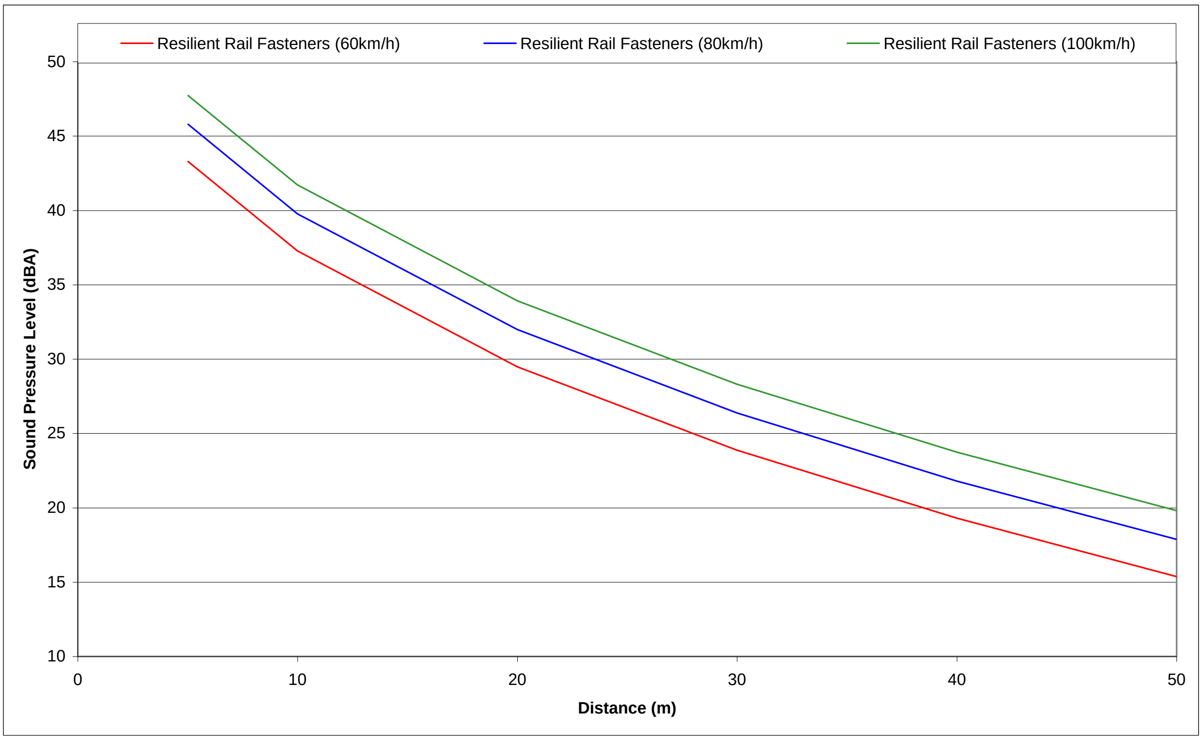
The ground-borne noise modelling methodology followed the same calculation procedure discussed in **Section 6.2** for the ground-borne vibration modelling, with the addition of two final steps to account for the conversion of vibration in a building into noise.

In accordance with Nelson (1987) and the ANC Guidelines (2001), an adjustment of -27 dB was used in the model to convert each 1/3 octave band vibration level (dB_V re 1 nm/s) to a sound pressure level (dB re 20 µPa). The 1/3 octave band sound pressure levels were then A-weighted and logarithmically summed to provide the overall $L_{Amax,Slow}$ noise level predictions. The employed relationship is conservative and it is noted that the latest version of the ANC guideline (2012) has moved to recommend a conversion factor of -32 (rather than -27).

On the basis of the ground-borne noise and vibration modelling assumptions discussed above and in **Section 6.2**, **Figure 15** presents a summary of the predicted ground-borne noise levels at various distances from the proposed railway tunnel for train speeds of 60 km/h, 80 km/h and 100 km/h, assuming a “Resilient” trackform and “Single Residential” building as specified in **Section 6.2**.

Figure 15 is illustrative only and its purpose is to show how ground-borne noise levels are dependent on speed and reduce as the distance between the tunnel (rail level) and receiver increases. The distances are slant distances, and are therefore dependent on the depth of the tunnel (rail level) as well as the horizontal offset distance. For the modelling results presented in the following section, the ground-borne noise level predictions are based on the 3-dimensional track layout, actual train speeds, track features, receiver building type etc, which are not included in **Figure 15**.

Figure 15 Ground-borne Noise Level (Resilient Rail Fasteners) Versus Slant Distance Illustrative Only - Not to be used for Assessment



Note: The distance refers to the slant distance between the receiver location (on the surface) and the track (within the tunnel). For example, if the track is located 20 m below ground and the receiver is located 30 m to the side of the tunnel, the receiver would be located at a slant distance of 36 m from the track. For buildings with piles or otherwise directly connected to the bedrock, a 5 dBA increase of the ground-borne noise levels are expected.

7.3 Ground-borne Noise Mitigation Options

The potential ground-borne noise mitigation options for a new railway line include the following:

- Operational measures such as reduced train speeds or allowing system access only to trains with wheels in “good” condition.
- Track design measures including the provision of resilient rail fasteners, booted sleepers or floating slab track to reduce the vibration energy transferred to the tunnel footing, foundation, surrounding ground and nearby buildings.
- Track maintenance/rolling stock measures such as maintenance to keep rail and wheel roughness within required tolerances, maintaining existing rolling stock to ensure “good” wheel condition and / or implementing long-term measures to improve wheel condition over time.
- Receiver controls at existing or proposed developments such as full or partial vibration isolation of the building using springs or rubber bearings.
- Planning measures such as locating sensitive developments at an acceptable distance from the tunnel alignment.
- Avoiding tight curves (less than approximately 600 m radius) and maximising the vertical alignment (tunnel depth) where possible.

The Reference Project alignment has been designed to avoid major buildings insofar as possible by running the route in-line with existing roads and surface rail tracks. The vertical alignment (tunnel depth) has also been maximised where possible to reduce potential noise and vibration impacts.

Further approaches to mitigation therefore focus on operational measures, track design, maintenance regimes and source control measures. These options are likely to be far more cost effective than receiver controls such as full or partial vibration isolation of buildings above the railway tunnel (which are also usually impracticable for most existing buildings).

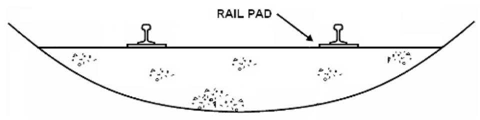
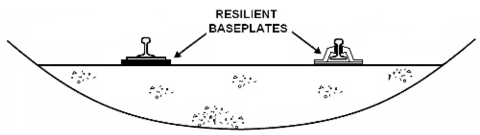
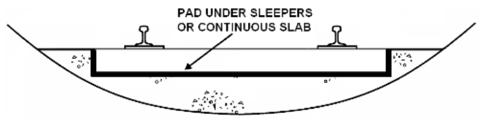
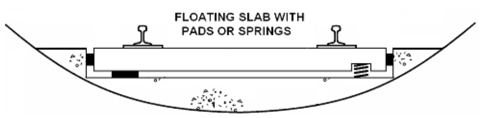
Operational measures such as improved wheel and rail condition would provide ground-borne noise and vibration benefits across the whole project area, whilst track design measures and a reduction in train speeds could provide benefits in specific areas.

For the Project, the ground-borne noise and vibration modelling assumed that the condition of the wheels and rails would be maintained at "good" condition (i.e. within specified roughness limits in Annex C of ISO 3095 or better) and a monitoring program is proposed to be implemented by the operators to identify and repair track and wheels in poor condition.

In order to reduce the potential for ground-borne noise impacts at sensitive receivers without impacting operations via speed reductions, mitigation measures would need to focus on improving the vibration isolation characteristics of the track.

In order to reduce ground-borne noise and vibration levels within buildings located close to railway lines, a range of alternative track designs are available. These generally include the insertion of a resilient layer between the rail and tunnel foundation, either in the form of a resilient rail fastener, booted sleeper, floating track slab or a combination of approaches. The resilience is usually in the form of elastic/resilient pads or mats (or moulded rubber elements in the resilient baseplates/fasteners). **Figure 16** presents the principal features of generic designs for slab tracks and the location of the resilient components in each case.

Figure 16 Generic Trackforms to Mitigate Ground-borne Noise and Vibration on Slab Track

Generic Trackform Layouts	***Acoustic Performance***	***Description***
		*Direct fixation with standard rail foot pads (eg HDPE)*
	*Increasing Ground-borne Noise and Vibration Reduction*	*Resilient rail fasteners (eg, Delkor Alt 1, Pandrol Vipa, Pandrol Double Fastclip)*
		Highly resilient rail fasteners (eg, Delkor Egg or Pandrol Vanguard)
		*Resiliently supported sleepers/blocks or continuously supported slabs (eg slab on ballast mat)*
		*Floating Slab Track (FST) systems using short, long or continuous slabs with rubber or spring elements*

The trackforms included in the assessment for the BaT Reference Project are described in **Section 6.2.2** and include direct fixation with standard "stiff" rail foot pads, resilient and highly resilient rail fasteners.

Resilient rail fasteners can significantly reduce the level of ground-borne noise and vibration; however the following important factors should be noted:

- Careful attention is needed during detailed design to ensure that the loaded natural frequency of the resilient rail fastener does not coincide with other frequencies associated with the fastener spacing, wheel diameter, bogie passing frequency, etc. If this occurs, the performance of the system will be impaired.
- An increase in the fastener spacing and decrease in the static stiffness of the resilient rail fasteners will increase the maximum rail deflection (and rail stress).

7.4 Ground-borne Noise Predictions

On the basis of the speed profile for the Project (shown in **Table 15**), the proposed vertical alignment and the modelling assumptions described in the previous sections, predicted ground-borne noise levels for buildings located above or close to the proposed rail alignments have been performed. These calculations have been performed for the Reference Project trackform configuration as outlined in **Section 6.2.2**.

At this stage in the assessment process, it has been necessary to undertake a best estimate of several parameters that form part of the ground-borne noise and vibration modelling. These parameters include the source vibration levels of the proposed rolling stock, vehicle/track interaction, speed profile and ground conditions. For these reasons, it is considered prudent to incorporate a 5 dBA safety factor on the predicted ground-borne noise and vibration levels.

The ground-borne noise predictions for the sensitive receivers along the tunnel alignment (with the Reference Project trackform configuration) are provided in **Table 21**. Exceedances are shown in **bold**.

Table 21 Summary of Predicted Ground-borne Noise Levels (Direct Fixation Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Base Case Mitigation Measure
0.37 – 1.8 Southern Connection to Woolloongabba Station	Residential	23 m – 134 m	<10 dBA to **46 dBA**	35 dBA (night-time)	Direct Fixation Rail Fasteners
	Commercial	40 m – 234 m	<10 dBA to 36 dBA	40 dBA	
	Educational	98 m – 176 m	<10 dBA to 11 dBA	40 dBA	
	Worship	116 m – 154 m	<10 dBA	40 dBA	
	Hotel	79 m	15 dBA	35 dBA (night-time)	
1.8 – 3.55 Woolloongabba Station to George Street Station	Residential	43 m – 310 m	<10 dBA to 33 dBA	35 dBA (night-time)	Direct Fixation Rail Fasteners
	Commercial	42 m – 293 m	<10 dBA to 29 dBA	40 dBA	
	Educational	103 m – 173 m	<10 dBA	40 dBA	
	Worship	39 m – 312 m	<10 dBA to 32 dBA	40 dBA	
	Medical	311 m	<10 dBA	40 dBA	
	Hotel	54 m – 251 m	<10 dBA to 24 dBA	35 dBA (night-time)	
3.55 – 4.8 George Street Station to Roma Street Station	Residential	37 m – 97 m	<10 dBA to **42 dBA**	35 dBA (night-time)	Direct Fixation Rail Fasteners
	Commercial	33 m – 311 m	<10 dBA to **42 dBA**	40 dBA	
	Educational	67 m – 267 m	<10 dBA	40 dBA	
	Worship	241 m – 278 m	<10 dBA	40 dBA	
	Medical	232 m – 249 m	<10 dBA	40 dBA	
	Hotel	35 m – 304 m	10 dBA to **43 dBA**	35 dBA (night-time)	
4.8 – 6.05 Roma Street Station to Northern Connection	Residential	41 m – 124 m	<10 dBA to 35 dBA	35 dBA (night-time)	Direct Fixation Rail Fasteners
	Commercial	40 m – 131 m	<10 dBA to 33 dBA	40 dBA	
	Educational	41 m – 161 m	<10 dBA to 35 dBA	40 dBA	
	Medical	88 m	10 dBA	40 dBA	
	Hotel	58 m – 119 m	<10 dBA to 25 dBA	35 dBA (night-time)	

Note: Predictions are for the $L_{Amax,Slow}$ noise level and refers to the 95th percentile train passby event. The ground-borne noise level of the “average” or median train event would be approximately 3 dB lower than the 95th percentile event.

It can be seen in **Table 21** that there are two track sections where there are residential receivers exceeding the night-time ground-borne noise goal of 35 dBA for the Direct Fixation trackform.

A summary of the extent of the various trackforms that would be required to achieve compliance with the ground-borne noise goals at all sensitive receiver locations is given in **Table 22** and graphically shown in **Figure 17**. In total, 790 m of resilient rail fasteners for the Down Track, 665 m of resilient rail fasteners for the Up Track are required.

A summary of the predicted ground-borne noise levels with the proposed trackform configuration including the additional “Resilient” trackform discussed above is shown in **Table 23,** which show compliance with the ground-borne noise goals at all sensitive receivers.

It should also be noted that the modelling results include a 5 dB safety factor which could possibly be refined downwards during the detailed design phase. Alternatively, it may be possible during detailed design for alternative track designs to be used with different dynamic stiffness properties - this may alter the number of receivers above the noise goals.

Table 22 Proposed Trackforms to Comply with the Ground-borne Noise Goals

Down Track			Up Track		
Chainage (km)		Trackform	Chainage (km)		Trackform
From	To		From	To	
0	0.35	Direct Fixation	0	0.79	Direct Fixation
0.35	0.45	Resilient	0.79	1.245	Resilient
0.45	0.78	Direct Fixation	1.245	4.43	Direct Fixation
0.78	1.25	Resilient	4.43	4.64	Resilient
1.25	4.41	Direct Fixation	4.64	6.735	Direct Fixation
4.41	4.63	Resilient			
4.63	6.725	Direct Fixation			

Note 1: The Direct Fixation and Resilient trackforms are specified in **Figure 11**.

Figure 17 Extent of Proposed Trackforms

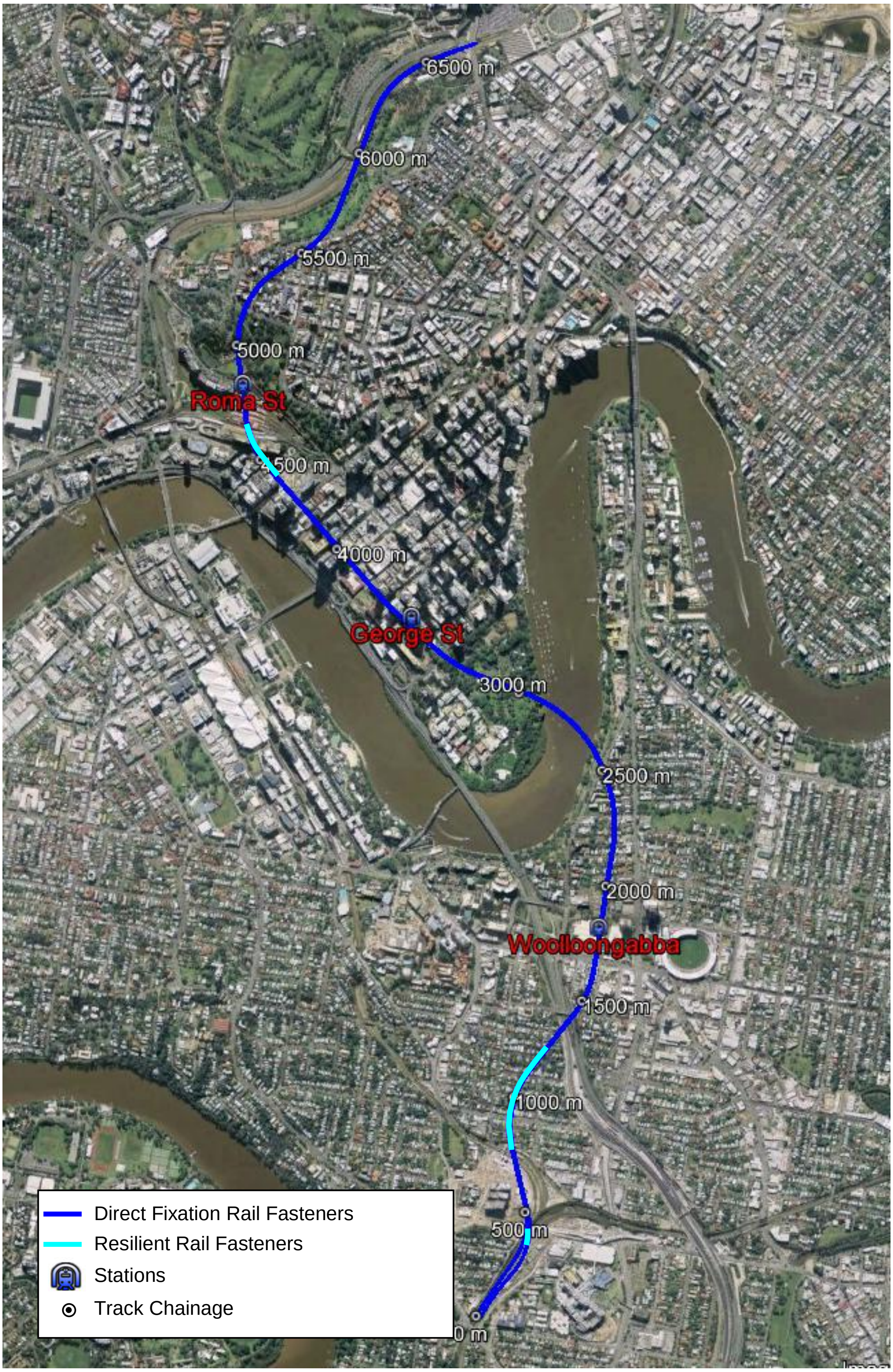


Table 23 Summary of Predicted Ground-borne Noise Levels (Proposed Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Proposed Mitigation Measure[1]
0.37 – 1.8 Southern Connection to Woolloongabba Station	Residential Commercial Educational Worship Hotel	23 m – 134 m 40 m – 234 m 98 m – 176 m 116 m – 154 m 79 m	<10 dBA to 35 dBA <10 dBA to 36 dBA <10 dBA <10 dBA 15 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners (Chainage 0.35 – 0.45 km, only for Down Track) and (Chainage 0.78 – 1.25 km, both tracks) Direct Fixation Rail Fasteners (elsewhere)
1.8 – 3.55 Woolloongabba Station to George Street Station	Residential Commercial Educational Worship Medical Hotel	43 m – 310 m 42 m – 293 m 103 m – 173 m 39 m – 312 m 311 m 54 m – 251 m	<10 dBA to 33 dBA <10 dBA to 29 dBA <10 dBA <10 dBA to 32 dBA <10 dBA <10 dBA to 24 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Direct Fixation Rail Fasteners
3.55 – 4.8 George Street Station to Roma Street Station	Residential Commercial Educational Worship Medical Hotel	37 m – 97 m 33 m – 311 m 67 m – 267 m 241 m – 278 m 232 m – 249 m 35 m – 304 m	<10 dBA to 34 dBA <10 dBA to 37 dBA <10 dBA <10 dBA <10 dBA 10 dBA to 35 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners (Chainage 4.41 – 4.63 km, both tracks) Direct Fixation Rail Fasteners (elsewhere)
4.8 – 6.05 Roma Street Station to Northern Connection	Residential Commercial Educational Medical Hotel	41 m – 124 m 40 m – 131 m 41 m – 161 m 88 m 58 m – 119 m	<10 dBA to 35 dBA <10 dBA to 33 dBA <10 dBA to 35 dBA 10 dBA <10 dBA to 25 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Direct Fixation Rail Fasteners

Note: The LAmax,Slow noise level refers to the 95th percentile train passby event. The ground-borne noise level of the “average” or median train event would typically be approximately 3 dB lower than the 95th percentile event.

Note 1: The extent of the proposed mitigation measures (ie trackforms) is detailed in Table 22 and Figure 17.

7.5 Ground-borne Noise Impacts on Rodents

As outlined in **Section 6.4.3** medical and specialist research facilities holding rodents are sensitive to noise and vibration, however specific industry guidelines on these aspects is limited within Australia. Following a review of the literature, SLR believes a noise criteria of 40 dBA $L_{AmaxFast}$ is likely to be acceptable in line with Section 3.3.4 of the Victorian Government Department of Primary Industries Code of Practice for the Housing and Care of Laboratory Mice, Rats, Guinea Pigs and Rabbits and the 2008 US National Institutes of Health (NIH) Design Requirements Manual for Biomedical Laboratories and Animal Research Facilities.

At the TRI facility within the PA Hospital grounds, ground-borne noise emissions from the BaT project are predicted to be 27 dBA $L_{AmaxSlow}$ (difference between the $L_{AmaxFast}$ and $L_{AmaxSlow}$ parameter is approximately 2.5 dB), which is below the above recommended noise limits.

Additionally, we note that noise levels experienced by the rodents within TRI facility are (and will continue to be) typically higher than the above values during normal activities, and they generally include door closing/slamming, normal speech, spray hoses (cleaning and maintenance), bench activities, cage feedstocking, cage ventilation systems and radios / public address systems.

On this basis, we expect noise emissions from the BaT project to be acceptable to the mice holding facilities. Regardless, it is recommended that noise monitoring is undertaken at commencement of operation to ensure ongoing noise levels are compliant with the criteria recommended.

7.6 Ground-borne Noise Conclusion

With the proposed track form in **Table 22**, the predicted ground-borne noise achieves the noise goals at all sensitive locations.

8 AIRBORNE NOISE ASSESSMENT - TRAIN OPERATIONS

The Project Rail Operations team has prepared a rail operations summary paper to help the Underground Bus and Train design team to define the scope of infrastructure works required to meet the operational requirements of the Project. Overviews for the existing and proposed new Underground Bus and Train project surface tracks for the northern section and southern section (ie north and south of the tunnel portals) are presented in **Figure 18** and **Figure 19** respectively.

The noise assessment for the surface train operations have been performed based on predicted future Year 2031 train operations. The following sections present modelling methodology, modelling input data and assumptions, predicted noise levels and possible mitigation measures to meet project noise goals where applicable.

Figure 18 Overview of Northern Connection Precinct

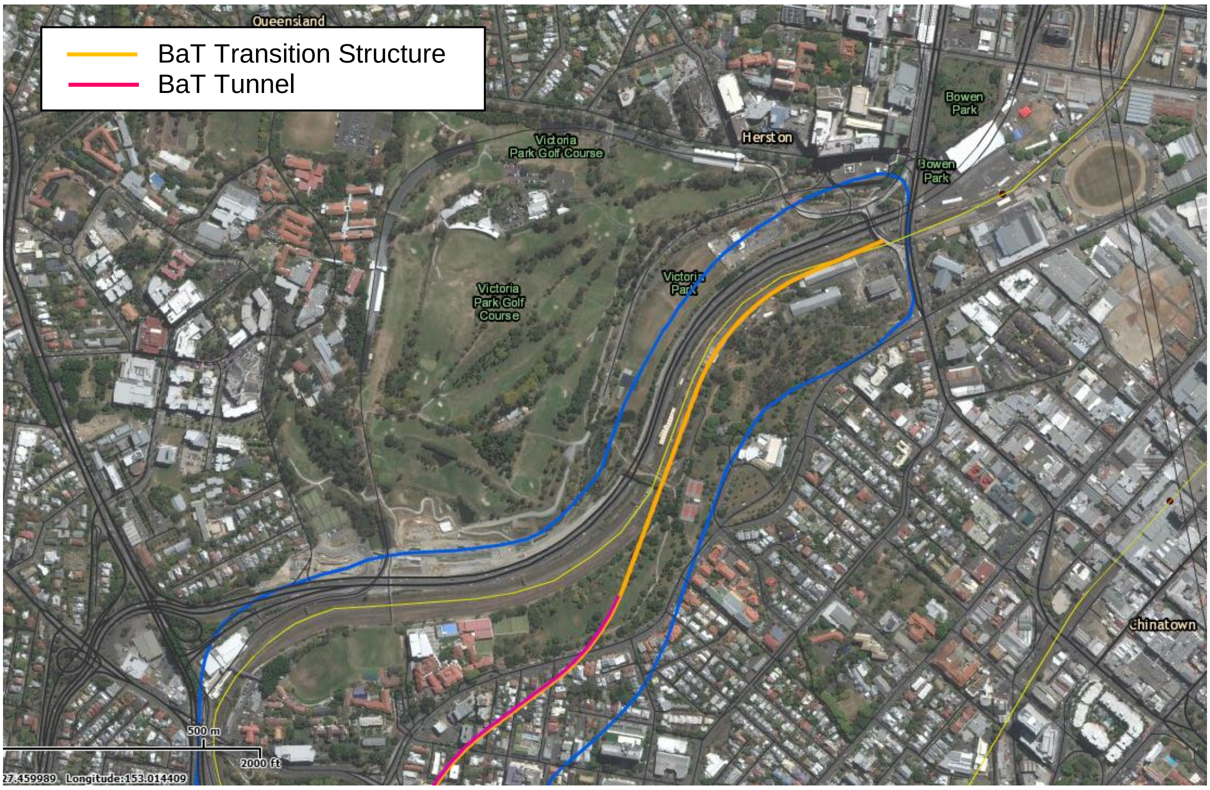


Figure 19 Overview of Southern Connection Precinct

8.1 SoundPLAN Modelling Methodology

A SoundPLAN (Version 6.5) computer noise model has been used for the prediction of noise levels at sensitive receivers. The noise model comprises topography, buildings, number of trains and calibrated noise emission levels (against measurements), relevant noise sources for portal noise emissions as well as the location of noise sensitive receivers. The computer model calculates the noise levels at sensitive locations, taking into account:

- All noise source sound power levels and frequency spectra.
- Noise propagation variables such as distance attenuation, ground absorption, air absorption and shielding attenuation from topography, buildings or barriers.

The calculation procedure involves a 360^{o} scan from each receiver point (using fixed angular steps), with the contributions from each angular increment summed to determine the total received noise level. The calculation procedure takes into account the direct noise, the noise diffracting over obstacles or barriers and the noise reflected off buildings.

The assessment undertaken for this report has been based on the single point calculations at each receiver point.

A separate model run was also carried out using a fixed calculation grid with a spacing of 10 m to produce noise contours. The resultant contours were interpolated between the grid points.

Two different computation algorithms were utilised within the SoundPLAN model. The Nordic Rail Traffic Noise Prediction Method (Kilde 130) has been used for all surface rail noise assessments and the CONCAWE industrial prediction model has been used to account for the additional noise emission through the portal openings. These prediction models and the utilised model inputs are described below.

Nordic Rail Traffic Noise Prediction Method

The Nordic Rail Traffic Noise Prediction Method (Kilde 130) dates from 1984 and is commonly utilised for Queensland Rail noise assessments. It calculates emission noise level based on the number of trains, speed and length. It predicts $L_{Aeq(24hour)}$ and maximum noise levels as required by the Queensland Rail Code of Practice.

The CONCAWE Standard for Industrial Noise Modelling

Noise emissions from the portals have been predicted using the CONCAWE prediction model.

CONCAWE is commonly implemented in industry and resource sector projects for environmental noise prediction. It allows for investigation of effects of wind and atmospheric stability on noise propagation. The CONCAWE standard is based on a research paper published in 1981 under the title "The propagation of noise from petroleum and petrochemical complexes to neighbouring communities".

The statistical accuracy of environmental noise predictions using CONCAWE was investigated by Marsh (Applied Acoustics 15 - 1982), with the conclusion that CONCAWE was accurate to ±2 dBA in any one octave band between 63 Hz and 4 kHz and ± 1 dBA overall.

8.2 Train Operations – Upgraded Rail Alignments including BaT

8.2.1 Model Inputs and Assumptions – Through Traffic

The SoundPLAN model was created from topography, rail alignments, existing buildings and resumption plans supplied by the Project team. The topography, BaT rail alignments and existing buildings were supplied in 3-D; the existing rail alignments were supplied in 2-D. A digital ground model was created based on the supplied topography and applied to the existing rail alignment strings to generate the 3-D model.

The suburban and freight train movements for a typical day were supplied by the Project Rail Operations Team and are shown in **Table 24**.

Table 24 Daily (24-hour) Train Movements – Surface Tracks

Section	Train Lines	2031
Passenger Trains		
Yeerongpilly to South Brisbane	Dual Gauge/South Coast	200
Cleveland to South Brisbane	Cleveland	232
Yeerongpilly to BaT	Dual Gauge/South Coast	222
BaT Services (Empty/Turnbacks)	Exhibition	150
Freight Trains		
Yeerongpilly to South Brisbane	Dual Gauge	6
Yeerongpilly to Port of Brisbane	Dual Gauge/Cleveland/South Coast	28
North Coast	Exhibition	16

Note: Train numbers are the total for both directions

Train noise source data for the existing fleet have been taken from Queensland Rail's standard table of noise emissions. Based on advice from the Project team, all suburban trains were modelled as the proposed new 7-car passenger trains. The Project team advised these new trains have similar specifications to the existing EMU fleet, therefore the noise emission levels for the 7-car passenger trains were extrapolated from those for a 6-car EMU citytrain.

A "typical-maximum" speed profile for passenger trains was provided by the Project team. These speeds have been applied to all passenger trains within the study area. Acceleration and deceleration rates (for approach to and departure from stations) have been roughly estimated in this initial stage of modelling as no data is available for the proposed new 7-car passenger trains.

In the absence of any data, all freight traffic was modelled as double-header locomotives (current generation) with 1,500 m of consist. All freight movements were assumed to travel at a constant speed of 60 km/h and the locomotives were assumed to be at a notch setting of 6.

Corrections for curves, bridges and turnouts have been modelled based on features identified in the Reference Design, existing track alignments and aerial photography.

Plans and coordinates of existing noise barriers along the Cleveland line were supplied by Queensland Rail. All other existing noise barriers were digitised based on aerial imagery and site visits. All noise barriers have been included in the noise modelling as fully reflective noise barriers.

8.2.2 Modelling Assumptions – Portal noise emissions

Noise emissions from the tunnel portals have been modelled as a vertical area noise source across the tunnel portal openings. A sound power level has been assigned to these portal noise sources based on in tunnel noise measurements in rail tunnels in Sydney. The source level has for the Reference Project assumed no absorption in the tunnel, resulting in a higher reverberant build up noise level in the tunnels. The maximum sound power level for the portal noise emission is 121 dBA, based on a reverberant in-tunnel sound pressure level of 105 dBA. The average $LA_{eq(24hour)}$ sound power level for the portals have been calculated following the methodology outlined in a paper "Prediction of sound radiated from tunnel openings" by Wolfgang Probst, 2010. The $LA_{eq(24hour)}$ sound power level for the portals are presented in **Table 25**.

Table 25 Average LAeq(24hour) Sound Power Level per Portal

Portal	2031	
	Train Numbers	SWL (dBA)
Southern Connection Portals	111	94
Northern Connection Inbound Portal	113	94
Northern Connection Outbound Portal	37	89

Directivity for the portal opening area noise sources in accordance with recommendations in (Wolfgang Probst, 2010) has been adopted. The directivity formula for the portal noise emission is:

$D = -0.115 * \Psi + 3.08$ dB

Where Ψ is the angle between centreline of the tunnel and the line from the centre of the tunnel to the receiver position ($0 \leq \Psi \geq 90^o$).

8.2.3 Predicted Noise Levels

Rail traffic noise levels have been predicted for the future Year 2031 (10 year horizon) scenario.

For the northern section, Year 2031 rail noise levels of up to 59 dBA $L_{Aeq(24hour)}$ and 78 dBA L_{Amax} are predicted. Based on these predictions, all sensitive locations within the northern section are predicted to comply with Queensland Rail's operational planning levels.

For the southern section, Year 2031 rail noise levels of up to 77 dBA $L_{Aeq(24hour)}$ and 97 dBA L_{Amax} are predicted. Based on the predicted noise levels, 19 sensitive locations within the southern section are predicted to exceed Queensland Rail's operational planning levels in Year 2031.

The predicted noise levels for Year 2031 for each section are tabulated in **Appendix F**. The predicted noise levels in **Appendix F** include contributions from the through traffic and tunnel portals and include shielding from any existing noise barriers. All predicted levels include a +3 dBA facade correction. **Appendix F** also indicates which receivers are located adjacent to train stations.

Noise contours for Year 2031 are presented in **Appendix G**. The noise contours include contributions from the through traffic, tunnel portals and a +3 dBA facade correction. The existing noise barriers included in the modelled noise levels are shown on the noise contour plans.

It should be noted that the contours are interpolated over a 10 m grid space. The assessment undertaken for this report has been based on single point calculations at each receiver (**Appendix F)**.

8.2.4 Mitigation Measures

As all sensitive locations within the northern section are predicted to comply with Queensland Rail's operational planning levels, no mitigation measures are required in this area.

The Year 2031 operational noise levels are predicted to exceed Queensland Rail's planning levels in the southern section. A noise barrier has been designed to reduce operational noise levels to achieve compliance with Queensland Rail's planning levels, where possible.

Queensland Rail's Code of Practice states the following with regard to noise barriers adjacent to stations:

For safety reasons, noise barriers will not be built at or near stations.

Noise barriers adjacent to existing train stations have therefore not been included in the below proposed noise barrier design.

Also, in line with current practice in Queensland, noise barrier heights have been capped at 6 m on consideration of "reasonableness".

Railway Terrace Noise Barrier

Upgrading the existing noise barrier to a height of 6 m provides a significant noise reduction at most facades. However, this noise barrier is insufficient to achieve compliance with Queensland Rail's operational planning levels at all residences. It has not been proposed to extend this noise barrier in front of the Leukaemia Foundation building at the northern end as the building's height would make any noise barrier ineffective. The total area of the upgraded noise barrier is approximately 1,919 m^2.

Due to Queensland Rail's policy to not build noise barriers adjacent to existing train stations for safety reasons, there are 7 additional sensitive receivers adjacent to the Dutton Park (5) and Park Road (2) Stations exceeding Queensland Rail's operational planning levels taking into account the proposed Project noise barriers. Rail noise levels of up to 77 dBA $L_{Aeq(24hour)}$ and 97 dBA L_{Amax} are predicted at these residences, being an exceedance of 12 dBA and 10 dBA respectively.

During the detailed design phase, all noise barriers will need to be designed in cooperation with Queensland Rail to take into account all aspects of noise, visual amenity and safety.

Furthermore, it is recommended that the following actions take place at the detailed design phase:

- Review recent Development Applications (DAs) to ensure existing rail noise levels have been / are adequately addressed at the time of development (e.g. through the use of upgraded building facades where required).
- Undertake further detailed modelling to include a more accurate composition of passenger trains on surface tracks (eg mix of SMU and EMU, mix of 3-car, 6-car and 7-car sets), instead of the current conservative modelling assumption that all suburban train movements are EMU trains).
- Obtain the (external) pass-by noise level specifications for the new-generation rolling stock passenger trains and incorporate this into the detailed design stage modelling.

As part of Queensland Rail's ongoing community consultation process, Queensland Rail has committed to progressively introduce quieter "new generation" freight locomotives. The noise reduction with the introduction of the quieter freight locomotives is expected to be 7 to 8 dBA. This is another aspect that is recommended to be considered in the detailed design phase.

The predicted noise levels for Year 2031 with the designed noise barriers are tabulated in **Appendix F**. The predicted noise levels in **Appendix F** include contributions from the through traffic and tunnel portals, and include shielding from the designed noise barriers and any retained existing noise barriers. All predicted noise levels include a +3.0 dBA facade correction. **Appendix F** also indicates which receivers are located adjacent to train stations.

Noise contours for Year 2031 with the designed noise barriers for the southern section are presented in **Appendix H**. The noise contours include contributions from the through traffic, tunnel portals and a +3.0 dBA facade correction. The designed and (retained) existing noise barriers included in the modelled noise levels are shown on the noise contour plans.

It should be noted that the contours are interpolated over a 10 m grid space. The assessment undertaken for this report and associated mitigation measures have been based on single point calculations at each receiver (**Appendix F)**.

8.3 Train Operations – Existing Rail Alignments (no upgrade) between Portals

The rail tracks between the portals in Dutton Park and Victoria Park will not be (physically) changed as part of the BaT project. However, the BaT project will free up capacity on these surface tracks by redirecting a significant portion of the passenger rail operation through the rail tunnels.

The incremental change to the daily averaged $L_{Aeq(24hour)}$ noise emission levels from the existing surface rail tracks between the portals due to change in freight and passenger train numbers as a result of the BaT project have been assessed.

The maximum noise level during train passbys will not change due to the change in passenger and freight train numbers. There would only be a change to the number of train passby events. In fact over time it is likely that the maximum noise levels from train passbys would be reduced as new generation rolling stock are progressively introduced into Queensland Rail's operation.

8.3.1 Inputs and Assumptions

The passenger and freight train numbers for assessing the incremental change to the daily averaged $L_{Aeq(24hour)}$ noise emission levels from the existing surface rail tracks between the portals have been provided by the BaT Rail Operations team.

The 'no upgrade' and 'with upgrade' train numbers on the surface tracks between the portals are shown in **Table 26**.

Table 26 Year 2031 'With Upgrade' and 'Without Upgrade' Train Numbers on Surface Tracks

Section	Number of Trains				
	Freight		Passenger		Notes
No Upgrade – Without BaT					
Northern Connection Portal	16		0		
Southern Connection Portal	31		556		3 freight services travel north toward Roma Street, the other 28 in direction of Cleveland Services
Kuraby/Loganlea/Coopers Plains Services (Kuraby)	31		84		Kuraby and Beenleigh services run along same section of tracks, therefore the number of freight for each service are the same
Beenleigh/Helensvale/Varsity Lakes Services (Beenleigh)	31		208		
Cleveland Services	28		184		
Empty Services	0		80		All Empty Services in Southern Portal Precinct
With Upgrade					
Northern Connection Portal	16	(+0)	113	(+113)	Brackets indicate change in train numbers with and without BaT
Southern Connection Portal	31	(+0)	432	(-124)	
Kuraby/Loganlea/Coopers Plains Services (Kuraby)	31	(+0)	176	(+92)	
Beenleigh/Helensvale/Varsity Lakes Services (Beenleigh)	31	(+0)	0	(-208)	
Cleveland Services	28	(+0)	192	(+8)	
Empty Services	0	(+0)	64	(-16)	

8.3.2 Predicted Future Change in Rail Noise Emission between Portals

As can be seen in **Table 26**, the freight volumes are not predicted to change when BaT is operational. All trains on the Beenleigh Service will be removed from service with BaT, allowing more Kuraby Services. There will be an additional 113 passenger trains in the Northern Connection Precinct and 124 less passenger trains in the Southern Connection Precinct. The empty passenger train services in the Southern Connection Precinct will also reduce with BaT.

The rail traffic volumes in **Table 26** have been used to predict the incremental change in future $L_{Aeq(24hour)}$ rail noise emissions for the surface tracks, presented in **Table 27**.

Table 27 Predicted Incremental Changes in Rail Noise Emission for Tracks between Portals

Section	Change in Noise Level (dBA $L_{Aeq(24hour)}$)		
	Freight	**Passenger**	**Total [1]**
Northern Connection Portal	---	53.9	2.5
Southern Connection Portal	---	-1.1	-0.7
Kuraby/Loganlea/Coopers Plains Services (Kuraby)	---	3.2	1.0
Beenleigh/Helensvale/Varsity Lakes Services (Beenleigh)	---	-56.5	-2.4
Cleveland Services	---	0.2	0.1
Empty Services	---	-1.0	-1.0

Note 1: The total change in noise level is the change in the logarithmic sum of the freight and passenger noise levels, not the linear sum of the individual changes for freight and passenger noise levels.

It can be seen in **Table 27** that the $L_{Aeq(24hour)}$ noise emission levels increase up to 2.5 dBA due to the change in passenger train traffic for the Year 2031 in the Northern Connection area.

The $L_{Aeq(24hour)}$ noise emission levels decrease -1.7 dBA due to the change in passenger train traffic for the Year 2031 in the Southern Connection area.

It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear. The absolute noise levels in the Northern Connection area are also below Queensland Rail's noise limits. Therefore, negligible impacts are predicted for the general rail network.

It should be noted again that the maximum noise level during train passbys will not change due to a change in passenger and freight train numbers. There would only be a change to the number of train passby events. The maximum noise levels from train passbys is expected to be reduced as new generation rolling stock are progressively introduced into Queensland Rail's operation

9 AIRBORNE NOISE ASSESSMENT – BUS OPERATIONS

Associated with BaT are surface bus operations at the northern and southern connections of the project. Proposed surface bus operations include:

- Upgrading the Eastern Busway adjacent Boggo Road station, Dutton Park to connect with the southern BaT bus connection.

- Connecting the northern BaT busway with the Inner Northern Busway and Inner City Bypass, Herston.

Overviews for the existing and proposed new BaT surface bus alignments for the northern section and southern section (ie north and south of the tunnel portals) are presented in **Figure 20** and **Figure 21** respectively. The potential road traffic noise impact associated with the bus operations at the two (2) portals have been assessed at nearby residential properties, educational, community and health buildings and outdoor educational and passive recreational areas (parks).

Section 2.3 of this report presents the *DTMR Code of Practice* road traffic noise goals. For the busway alignment, the noise goals for "Busway" are applicable, except for the section of alignment adjoining the ICB, where the "Multi-modal Corridor" noise goals are applicable.

In the northern connection area, all sensitive receivers (residential; educational, community and health buildings; and parks) have been assessed against the 'Upgrading Existing Road' category under the Multi-modal Corridor noise goals. For this assessment, all traffic (general and busways) has been modelled.

The ‘New Busway’ category under the Busway noise goals is also applicable to sensitive receivers in the northern section. For the Busway only noise goal, only the new sections of busway have been modelled. No other general traffic (eg ICB) or existing busways have been modelled. The ‘Upgraded Busway’ category under the Busway noise goals is also applicable to the RBH in the northern section where the new BaT busway sections link into the existing Northern Busway.

In the southern connection area, most sensitive receivers have been assessed against the ‘Upgrading Existing Busway’ category under the Busway noise goals, except those directly adjacent the Kent Street section of the BaT busway alignment where the ‘New Busway’ noise goals apply. Apart from the Kent Street section of alignment, BaT surface bus operations directly adjoin existing busway alignments in the southern section.

The noise assessment for the surface bus operations have been performed based on predicted future Year 2031 bus movements. The following sections present modelling methodology, modelling input data and assumptions, predicted noise levels and possible mitigation measures to meet project noise goals where applicable.

Figure 20 Overview of Northern Section Surface Bus Operations

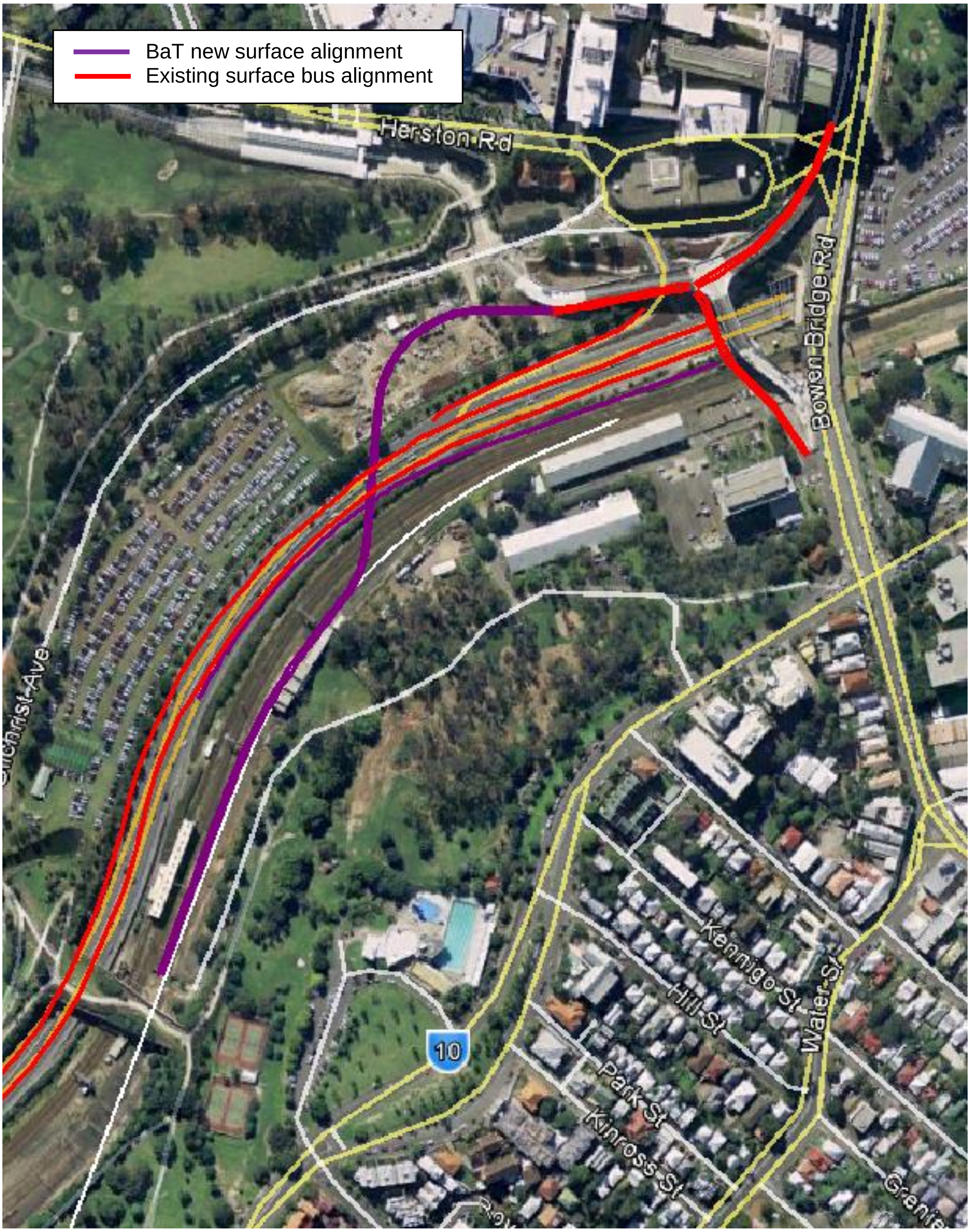
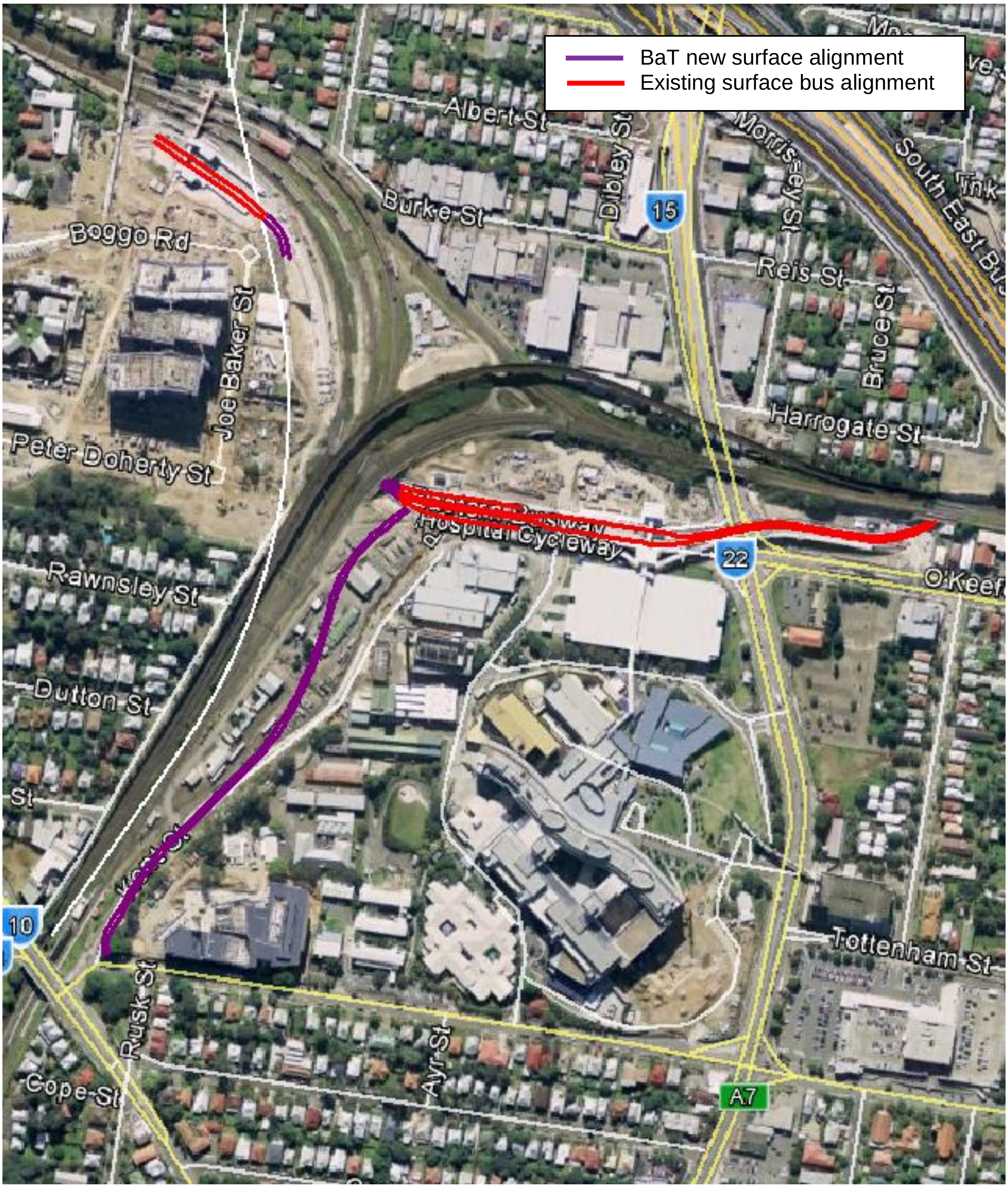


Figure 21 Overview of Southern Section Surface Bus Operations



9.1 Road Traffic Noise Modelling Methodology

As discussed in **Section 2.3**, the assessment criteria for busways are represented as LAeq and LAmax noise goals. In order to predict both LAeq and LAmax noise levels using the SoundPLAN software, the Nordic Rail Model was utilised, calibrated to the specific noise emission characteristics of BCC buses, to predict noise levels associated with the proposed busway corridors. The Nordic Rail Model is the only existing transportation model that predicts both LAeq and LAmax noise levels. It models the same noise propagation behaviour as that of road traffic.

Noise modelling of the section of alignment adjoining the ICB (multi-modal) was carried out using the UK Department of Transport, *"Calculation of Road Traffic Noise"* (CORTN 1988) algorithms incorporated in the SoundPLAN 7.2 noise software. The modelling allows for traffic volume and mix, type of road surface, vehicle speed, road gradient, reflections off building surfaces, ground absorption and shielding from ground topography and physical noise barriers.

CORTN calculates the $L_{A10(18hour)}$ descriptor directly for comparison with the 'Multi-modal Corridor' road traffic noise goal.

In addition, calculations have also taken into consideration the contribution to overall traffic noise levels from the tunnel portals. All predicted levels include a +2.5 dBA facade correction

9.2 Inputs and Assumptions

9.2.1 Through Traffic

The SoundPLAN model was created from 3-D topography, busway alignments and existing buildings supplied by the BaT project team.

SLR was provided with 1-hour traffic counts for the majority of busway traffic. Average Annual Daily Traffic Flow (AADT) numbers were provided for the section of road which joins the ICB. The AADT's were converted to 18 hour traffic flows using a correction of 0.95 (i.e. 95% of the daily traffic volume falls between the hours of 6am and midnight). The traffic volume parameters utilised in the noise modelling are summarised in **Table 28.**

Table 28 Traffic Volume Details for the BaT Realigned Roads

Road Section	Traffic Volume				Heavy Vehicles (%)
	AADT	Daytime 1hr	Evening 1hr	Night-time 1hr	
To UQ	-	78	68	4	100
From UQ	-	78	68	5	100
To Buranda via PAH	-	46	36	0	100
From Buranda via PAH	-	109	49	44	100
Lower level PAH East [1]	-	107	76	6	100
Lower level PAH West [1]	-	108	76	6	100
Kent St North	-	2	2	1	100
Kent St South	-	2	2	1	100
From BaT tunnel	-	179	177	29	100
To BaT tunnel	-	179	177	26	100
INB west	-	135	133	22	100
INB east	-	122	62	28	100
To RBWH	-	80	86	13	100
From RBWH	-	84	89	10	100
To Bowen Bridge Rd	-	23	27	0	100
From Bowen Bridge Rd	-	29	32	6	100
ICB Northbound	74314	-	-	-	8
ICB Southbound	78879	-	-	-	8
Busway Ramp to ICB (Southbound)	3790	-	-	-	100

Note 1: Traffic volume includes buses performing U-turn from UQ.

The design speed along the busway (including all sections of busway within the project area) was modelled at 70 km/h and the surface type modelled as dense-graded asphalt (DGA). The traffic speed along the ICB (including the new onramp from the INB) was modelled at 80 km/h and the surface type modelled as DGA.

It is proposed that 100% of the bus vehicles are new EEV type buses. As part of this BaT study, SLR undertook a series of EEV type bus (near-field) passby noise measurements at varying speeds between 30km/h and 80 km/h to ensure the emission characteristics of EEV type buses was accurate for this assessment. The results of this testing has been incorporated in the 3D modelling.

9.2.2 Portal Noise Emissions

Noise emissions from the tunnel portals have been modelled as vertical area noise sources across the tunnel portal openings. The source sound power for this area source and distribution of sound power over the portal area has been modelled as described by S. Olafsen's Inter-Noise 96 paper titled *"Noise from Road Tunnel Openings – An Engineering Approach"*. The propagation of the portal noise emissions has been modelled using the Concawe industrial noise model within the SoundPLAN modelling suite. The noise predictions for the portal noise model has then been added logarithmically to the noise predictions for the standard Kilde traffic noise predictions to generate overall noise levels for the combination of portals and busways.

The $LA_{eq(24hour)}$ sound power level for the portals are presented in **Table 29**.

Table 29 Average LAeq(1hr) Sound Power Level per Portal

Tunnel Section	SWL (dBA)		
	Daytime	Evening	Night-time
To UQ	99	99	87
Southern Connection Portal	101	100	89
PAH Station	99	97	94
Adjacent O'Keefe St	100	97	94
Northern Connection Portal	102	102	94

The LAmax sound power level for the portals is not important as the reverberant noise escaping from the tunnel would not exceed that of the passby noise outside the tunnel.

9.2.3 Bus Layover

There are two (2) proposed bus layovers for BaT. One is to be located in the southern connection precinct adjacent the Princess Alexandra Busway Station at Kent Street, the other is to be located in the northern connection precinct adjacent the existing Northern Busway, with access via Gilchrist Avenue, Herston.

The nearest noise sensitive receptor to the southern bus layover is the PA Hospital Childcare Centre. Based on noise levels measured at the PA hospital, the existing ambient noise levels at the Childcare Centre are already high and any additional noise attribution from the bus layover activities would be insignificant.

Other nearby sensitive receptors are located on the other side of the railway tracks. Given the high noise environment adjacent to this railway corridor, noise from bus layover activities would again be insignificant.

There are no nearby noise sensitive receptors to the northern bus layover.

No further assessment of the bus layover noise emissions is therefore considered necessary.

9.3 Predicted Noise Levels

Road traffic noise levels have been predicted for the Year 2031 scenario.

For the northern section, multimodal corridor noise levels of up to 66 dBA $L_{A10(18hour)}$ and 70 dBA $L_{A10(1hour)}$ are predicted. Based on these predictions, all residential locations within the northern section are predicted to comply with the BaT noise goals.

Three (3) educational buildings are predicted to exceed the DTMR Code of Practice 65 dBA $L_{A10(1hour)}$ noise criterion. These three (3) buildings are part of St Joseph's College. Two (2) health buildings are predicted to exceed the DTMR Code of Practice 65 dBA $L_{A10(1hour)}$ noise criterion. These two (2) buildings are part of the RBH (QIMR and Surgical Building).

Also in the northern section, Year 2031 busway (only) noise levels of up to 56 dBA $L_{Aeq(1hour)}$ and 71 dBA L_{Amax} are predicted. Based on the predicted noise levels, one (1) health building (RBH Block 7) is predicted to exceed the DTMR Code of Practice 69 dBA L_{Amax} noise criteria for upgraded busway. All residential and educational locations are predicted to meet the applicable busway (only) noise goals in the northern section.

For the southern section, Year 2031 busway noise levels of up to 59 dBA $L_{Aeq(1hour)}$ and 62 dBA L_{Amax} are predicted. Based on the predicted noise levels, all residential locations and all community, educational and health buildings are predicted to meet the relevant noise criteria in the southern section.

All parks comply with the DTMR Code of Practice guideline for at least 2000m^2 open space below the specified busway and multi-modal corridor criteria.

Noise mitigation for the six (6) buildings which exceed the various noise criteria within the project area are discussed further in the following section.

Results of the single point calculations for Year 2031 are tabulated in **Appendix I**.

Noise contours for Year 2031 are presented in **Appendix J**. The noise contours include contributions from the through traffic, tunnel portals and a +2.5 dBA facade correction. The existing noise barriers included in the modelled noise levels are shown on the noise contour plans.

9.4 Mitigation Measures

The three (3) buildings at St Josephs and two (2) buildings at RBH (QIMR and Surgical Building) exceed the multi-modal corridor noise goal for upgraded roads (65 dBA $L_{A10(1hour)}$) by 2 to 5 dBA.

The noise levels at these five (5) buildings are heavily dominated by the general traffic lanes on the ICB. Predicted noise levels from the BaT onramp onto the ICB are:

- 34 to 36 dBA $L_{A10(1hour)}$ at St Joseph's School, and
- 48 to 49 dBA $L_{A10(1hour)}$ at the RBH buildings (QIMR and Surgical Building).

These noise levels are well below the noise goal and therefore noise mitigation at the five (5) buildings is not recommended due to the fact that the BaT project results in essentially no change (less than 0.2 dBA) on the overall noise levels experienced at these locations.

One (1) building (RBH Block 7) exceeds the upgraded busway 69 dBA L_{Amax} noise goal by up to 2 dBA. This is a minor exceedance and noise levels are contributable to road traffic from Northern Busway rather than BaT. Noise contributions from BaT (only) are considerably below the new busway noise criteria (at least 20 dBA below the criteria). As such further noise mitigation is not recommended.

10 AIRBORNE NOISE ASSESSMENT – ANCILLARY FACILITIES

Ancillary noise sources would typically include mechanical plant facilities and ventilation shafts for underground areas and feeder stations for power distribution of the Project rail operations. Tunnel ventilation stacks are located at Boggo Road (southern connection), Woolloongabba Station, George Street Station, Roma Street Station and Victoria Park (northern connection).

The following sections present the assessment of these ancillary facilities associated with the Project.

10.1 Underground Bus and Train Project Feeder Stations

Two feeder stations are proposed to service the train operations for BaT. The locations of the feeder stations are near the northern connection at Victoria Park and near the southern connection at Woolloongabba adjacent to Princess Alexandra Hospital. The internal network load for BaT is estimated at approximately 12MVA.

BaT will be supplied at 110kV at both ends of the tunnel which will directly supply the Feeder traction stations via Static Frequency Converter (SFC) technology. In addition there will be 110/22kV transformers to supply the network internal to the tunnel which supplies station and pumping loads. The SFCs will remove power quality phenomena and no additional harmonic filters are required.

The Australian Standard AS 2374.6-1994 *Power Transformers – Part 6; Determination of transformer and reactor sound levels*, gives generic sound power levels as a function of the power requirement. For a power transformer of 12 MVA capacity, the sound power levels provided in Appendix AA of AS 2374.6-1994 are presented in **Table 30**.

Table 30 Sound Power Level for Transformers According to AS 2374.6-1994

Power Transformer	LWA(standard maximum) (dBA)	LWA(reduced maximum) (dBA)
12 MVA	89	81

Note: If there are components with tonal character, an adjustment to the measured noise level of +5 dBA is required in accordance with AS 1055.1-1997.

All components will be enclosed in buildings. This assessment is based on the existing feeder station at Roma Street where the larger building was constructed of brick and the smaller buildings in metal cladding with the transformer building open in the direction of the tracks.

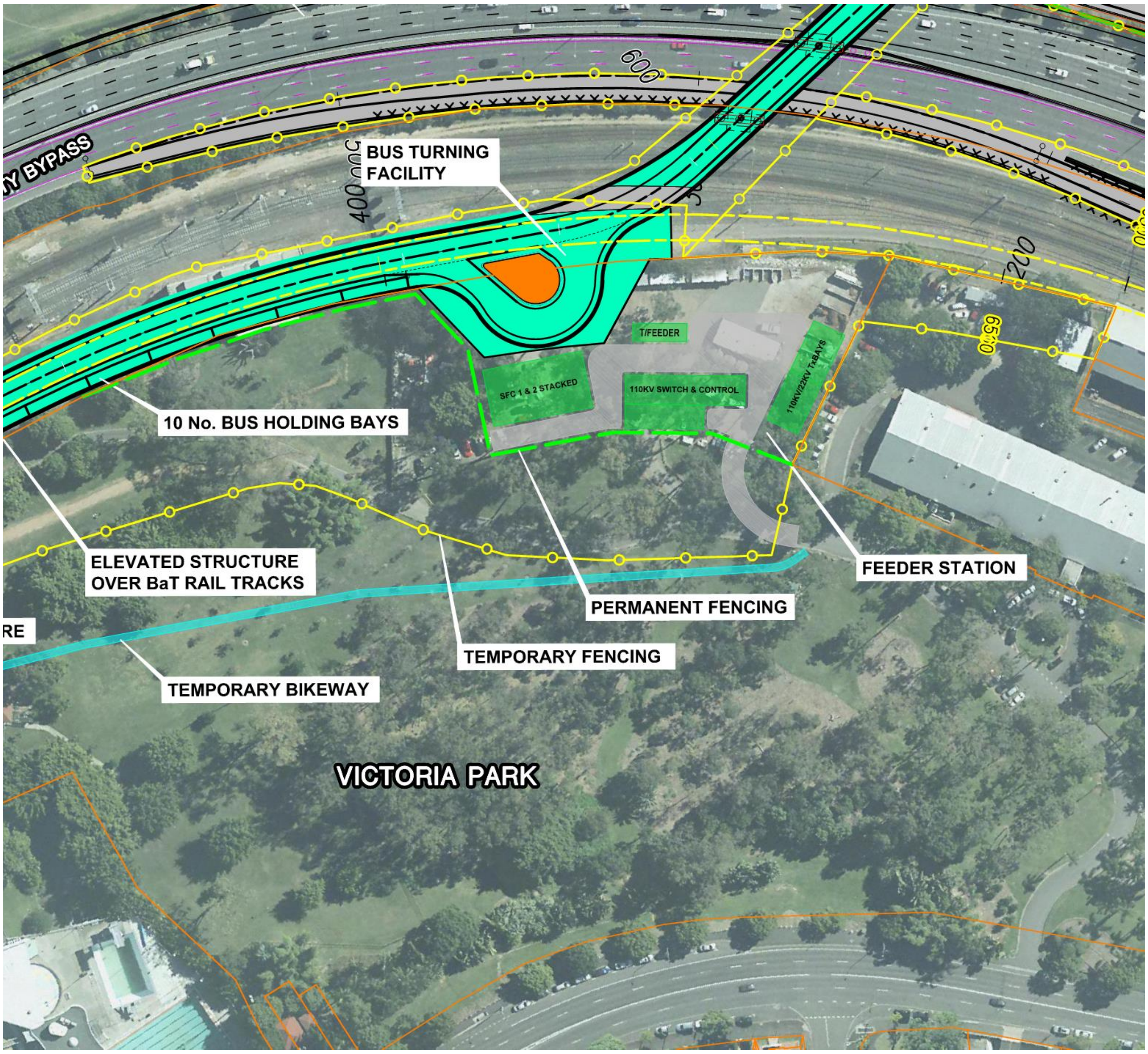
10.1.1 Victoria Park Feeder Station

The location of the feeder station at Victoria Park is shown in **Figure 22**. The nearest sensitive receiver is approximately 200 m from the proposed feeder station location, which is located in an industrial dominated area. The feeder station buildings are assumed to be oriented with no openings away from the railway, which is the direction of the nearest sensitive receivers. A noise reduction through the feeder station building facades of approximately 20 dBA can be expected.

The existing background noise for this area has conservatively been assumed to be 40 dBA RBL (refer to monitoring location 1 in **Table 9** - due to the close proximity to the Mayne Yards and ICB, higher background noise levels are expected than at monitoring location 3). The noise goal for continuous mechanical plant noise is RBL + 0 = 40 dBA LA90 (refer to **Table 7**).

Using the sound power level in **Table 30**, the predicted noise levels at the nearest sensitive receiver is less than 30 dBA. As such, the predicted noise emission from the Victoria Park feeder station is predicted to comply with the noise goal.

Figure 22 Proposed Location of Victoria Park Feeder Station



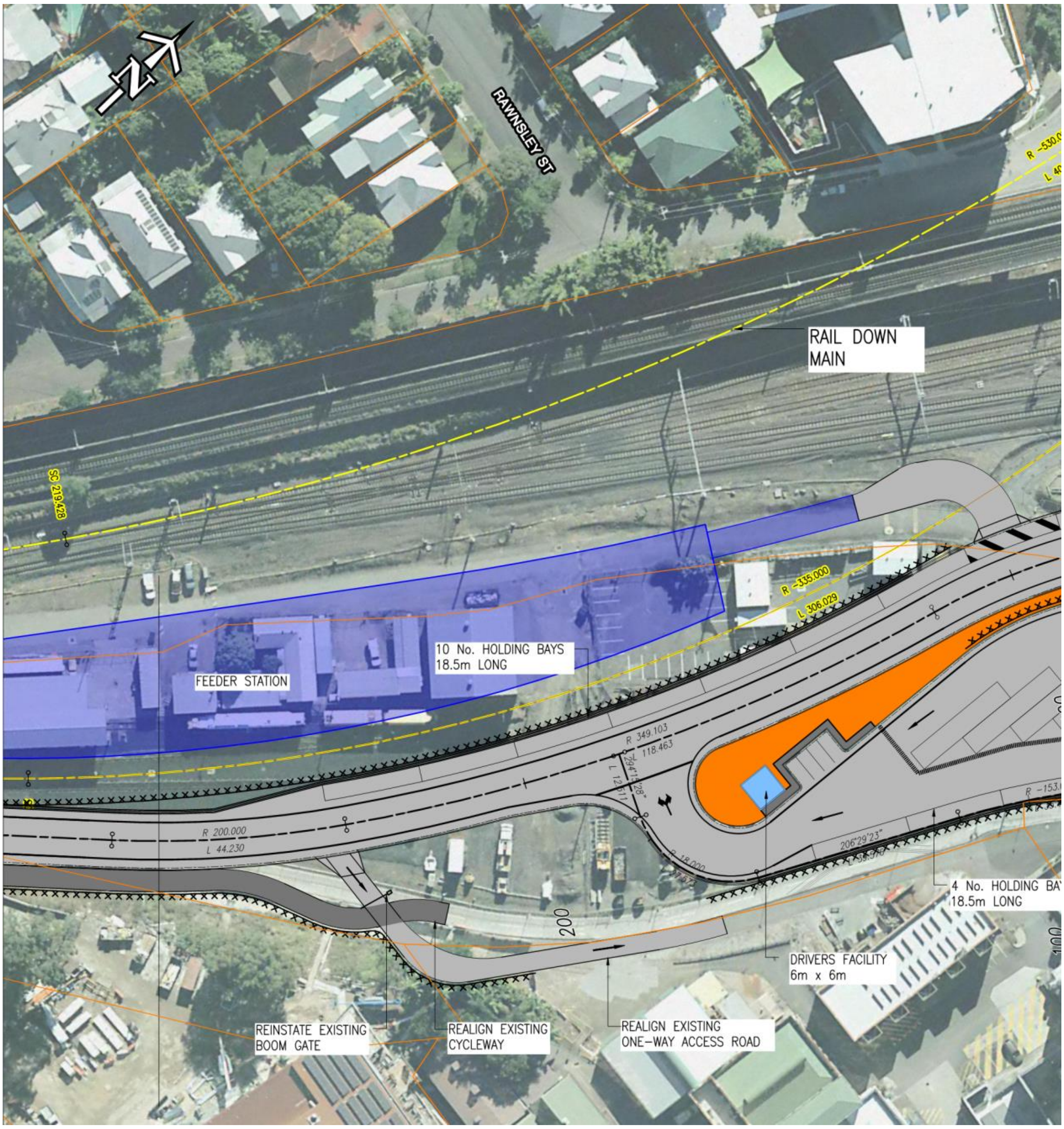
10.1.2 Woolloongabba Feeder Station

The location of the feeder station at Woolloongabba is showed in **Figure 23**. The nearest sensitive receiver is approximately 70 m from the proposed feeder station location. The feeder station buildings are assumed to be oriented with openings towards the railway, which is the direction of the nearest sensitive receivers. There is an existing noise barrier adjacent to the existing railway towards the nearest sensitive receivers. A noise reduction of approximately 10 dBA through the partially open feeder station buildings and another 10 dBA due to the noise barrier can be expected.

The existing background noise for the area is approximately 41 dBA RBL (refer to monitoring location 13 in **Table 9**). The noise goal for continuous mechanical plant noise is RBL + 0 = 41 dBA L_{A90} (refer to **Table 7**).

Using the sound power level in **Table 30**, the predicted noise level at the nearest sensitive receiver is less than 30 dBA. The predicted noise emission from the Woolloongabba feeder station therefore complies with the noise goal.

Figure 23 Proposed location of Woolloongabba Feeder Station



10.2 Underground Stations Mechanical Plant and Ventilation

10.2.1 Modelling Methodology

The modelling of the mechanical services airborne noise presented in this assessment is based on the preliminary plant locations which are still potentially subject to change. Specific equipment is also not known at this stage and the expected noise levels can therefore not be predicted. As such, the maximum total allowable emitted sound power at each location has been calculated, specifying the acoustic emission limit for all equipment (combined operation) at each location. The noise sources have been assumed to operate without a noticeable tonal, impulsive or intermittent nature. Based on previous experience, these emission limits are achievable with appropriate equipment selection and silencing treatments, if required.

10.2.2 Noise Predictions

The maximum allowable sound power levels emitted by industrial-type noise sources have been predicted for each location in order to meet the noise goal (refer to **Table 7**) at nearby sensitive receivers. The results are presented in **Table 31**.

Table 31 Ventilation Stacks and Station Ancillary Facilities - Maximum Acceptable Noise Emissions

Site Location	Ancillary Location	Distance to Nearest Sensitive Receiver (m)	Noise Goal (dBA LA90)[1]	Maximum Acceptable Sound Power Level (dBA)
Boggo Rd Southern Ventilation Stack	Vent stack located above the busway adjacent to its connection with the Boggo Rd busway, 11m above roof of busway tunnel	~150	40	92
Woolloongabba Station	Main plant room with vent located at the north end of the station.	~75	46	92
Woolloongabba Ventilation Stack	Vent stack located at the north end of the station, 24m above ground level	~ 75	46	92
George St Station	Main plant room located underground, location of above ground ventilation louvres unknown at this stage.	~4	51	71 (from each ventilation louvre)
George St Ventilation Stack	Along the southeast side of George Street Station	~25	51	87
Roma St Station	Main plant room located underground under Parkland Crescent car park, location of fresh air shaft east of car park 5m of nearest receiver.	~65	47	91 (from ventilation louvres)
Roma St Ventilation Stack	Two exhaust shafts shown on the drawing, nearest to residences located north of platform 10 adjacent Parkland Crescent, 8m above ground level.	~45	47	88
Victoria Park Northern Ventilation Stack	Located west of the Gregory Terrace tennis courts	~160	51	103

Note 1: Background creep noise goal in accordance with EPP(Noise) refer to **Table 7**. The background creep is the RBL + 0 assessed as the LA90 parameter. Existing background noise levels RBLs as presented in **Table 9**.

The locations and designs of the mechanical plants, air exhausts and intakes and tunnel ventilation for the Project will need to be assessed in more detail during the detailed design phase.

10.2.3 Mitigation Measures

The maximum allowable mechanical services and ventilation stacks sound power levels emitted at each location have for detailed design purposes been calculated and range from 71 dBA to 103 dBA.

Mitigation measures are likely to be required for some station mechanical plant and ventilation stacks in order to comply with the project noise goals. Mitigation measures that may need to be considered at some locations include appropriate equipment selection, in-duct attenuators, noise barriers, acoustic enclosures and the strategic positioning of critical plant away from sensitive receivers.

11 CONCLUSIONS

For new underground bus and railway projects, consideration of the potential noise and vibration impacts during the design stage is critical in order to achieve a cost-effective and acceptable environmental outcome for the surrounding community. The application of add-on mitigation measures after construction is completed is frequently expensive, and in many cases is not feasible or practical after bus and train operations commence.

11.1 Ground-borne Vibration Assessment – Train Operations

Ground-borne vibration modelling was undertaken for the BaT project track alignment.

On the basis of the speed profile for the BAT project (refer **Table 15**) and on the proposed vertical alignment and modelling assumptions described in the previous sections, compliance with the ground-borne vibration limits is predicted for all sensitive receiver locations above or near the proposed alignments.

The predicted ground-borne vibration levels for the electron microscope at the Eco-science precinct complies with the instrument specific vibration criteria supplied by the tenant.

Princess Alexandra Hospital, QUT at 2 George Street and St Andrews Hospital have been identified as having special vibration sensitive equipment (i.e. electron microscope or Magnetic Resonance Imaging (MRI) systems). For the purpose of assessment, it has been assumed all nearby research and medical facilities may contain vibration sensitive equipment. All identified special receivers have predicted ground-borne vibration velocity below the limit of 0.013 Mm/s (82 dBv) per octave band.

The predicted vibration levels associated with train operations in the tunnels are less than 0.144 mm/s at any buildings near the tunnels and therefore the risk to any heritage buildings is negligible. Similarly, the potential for damage to other key utilities/ infrastructure is also negligible on the basis that the tunnel wall vibration levels are anticipated to be approximately 0.1 mm/s (100 dB_V).

11.2 Ground-borne Noise Assessment – Train Operations

Ground-borne noise modelling was undertaken for the BaT project proposed track form. The assessment concluded that the track forms contained in **Table 32** are required to achieve compliance with the nominated goals.

Table 32 Proposed Trackforms to Comply with the Ground-borne Noise Goals

Down Track			Up Track		
Chainage (km)		Trackform	Chainage (km)		Trackform
From	To		From	To	
0	0.35	Direct Fixation	0	0.79	Direct Fixation
0.35	0.45	Resilient	0.79	1.245	Resilient
0.45	0.78	Direct Fixation	1.245	4.43	Direct Fixation
0.78	1.25	Resilient	4.43	4.64	Resilient
1.25	4.41	Direct Fixation	4.64	6.735	Direct Fixation
4.41	4.63	Resilient			
4.63	6.725	Direct Fixation			

Note 1: The direct fixation and resilient trackforms are specified in **Figure 11**.

The predicted ground-borne noise with the **Table 32** trackforms achieves the noise goals at all locations.

11.3 Airborne Noise Assessment – Train Operations

A SoundPLAN (Version 6.5) computer noise model has been used for the prediction of noise levels at sensitive receivers. Two computation algorithms were utilised within the SoundPLAN model. The Nordic Rail Traffic Noise Prediction Method (Kilde 130) has been used for all surface rail noise assessments and the CONCAWE industrial prediction model has been used to account for the additional noise emission through the portal openings.

The predicted noise levels include contributions from the through traffic and tunnel portals and include shielding from any existing noise barriers. All predicted levels include a +3 dBA facade correction.

In the northern section, all sensitive locations are predicted to comply with Queensland Rail's operational planning levels in Year 2031. Therefore, no mitigation measures are required in this section.

The Year 2031 operational noise levels are predicted to exceed Queensland Rail's planning levels in the southern section. A noise barrier has been designed to reduce operational noise levels to achieve compliance with Queensland Rail's planning levels, where possible (eg noise barrier heights have been capped at 6m).

The noise barrier detailed in **Table 33** has been designed to achieve the best possible noise mitigation at all noise sensitive receivers which exceed the Queensland Rail planning levels.

Table 33 Designed Operational Noise Barrier

Noise Barrier	Location	Length (m)	Height (m)	Area (m^2)
1	Railway Terrace – Upgrade Existing	320	6	1,919

The designed noise barrier helps achieve the planning noise levels at some of the noise sensitive receivers however some exceedances are still predicted even with the recommended noise barrier in place.

The rail tracks between the portals in Dutton Park and Victoria Park will not be changed as part of the BaT project. However, the BaT project will free up capacity on these surface tracks by redirecting a significant portion of the passenger rail operation through the rail tunnels.

The incremental change to the daily averaged $L_{Aeq(24hour)}$ noise emission levels from the existing surface rail tracks between the portals due to change in freight and passenger train numbers as a result of the BaT project have been assessed.

It can be seen in **Table 27** that the $L_{Aeq(24hour)}$ noise emission levels increase up to 2.5 dBA due to the change in passenger train traffic for the Year 2031 in the Northern Connection.

The $L_{Aeq(24hour)}$ noise emission levels decrease -0.7 dBA due to the change in passenger train traffic for the Year 2031 in the Southern Connection.

It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear. The absolute noise levels in the Northern Connection area are also below Queensland Rail's noise limits. Therefore, negligible impacts are predicted for the general rail network.

Airborne Noise Assessment – Bus Operations

In order to predict both L_{Aeq} and L_{Amax} noise levels using the SoundPLAN software, the Nordic Rail Model was utilised, calibrated to the specific noise emission characteristics of BCC buses, to predict noise levels associated with the proposed busway corridor.

Noise modelling of the section of alignment adjoining the ICB (multi-modal) was carried out using the UK Department of Transport, *"Calculation of Road Traffic Noise*" (CORTN 1988) algorithms incorporated in the SoundPLAN 7.2 noise software. The algorithm output of CORTN calculates the $L_{A10(18hour)}$ descriptor directly for comparison with the 'Multi-modal Corridor' road traffic noise goal.

In addition, calculations have also taken into consideration the contribution to overall traffic noise levels from the tunnel portals. All predicted levels include a +2.5 dBA facade correction.

For the northern section, three (3) educational buildings (St Joseph's College buildings) and two (2) health buildings (RBH QIMR and RBH Surgical Building) are predicted to exceed the DTMR Code of Practice 65 dBA $L_{A10(1hour)}$ noise criterion.

Also in the northern section, one (1) health building (RBH Block 7) is predicted to exceed the DTMR Code of Practice 69 dBA L_{Amax} noise criteria for upgraded busway.

For the southern section, all noise sensitive receivers are predicted to meet the relevant noise criteria.

Noise mitigation has not been recommended at any of the six (6) noise sensitive receivers which exceed the applicable noise goals as all exceedances are contributable to the existing road networks and not the BaT project. Noise levels at all six (6) locations, attributable to only the BaT alignment (not including existing roads) would be significantly below the applicable criteria (at least 15 dBA below the relevant criteria).

11.4 Airborne Noise Assessment – Ancillary Facilities

Two (2) feeder stations are proposed to service the train operations for BaT. The locations of the feeder stations are near the northern connection at Victoria Park and near the southern connection at Woolloongabba adjacent to Princess Alexandra Hospital. Assuming a 20 dBA facade reduction for the enclosures, all two (2) feeder stations are predicted to comply with the project noise goals.

The modelling of the mechanical services airborne noise presented in this assessment are based on the preliminary plant locations which are still potentially subject to change. Specific equipment is also not known at this stage and the expected noise levels can therefore not be predicted. As such, the maximum total allowable emitted sound power at each ventilation stack and station ancillary facility has been calculated, specifying the acoustic emission limit for all equipment (combined operation) at each location. These results are shown in **Table 34**.

Table 34 Ventilation Stacks and Station Ancillary Facilities - Maximum Acceptable Noise Emissions

Site Location	Ancillary Location	Distance to Nearest Sensitive Receiver (m)	Noise Goal (dBA LA90)[1]	Maximum Acceptable Sound Power Level (dBA)
Boggo Rd Southern Ventilation Stack	Vent stack located above the busway adjacent to its connection with the Boggo Rd busway, 11m above roof of busway tunnel	~150	40	92
Woolloongabba Station	Main plant room with vent located at the north end of the station.	~75	46	92
Woolloongabba Ventilation Stack	Vent stack located at the north end of the station, 24m above ground level	~ 75	46	92
George St Station	Main plant room located underground, location of above ground ventilation louvres unknown at this stage.	~4	51	71 (from each ventilation louvre)
George St Ventilation Stack	Along the southeast side of George Street Station	~25	51	87
Roma St Station	Main plant room located underground under Parkland Crescent car park, location of fresh air shaft east of car park 5m of nearest receiver.	~65	47	91 (from ventilation louvres)
Roma St Ventilation Stack	Two exhaust shafts shown on the drawing, nearest to residences located north of platform 10 adjacent Parkland Crescent, 8m above ground level.	~45	47	88
Victoria Park Northern Ventilation Stack	Located west of the Gregory Terrace tennis courts	~160	51	103

Note 1: Background creep noise goal in accordance with EPP(Noise) refer to **Table 7**. The background creep is the RBL + 0 assessed as the LA90 parameter. Existing background noise levels RBLs as presented in **Table 9**.

Mitigation measures are likely to be required for some station mechanical plant and ventilation stacks in order to comply with the project noise goals. Mitigation measures that may need to be considered at some locations include appropriate equipment selection, in-duct attenuators, noise barriers, acoustic enclosures and the strategic positioning of critical plant away from sensitive receivers.

The locations and designs of the mechanical plants, air exhausts and intakes and tunnel ventilation for the Project will need to be assessed in more detail during the detailed design phase.

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CLOSURE

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