# Appendix E. Operation: Vibration and ground-borne Noise from Rail

## E.1 Introduction

Ground-borne vibration from operating railways can generally be experienced as:

- Tactile movement of building floors
- Shaking of shelves and wall hangings
- Rumbling sounds
- Damage to buildings (in extreme cases).

The primary source of rail ground-borne noise from the wheel rail interface is due to:

- Roughness of the rail and wheel (including wheel flats)
- Rail imperfections
- Resonance frequency of the vehicle suspension
- Resonance frequency of the track support system.

The subjective response of humans to noise varies between individuals. Typical impacts include:

- Loss of amenity
- Disturbance
- Stress
- Loss of concentration
- Health effects (increase in blood pressure)
- Sleep arousal.

Rolling stock which would use the Melbourne Metro lines would be the new High Capacity Metro Trains (HCMT) that are currently being procured by the Victorian Government.

## E.2 Criteria

### E.2.1 Vibration

Guideline targets for operational vibration are provided below for:

(i) Damage to buildings

(ii) Human Comfort

(iii) Vibration-sensitive Equipment and Highly Sensitive Areas

**(i) Damage to Buildings**

DIN 4150-3 *Structural Vibration Part 3: Effects of vibration on structures, February*, 1999 is appropriate for the assessment of operational vibration impacts on structures. It is shown here for information only. No separate assessment of operational vibration impacts on structures is required as the guideline targets for human comfort are far more onerous than those for damage to buildings. Compliance with guideline targets for vibration (Human Comfort) infers compliance with the guideline targets for building damage.

DIN 4150 sets vibration levels which *when complied with will not result in damage that will have an adverse effect on the structure's serviceability*. If the levels from DIN 4150 are exceeded it does not follow that damage would occur. Therefore, if exceedances are predicted then further site specific assessment would be required. The DIN 4150 values are provided in Table E.1 and Table E.2 for short term and long term vibration respectively.

**Table E.1: Guideline targets for vibration velocity for evaluating short-term vibration on structures**

| Type of Structure | Vibration at the foundation, mm/s (Peak Component Particle Velocity) | | | Vibration at horizontal plane of highest floor at all frequencies |
|---|---|---|---|---|
| | 1 to 10 Hz | 10 to 50 Hz | 50 to 100 Hz Note 1 | |
| **Type 1: Buildings used for commercial purposes, industrial buildings and buildings of similar design** | 20 | 20 to 40 | 40 to 50 | 40 |
| **Type 2: Dwellings and buildings of similar design and/or occupancy** | 5 | 5 to15 | 15 to 20 | 15 |
| **Type 3: Structures that have a particular sensitivity to vibration e.g. heritage buildings** | 3 | 3 to 8 | 8 to 10 | 8 |

Notes:

1. At frequencies above 100 Hz, the values given in this column may be used as minimum values.
2. Vibration levels slightly exceeding those vibration levels in the table would not necessarily mean that damage would occur.
3. For civil engineering structures (e.g. with reinforced concrete constructions used as abutments or foundation pads) the values for Type 1 buildings may be increased by a factor of 2.
4. For buildings short term vibration is defined as *Vibration which does not occur often enough to cause structural fatigue and which does not produce resonance in the structure being evaluated*.

**Table E.2: Guideline targets for vibration velocity to be used when evaluating the effects of long-term vibration on structures**

| Type of Structure | Vibration Velocity, mm/s (Peak Component Particle Velocity) in horizontal plane at all frequencies |
|---|---|
| **Buildings used for commercial purposes, industrial buildings and similar design** | 10 |
| **Dwellings and buildings of similar design and/or occupancy** | 5 |
| **Structures that have a particular sensitivity to vibration e.g. heritage buildings** | 2.5 |

Notes:

1. Vibration levels slightly exceeding those in the table would not necessarily mean that damage would occur.
2. In this context 'long-term' means vibration events that may result in resonant structural response.

**(ii) Human Comfort**

There is no Victorian or Commonwealth document that provides guidance with respect to human comfort from construction vibration.

For past projects, including large infrastructure projects, Australian Standard *AS2670.2 – 1990 Evaluation of human exposure to whole body vibration* has been used to provide *satisfactory magnitudes of building vibration with respect to human response.* This standard is now withdrawn. SAI Global has advised that it has been replaced with ISO 2631-2:2003 *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 2: Vibration in buildings (1 Hz to 80 Hz).* This document does <u>not</u> include magnitudes of vibration for human comfort.

The following guideline which addresses human response to vibration has been developed in NSW:

- Assessing Vibration: A Technical Guideline, February 2006, NSW Department of Environment and Conservation (*DEC Vibration*).

In developing this document Australian and International standards, current scientific research and the practices of other regulating authorities were reviewed.

DEC Vibration is based on British Standard BS6472-1:1992. Guide to Evaluation of Human Exposure to Vibration in Buildings (1 Hz to 80 Hz) (BS6472-1:1992) which is now superseded. Therefore, in assessing the impact of vibration on human comfort for the Melbourne Metro, the approach described in the DEC Vibration (Sections 2.3 and 2.4) has been used, together with the updated vibration criteria from the later version of the British Standard, being: British Standard BS6472-1:2008. Guide to Evaluation of Human Exposure to Vibration in Buildings. Part 1: Vibration sources other than blasting (BS6472-1:2008).

Vibration from rail operations is considered to be of an intermittent type. The vibration guideline targets for intermittent vibration are provided in Table E.3 and are proposed to be applied for the Melbourne Metro project within the Victorian assessment framework for addressing operational vibration impacts.

**Table E.3: Guideline vibration dose values for operational vibration**

| Location | VDV ($m/s^{1.75}$) | | | |
|---|---|---|---|---|
| | Day<br>7am to 10pm | | Night<br>10pm to 7am | |
| | Preferred Value | Maximum Value | Preferred Value | Maximum Value |
| **Residences** | 0.20 | 0.40 | 0.10 | 0.20 |
| **Offices, schools, educational institutions, places of worship** | 0.40 | 0.80 | 0.40 | 0.80 |
| **Workshops** | 0.80 | 1.60 | 0.80 | 1.60 |

Notes:

1. The VDVs are based on Table 1 in BS6472-1:2008
2. BS6472-1:2008 states that:
   - adverse comments are not expected at VDVs less than the Preferred Value
   - there is a low probability of adverse comments at VDVs between the Preferred and Maximum Values
   - adverse comments are possible at VDVs in the range [Maximum Value to 2 x the Maximum Value]
   - adverse comment is probable at VDVs in the range [2 x Maximum Value to 4 x Maximum Value]
   - adverse comment is very likely at VDVs greater than 4 x Maximum Value
3. Activities should be designed to meet the Preferred Values where an area is not already exposed to vibration. Where all feasible and reasonable measures have been applied, values up to the Maximum Value may be used if they can be justified. For values beyond the Maximum Value, the operator should negotiate directly with the affected community.
4. The guideline targets are non-mandatory; they are goals that should be sought to be achieved through the application of feasible and reasonable mitigation measures.
5. Vibration guideline targets for 'Highly Sensitive areas' such as hospital operating theatres or precision laboratories are provided below.

### (iv) Vibration-sensitive Equipment and Highly Sensitive Areas

Hospitals, laboratories and research institutions may utilise sensitive imaging equipment such as MRI machines and microscopes that are highly sensitive to vibration. Vibration guideline targets for sensitive equipment are defined either by referencing equipment supplier data or if this is not available the VC curves provided by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) Chapter 48, Noise and Vibration Control, 2011 can be used. Ambient vibration levels where sensitive equipment is successfully operating may also be used as guideline targets in the event that they are higher than the levels derived from the VC curves. The VC curves are presented in Figure E.1 and provide the 1/3 octave RMS vibration tolerances of different classes of sensitive equipment. The VC curve that applies to a specific site is dependent on the type of equipment and activities being conducted. The equipment requirements from ASHRAE are provide in Table E.4.

The location and types of vibration-sensitive equipment and highly sensitive areas have been identified and site-specific vibration targets derived from supplier data, VC curves or on-site measurements.

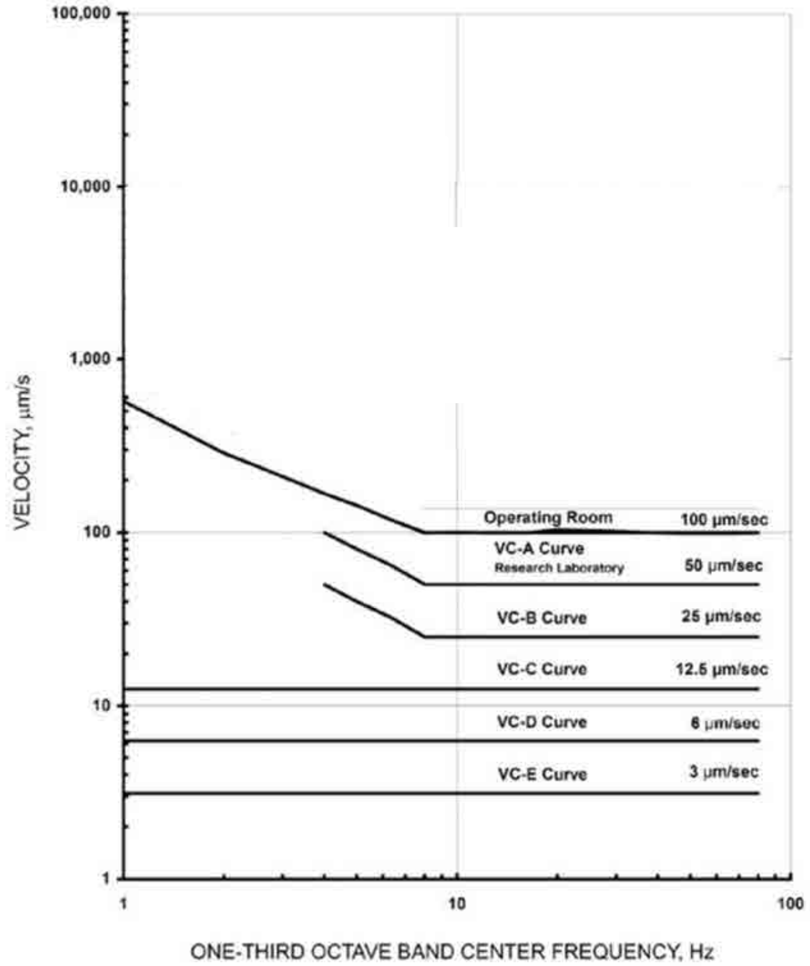



**Figure E.1: VC Curves from ASHRAE**

**Table E.4: Equipment Vibration Guideline Targets - ASHRAE**

| Equipment Requirements | Curve |
|---|---|
| **Bench microscopes up to 100x magnification ; laboratory robots** | Operating Room |
| **Bench microscopes up to 400x magnification; optical and other precision balances; co-ordinate measuring machines; metrology laboratories; optical comparators; micro electronics manufacturing equipment; proximity and projection aligners, etc.** | VC-A |
| **Microsurgery, eye surgery, neurosurgery; bench microscope at magnification greater than 400x; optical equipment on isolation tables; microelectronic manufacturing equipment such as inspection and lithography equipment (including steppers) to 3 mm line widths** | VC-B |
| **Electron microscopes up to 30,000x magnification; microtomes; magnetic resonance images; microelectronics manufacturing equipment such as lithography and inspection equipment to 1 mm detail size** | VC-C |
| **Electron microscopes at magnification greater than 30,000x; mass spectrometers; cell implant equipment; microelectronics manufacturing equipment such as aligners, steppers and other critical equipment for phot-lithography with line widths of ½ micro m; includes electron beam systems** | VC-D |
| **Unisolated laser and optical research systems; microelectronics manufacturing equipment such as aligners, steppers and other critical equipment for photolithography with line widths of ¼ micro m; includes electron beam systems** | VC-E |

### E.2.2 Ground-borne noise

There is no Victorian or national Australian document that provides specific requirements with regard to ground-borne noise from trains. The NSW EPA does, however, address ground-borne noise from trains in:

- Rail Infrastructure Noise Guideline, May 2013 (RING).

It is stated in the RING that *Limited research into the impact of ground-borne noise is available, and information on practices applied overseas is also scarce. From a review of the available material it appears that the factors that can affect reaction to ground- borne noise include: the level of noise, how often it occurs, whether an area is already exposed to rail noise and whether the area affected has a low density of development (e.g. low density residential) with associated low levels of ambient noise.* This is the basis of the trigger levels proposed.

This document has been successfully applied on recent projects in NSW which are similar to the Melbourne Metro. The relevant section of RING is Section 2.5. It sets trigger levels with respect to ground-borne noise for the assessment of feasible and reasonable mitigation to reduce noise down towards the relevant trigger level. The trigger levels are reproduced in Table E.5**.** It proposed that the values in Table E.5 (from Section 2.5 of the RING) apply for the Melbourne Metro. These are to be applied within the Victorian assessment framework of noise impact.

**Table E.5: Ground-borne noise trigger levels**

| Sensitive land use | Time of day | Internal noise trigger levels |
|---|---|---|
| **Residential** | Day<br>7am - 10pm | 40 $dBL_{ASmax}$ and an increase in existing rail noise level by 3 dB(A) or more |
| | Night<br>10pm - 7am | 35 $dBL_{ASmax}$ and an increase in existing rail noise level by 3 dB(A) or more |
| **Schools, educational institutions, places of worship** | When in use | 40-45 $dBL_{ASmax}$ and an increase in existing rail noise level by 3 dB(A) or more |

Notes:

1. Specified noise levels refer to noise from heavy or light rail transportation only (not ambient noise from other sources)
2. Assessment location is internal near to the centre of the most affected habitable room.
3. $L_{ASmax}$ refers to the maximum noise level not exceeded for 95 per cent of the rail pass-by events.
4. For schools, educational institutions, places of worship the lower value of the range is most applicable where low internal noise levels is expected.

Ground-borne noise levels are relevant only where they are higher than the airborne noise from railways (such as for the underground rail) and where the ground-borne noise levels are expected to be audible.

*RING* does not provide guidance on acceptable ground-borne noise levels for other types of sensitive occupancies. Ground-borne noise trigger levels for other types of sensitive occupancies are proposed in Table E.6.

**Table E.6: Ground-borne noise trigger levels for other sensitive receivers**

| Sensitive land use | Time of day | Internal noise trigger levels $L_{ASMax}$ (dB) |
|---|---|---|
| **Hospitals (bed wards and operating theatres)** | 24 hours | 35 |
| **Offices** | When in use | 45 |
| **Retail spaces** | When in use | 50 |
| **Cinemas and Public Halls** | When in use | 30 |
| **Drama Theatres** | When in use | 25 |
| **Concert halls, Television and Sound Recording Studios** | When in use | 25 |

Notes:

1. The values for performing arts spaces may need to be reassessed to address the specific requirements of a venue.

## E.3 Methodology

### E.3.1 Approach

The following approach has been used for the assessment of vibration and ground-borne noise from trains:

- Models have been developed to predict vibration and ground-borne noise levels from the trains operating in tunnels
- The models incorporate:
  - Operating speed profiles (Figure E.2) with 50 kph speed floor applied through stations
  - Maximum train length of 10 cars (225m)
  - Operational timetable located in Section 5 of MMR-AJM-PWAA-RP-NN-000820

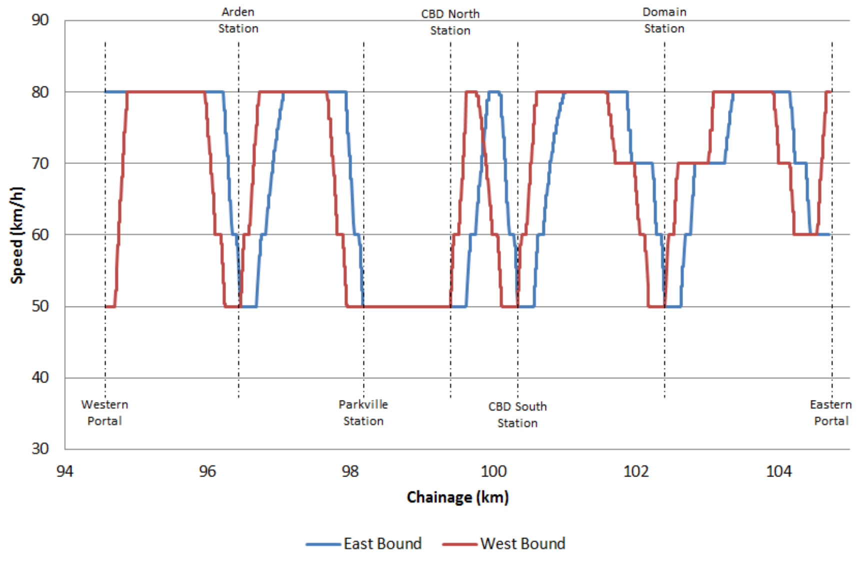



**Figure E.2 – Speed profile (with 50km/h speed floor through stations)**

- The type of occupancy (residential, commercial, other sensitive use) has been identified for each of the receivers
- A sophisticated spreadsheet modelling tool was used based on the Federal Transit Administration (FTA) predictive methodology described in US Department of Transportation FTA document, *Transit Noise and Vibration Impact Assessment*, (FTA-VA-90-1003-06, FTA 2006) incorporating test data and data from literature to define vibration source spectra and ground propagation parameters
- Vibration source spectra (one third octave band slow-weighted vibration levels) have been derived from measurements of rail fleet vibration data from the existing MURL. Utilising measured data in the model in addition to generic data from literature provides a higher degree of confidence that the modelled vibration source adequately accounts for the current rail and wheel maintenance regime and the statistical variation in wheel condition that it produces. This is important as the proposed vibration and ground-borne noise criteria are statistically based
- 5 dB tolerance was used in the predictions to account for any differences in the key parameters for vibration and ground-borne noise between the existing and new rolling stock (axle and wheel mass and primary suspension stiffness) as well as uncertainties in geotechnical conditions and modelling tolerances. Allowances for rail quality degradation, reflected vibrations from bedrock, tight radius curves, tunnel foundation stiffness and lining thickness have been made as noted in Sections E.3.2 to E.3.4
- The ground vibration attenuation characteristics for the alignment have been derived from a combination of literature-based data and interpretation of geotechnical measurements at borehole locations. Measurements of vibration attenuation through the ground from the existing MURL operation have been used for verification
- The model has been used to predict vibration and ground-borne noise levels for receivers in the vicinity of the rail alignment
- The predicted vibration and ground-borne noise levels have been compared with the proposed guideline targets for each occupancy type
- Where guideline targets are predicted to be exceeded, mitigation in the form of track-form vibration isolation has been developed to mitigate the responses
- Finite element modelling of track-form isolation schemes has been conducted as part of the input to the reference design.

## E.3.2 Vibration and Ground-borne Noise Model

Operational vibration and ground-borne noise levels for the project have been predicted using the modelling and assessment methodology described in the US Department of Transportation FTA document, *Transit Noise and Vibration Impact Assessment* (FTA-VA-90-1003-06, FTA 2006). Aspects of the general and detailed FTA modelling approach have been used to create a model for the entire alignment. The parameters described in ISO14837-1 *Mechanical vibration - Ground-borne noise and vibration arising from rail systems -- Part 1: General guidance* (ISO 2005) has been taken into consideration in the modelling, verification and validation strategies. A flow diagram describing the modelling process is shown in Figure E.3.

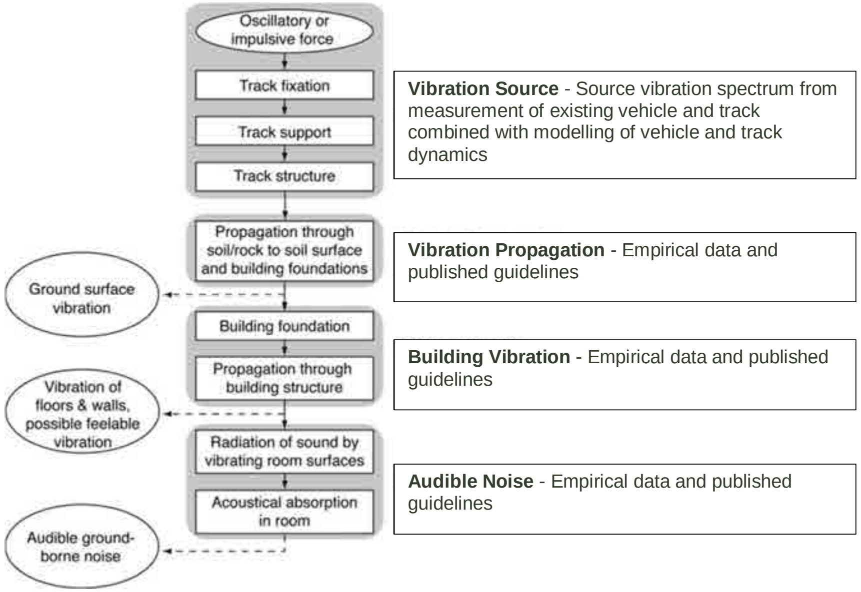



**Figure E.3: Operational vibration and ground-borne noise modelling process (source - FTA guideline)**

## E.3.3 Source Vibration Levels

Rail operational vibration source levels and spectral characteristics were determined by measuring vibration data from X'Trapolis trains operating within the MURL at two separate sites (City Circle Loop Ch 4428 and Ch 5039) to obtain data that are representative of the current rolling stock, track forms and maintenance regime. At each site vibration measurements have been recorded at three tunnel cross-sections located 10 m apart to check for data consistency. Figure E.4 shows the transducer setup at one of the tunnel cross-sections.

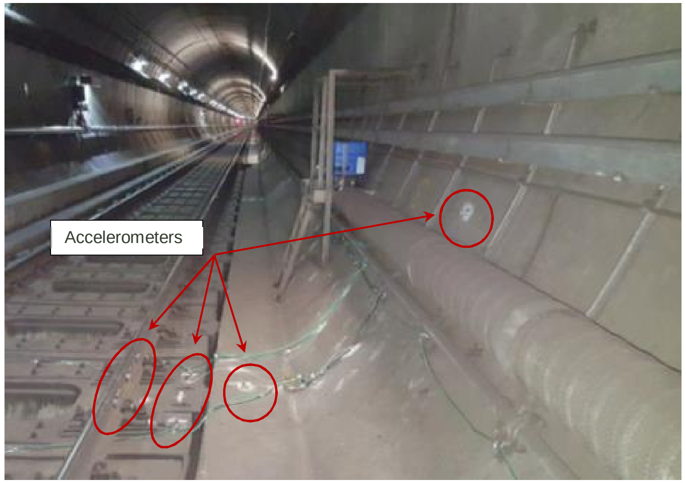



**Figure E.4: Vibration transducer installation at a single tunnel cross-section (Ch5039)**

The MURL trackform on the City Circle Loop consists of 60 kg rails on rubber pads mounted to twin sleeper floating track slabs on rubber bearings. Vibrations were measured on the rails, track slabs, tunnel invert and wall.

The maximum one second vibration level, $L_{Vmax}$, was recorded for each train passby. Average and 95$^{th}$ percentile $L_{Vmax}$ vibration levels were established for the current X'Trapolis rolling stock. The train speeds at the two test sites ranged from 45 kph to 60 kph. Data were normalised to a train speed of 80 kph.

The measured invert vibration spectra were transformed into equivalent tunnel wall vibration spectra for a range of other trackforms for use in the vibration and ground-borne noise propagation model for Melbourne Metro tunnels. The insertion loss of alternative track-forms has been calculated and applied to the invert vibration spectra using a wheel-rail interaction model.

The measured / modelled data were compared with invert and wall vibration spectra obtained on previous projects and rolling stock vibration data from the FTA Guideline to define vibration source spectra for input to the vibration and ground-borne noise propagation model. Figure E.5 shows the vibration spectra on the tunnel wall for three trackform alternatives that are used in the reference design:

- Standard attenuation track: 28 kN/mm dynamic stiffness direct fix track or 'booted sleeper'
- High attenuation track: 8.5 kN/mm dynamic stiffness direct fix track or 'booted sleeper'
- Very high attenuation track: Floating Slab Track with 20 kN/mm per metre rail dynamic stiffness bearings and 28 kN/mm dynamic stiffness baseplates.

In general, a lower dynamic stiffness for the track isolation system results in a better attenuation performance across a broader range of frequencies. The performance of the very high attenuation track also benefits from the mass of the floating track slab which lowers the natural frequency of the track and provides attenuation beginning at a lower frequency than would otherwise be the case. The performance of the very high attenuation track is based on a tunnel internal diameter of 6.3 m to accommodate the dimensions of the floating slab track used in the Concept Design (refer to report MMR-AJM-PWAA-RP-CC-001219 and drawings MMR-AJM-UGAA-DR-CS-610301 to 610351).

Other trackforms may provide equivalent performance and trackform selection during detailed design may vary from the above, being guided by refinements to the required noise and vibration performance as well as number of other parameters.

The following factors were allowed for in the model (the adjusted tangent track spectra for tunnel sections founded in moderately weathered to highly weathered Melbourne Formation, 'MF2' are shown in Table E.7:

- Degradation in rail surface condition: + 3dB at all 1/3 octave band frequencies and alignment locations
- Tight radius curves: + 3dB at all 1/3 octave band frequencies between chainages:
  - Ch 98+300 and Ch 98+915 as well as between Ch 98+970 and Ch 99+240 (300 m radius curves between Parkville and CBD North)
  - Ch 101+950 and Ch 102+215 as well as between Ch 102+725 and Ch 102+995 (400 m and 450 m radius curves between Domain and the eastern portal)
- Tunnel foundation impedance and wall thickness: various adjustments based on parametric modelling related to geotechnical conditions at each chainage and the use of a 300 mm thick tunnel lining in place of the 500 mm thick MURL tunnel lining
- Reflected energy from stiff rock layers underlying softer residual soils, silt and sand: 0 to +3 dB adjustment depending on geotechnical conditions at each chainage.

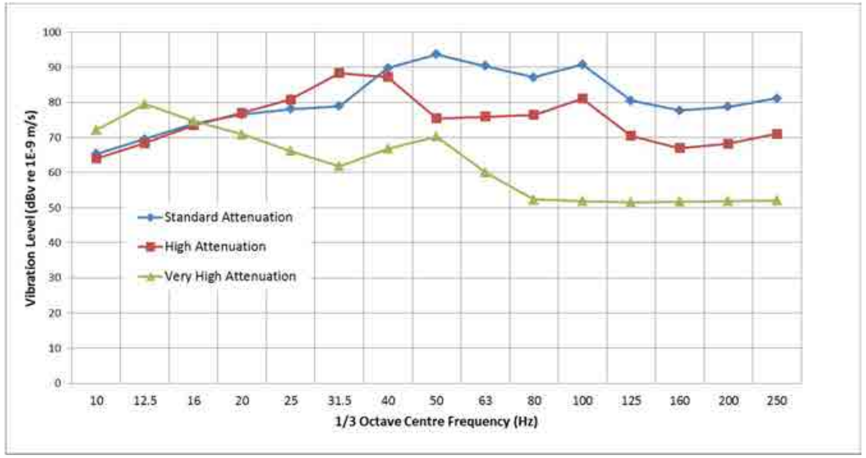



**Figure E.5: Tunnel wall vibration source spectra for standard attenuation, high attenuation and very high attenuation track forms (95$^{th}$ percentile train passby $L_{Vmax,slow}$ referenced to a train speed of 80kph)**

A summary of the reference vibration source spectra for the three Concept Design Concept Designtrack forms is given in Table E.7.

**Table E.7: Reference source tunnel wall vibration spectra for MRL trains (95th percentile passby $L_{Vmax,slow}$ referenced to a train speed of 80kph)**

| Track Type | Tunnel Wall Vibration Velocity Levels (dB re 1e-9 m/s) 1/3 Octave Band Frequency (Hz) | | | | | | | | | | | | | | | Overall Level (dB re 1e-9 m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12.5 | 16 | 20 | 25 | 31.5 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | |
| Standard Attenuation | 65 | 70 | 74 | 76 | 78 | 79 | 90 | 94 | 90 | 87 | 91 | 81 | 78 | 79 | 81 | 98 |
| High Attenuation | 64 | 68 | 73 | 77 | 81 | 88 | 87 | 75 | 76 | 76 | 81 | 70 | 67 | 68 | 71 | 92 |
| Very High Attenuation | 72 | 80 | 75 | 71 | 66 | 62 | 67 | 70 | 60 | 52 | 52 | 52 | 52 | 52 | 52 | 82 |

A line source is used to model the vibrations from trains operating inside a tunnel or on the surface.

A $20.\log_{10}(v/v_{ref})$ vibration-speed relationship was used to predict vibration levels at speeds other than the reference speed of 80 kph for input to the propagation model.

### E.3.4 Vibration Propagation

The transfer of vibrations from the tunnel invert into receiver buildings above the alignment involves a transmission path through the tunnel lining and surrounding soil/rock into building foundations and potentially through multiple floors before presenting as tactile vibration or structure-borne noise to be assessed at receiver sites. For the purposes of vibration and ground-borne noise predictive modelling, the vibration propagation path has been divided into path components each described in terms of frequency-dependent functions and coupling loss factors:

- Tunnel lining
- Ground attenuation (geometric spreading and damping losses)
- Building foundation
- Floor–to–floor transmission
- Amplification due to floor resonances.

Coupling loss factors for building foundations, floor-to-floor vibration transmission and floor resonances were taken from The Transportation Noise Reference Book, Nelson, 1987.

Vibration propagation through the ground is a complex phenomenon, producing multiple wave types with different propagation characteristics. It is influenced by the source-receiver geometry and geotechnical properties such as the soil/rock density, modulus and damping levels. At the planning stage it is appropriate to utilise empirical relationships from the literature to enable corridor-wide vibration propagation modelling. Further detailed measurement and modelling may be undertaken at the detailed design stage of the project to validate or refine predictive modelling.

The ground attenuation has two components: geometric loss due to a loss of vibration intensity with distance as the vibration wavefront spreads out; and damping loss due to the dissipation of energy in soil and rock between the source and receiver. The frequency-dependent ground vibration attenuation functions for use in the MMRL vibration and ground-borne noise propagation model were derived from the work of Unger and Bender, 1973 and supplemented by more recent studies for weathered rock by Nishi et al, 1989 and Chandler et al, 2005.

An examination of the geotechnical reports for the alignment indicates that much of the tunnels are to be located in moderately weathered to highly weathered siltstone (Melbourne Formation), with some zones of sand/silt/gravel between the western portal and Arden, and at the Yarra River crossing, Domain and the eastern portal.

Vibration attenuation in rock due to damping mechanisms is expected to be very low, resulting in the overall ground coupling loss being dominated by geometric losses. Higher damping losses are expected to occur in weathered rock and in sand/silt/gravel soils. The range of ground vibration attenuation functions used in the vibration and ground-borne noise predictive model are given in shown in Figure E.6.

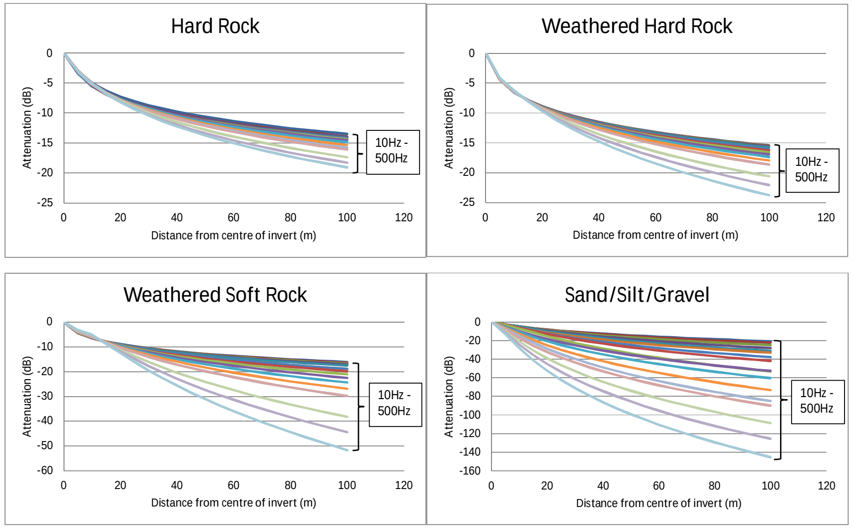



**Figure E.6: Ground vibration attenuation versus distance from centre of invert for rail vehicles operating in a tunnel**

Vibration measurements taken at the tunnel invert and at the surface above the City Circle Loop (MURL) at Ch 4428 (Flanigan Lane) and Ch 5039 (State Library) were used in order to provide a means of validating the ground attenuation losses for the project. The difference between vibration levels on the tunnel invert and surface was compared to the expected difference based on the propagation functions using the literature shown in Figure E.6.

Vibrations from the MURL were not able to be reliably measured on the surface at Flanigan Lane due to relatively low source vibration levels from the vibration isolated track and relatively high background vibration levels in the city. Vibrations on the surface at the State Library were measureable at low to mid frequencies, enabling a good comparison with the model predictions over a reasonable range of frequencies.

Figure E.7 shows the transducer installation near the state library corresponding to Ch 5039.

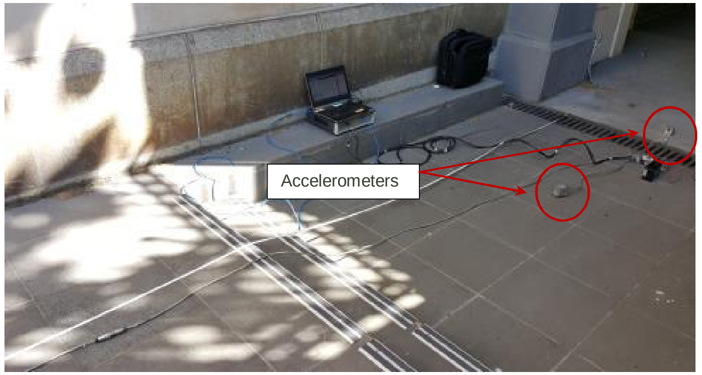



**Figure E.7: Surface vibration measurement above the City Circle Loop Ch 5039 (State Library)**

Figure E.8 presents the average vibration spectra measured at the MURL invert and at the surface compared with the surface vibration spectrum predicted using the propagation function for 'hard weathered rock' in the vibration propagation model.

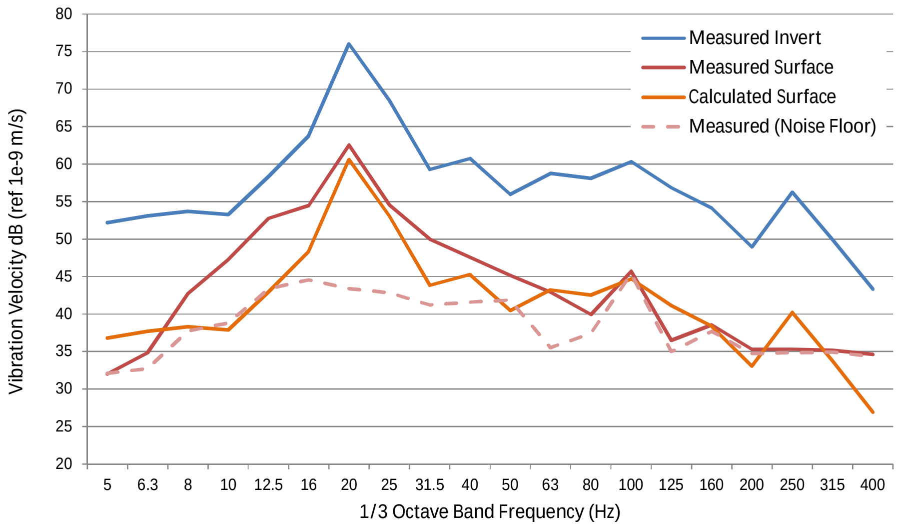



**Figure E.8: Average vibration spectrum at the tunnel invert and surface at Ch 5039 (State Library), reference speed 50 km/h**

Figure E.8 shows that there is a reasonable correlation between the test and model data at the low to mid frequencies at which measured data is valid.

## E.3.5 Vibration Prediction

Predicted levels of vibration for each vibration-sensitive receiver were based on the vibration source spectra and ground vibration attenuation functions as presented above and adjusted for:

- Vehicle speed
- Building coupling loss factors (Table E.8)
- Floor resonance factors (Figure E.9)
- Distance of each receiver to the track centreline
- Other adjustments as noted.

For each receiver point in the model a maximum vibration level ($L_{Vmax}$) and Vibration Dose Value (VDV) were calculated for comparison with vibration guideline targets for sensitive equipment/highly sensitive areas and for human comfort respectively. The graphical presentation of model predictions in Section E.4 and Section E.5 show VDV levels relative to guideline targets for each receiver occupancy type (this means that two sites at identical distances from the alignment may be presented as having different outcomes relative to the guideline targets for their occupancy type).

**Table E.8: Building coupling loss factors used in vibration prediction (Source: FTA Transit Noise and Vibration Impact Assessment Figure 11-5)**

| Building Type | Building Coupling Loss Factor (dB re 1e-9 m/s) 1/3 Octave Band Frequency (Hz) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 | 10 | 12.5 | 16 | 20 | 25 | 31.5 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 |
| Single Level Residential | 0 | 2 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 3 |
| 1-2 Story Residential | 2 | 5 | 6 | 7 | 8 | 8 | 8 | 9 | 8 | 8 | 8 | 8 | 7 | 7 | 6 | 5 |
| 2-4 Story Masonry | 3 | 7 | 9 | 10 | 11 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 11 | 10 | 9 | 8 |

Notes:

For buildings of five stories or more that may be founded in bedrock (including all buildings between CBD North and CBD South) zero coupling loss was assumed.

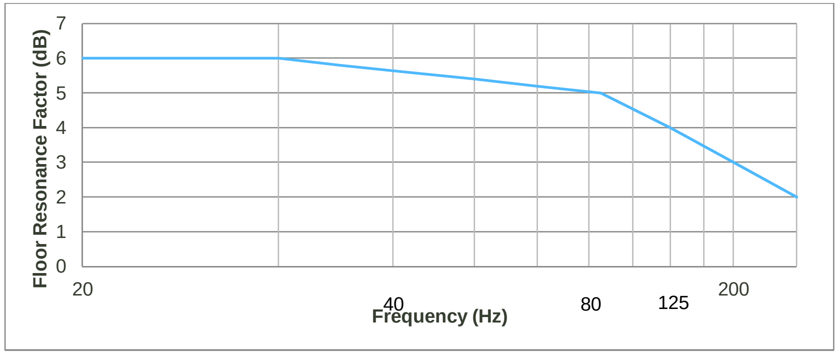



**Figure E.9: Floor resonance amplification factors**

The $L_{Vmax}$ vibration levels were used in the prediction of ground-borne noise as described below.

### E.3.6 Ground-borne Noise Prediction

The ground-borne noise model was based on the method outlined in Sections E.3.4 and E.3.5 for receiver vibration prediction with the addition of a conversion factor between maximum floor vibration level and maximum interior sound pressure level using the method described in the ANC publication – Measurement and assessment of ground-borne noise and vibration (Association of Noise Consultants 2012). The calculated 1/3 octave band interior sound pressure levels were then 'A'-weighted and logarithmically summed and converted to overall $L_{ASmax}$ noise levels for comparison with ground-borne noise guideline targets for the different occupancy types. The graphical presentation of model predictions in Section E.4 and Section E.5 show ground-borne noise levels relative to guideline targets for each receiver occupancy type (this means that two sites at identical distances from the alignment may be presented as having different outcomes relative to the guideline targets for their occupancy type).

### E.3.7 Assumptions

- The existing ground-borne noise and vibration levels for receivers at the portals have not been accounted for in the assessment. The need for ground-borne noise attenuation is only triggered if levels due to the project exceed the existing levels by the margins defined in the criteria for the project. A further assessment taking existing ground-borne noise levels into consideration during detailed design and may be used to optimise the trackform selection at the portals.
- The 'Unmitigated' case for vibration and ground-borne noise prediction was taken to be standard attenuation track as per Table E.7.
- The 'mitigated' case for vibration and ground-borne noise uses a mix of the three trackforms from Table E.7. Further optimisation of the trackforms may be undertaken at detailed design stage based on more detailed vibration and ground-borne noise modelling.
- The ground-borne noise and vibration propagation model contains approximately 3000 receivers, which have been individually assessed against ground-borne noise and vibration criteria according to their occupancy type, building type and distance from the alignment. The Proponent may be required to include additional receivers in their assessment and to verify building and occupancy types in order to verify compliance.
- No allowance has been made for future land development or future alternative land usage except as noted.

## E.4 Results

### E.4.1 Standard Attenuation Track - Unmitigated Vibration


Figure E.10: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 2: Western Portal

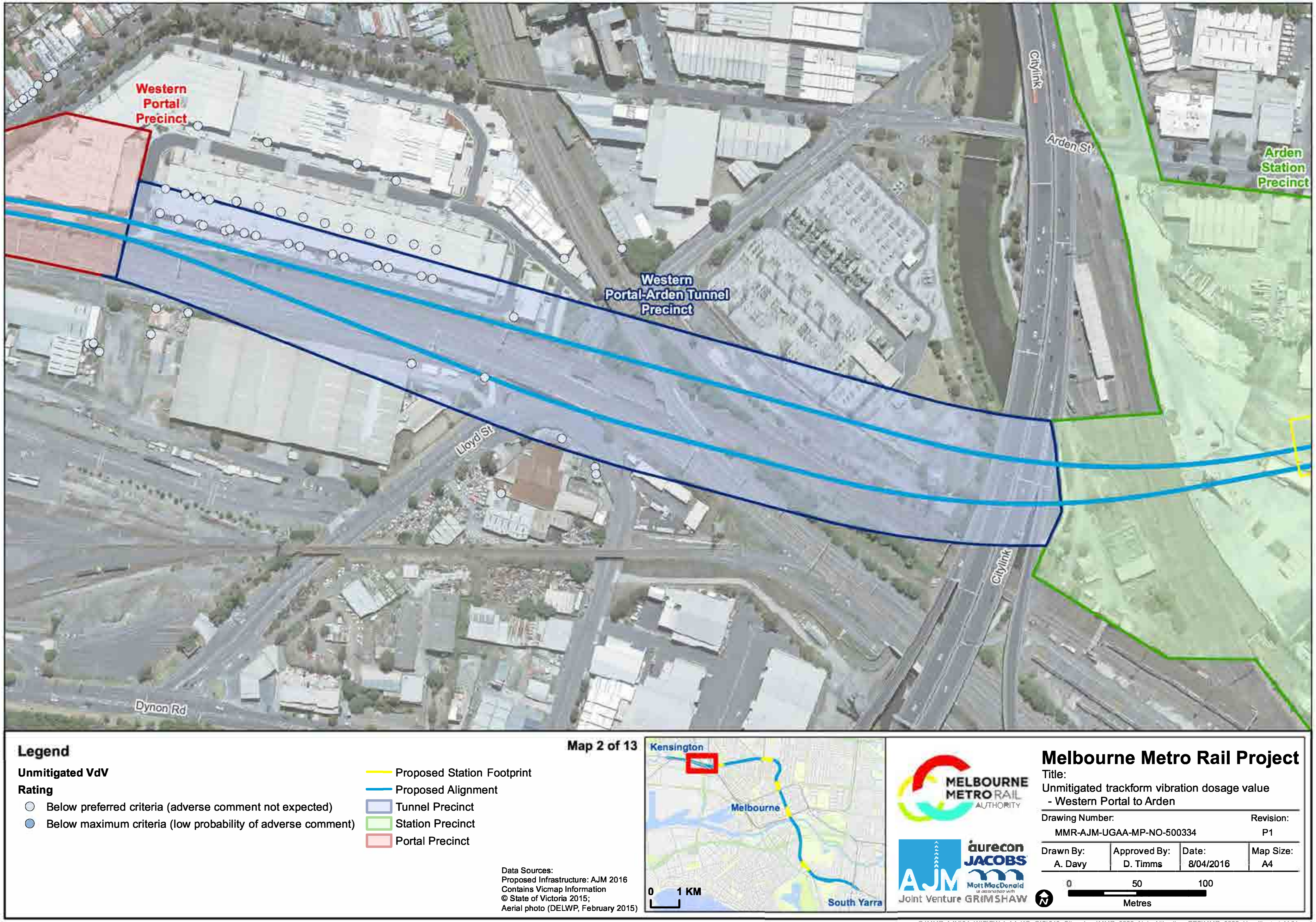



**Figure E.11: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 1: Western Portal to Arden Station**

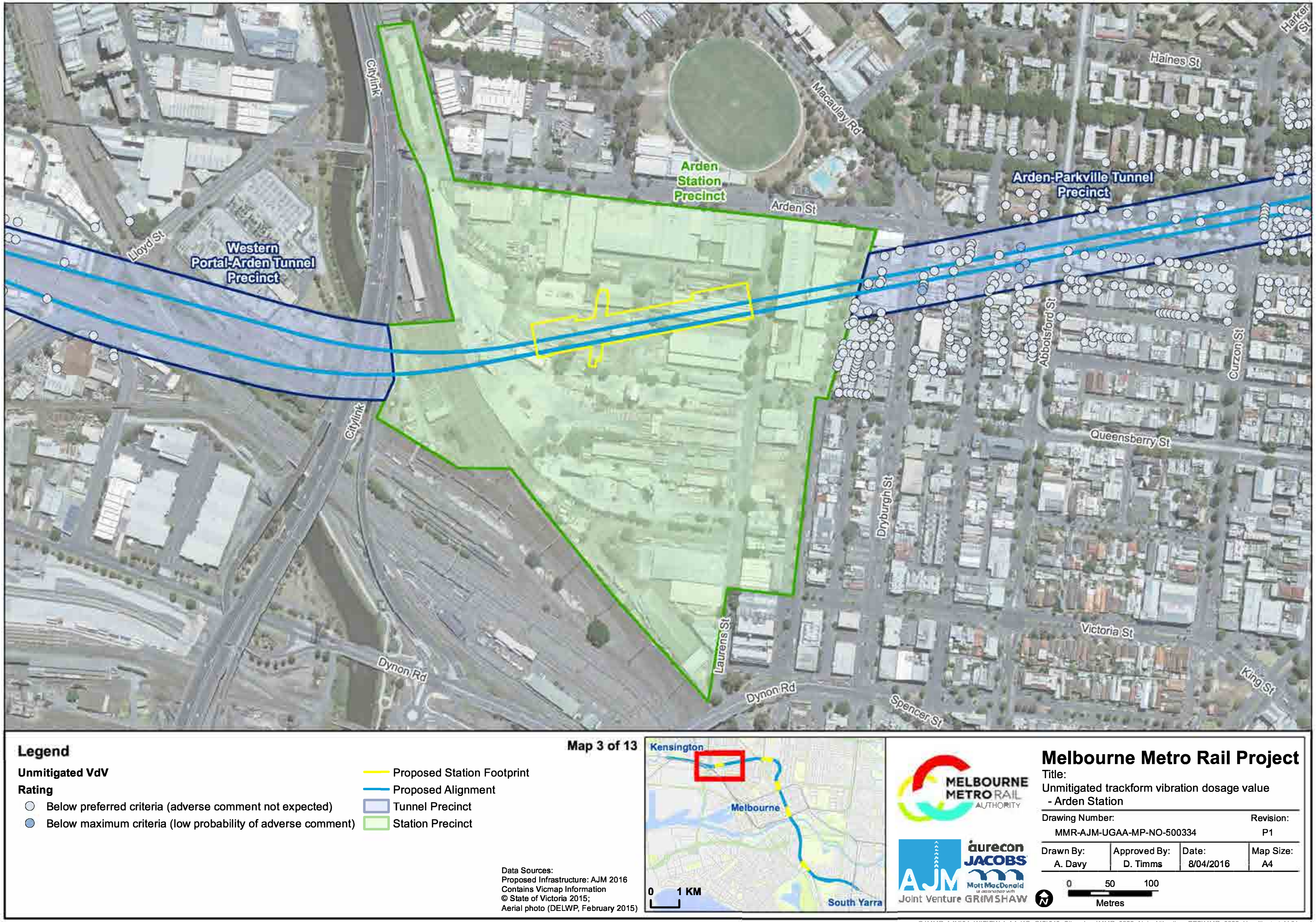
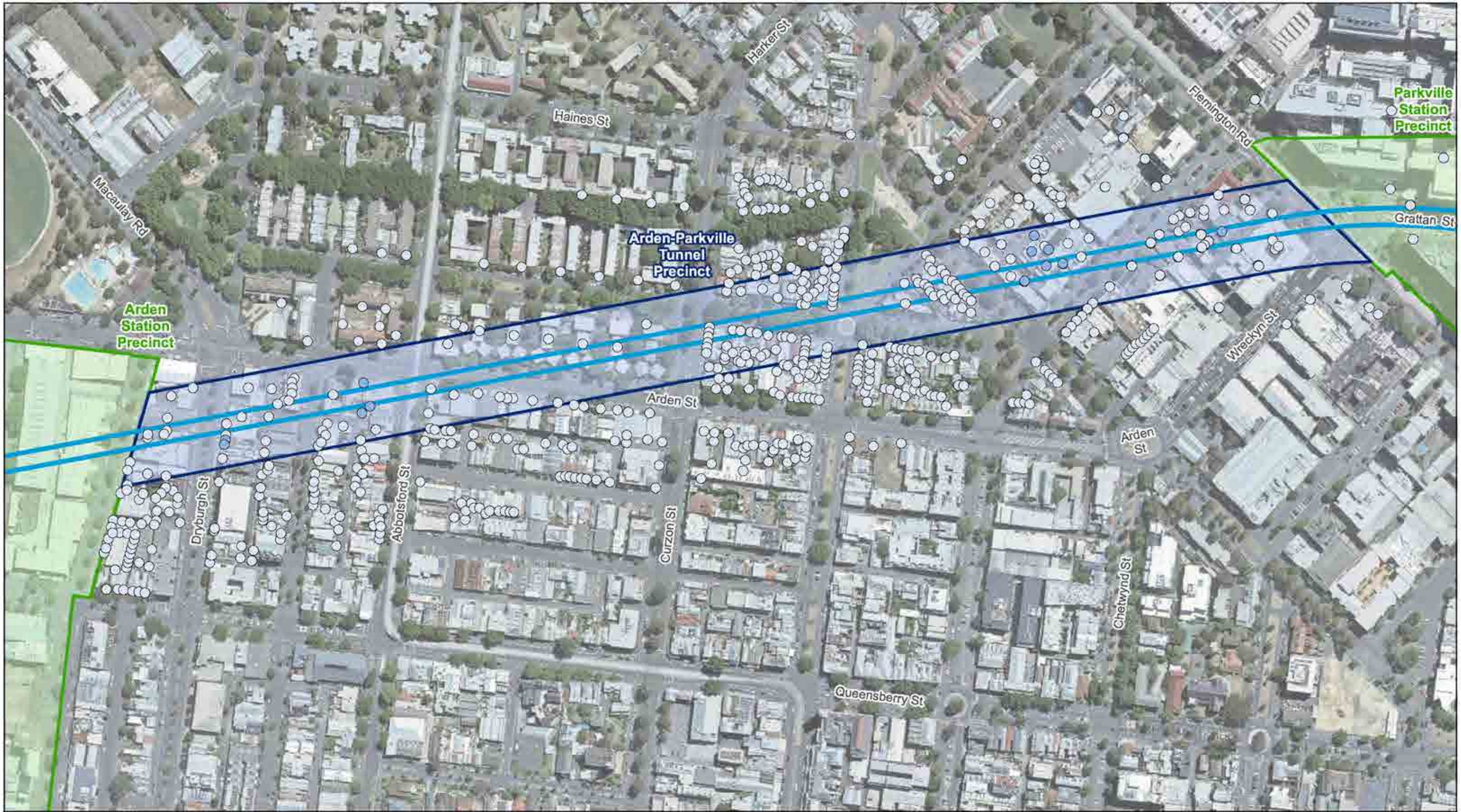



Figure E.12: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 3: Arden Station




## Legend

**Unmitigated VdV**

**Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 4 of 13


Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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aurecon JACOBS Mott MacDonald
AJM Joint Venture GRIMSHAW

**Melbourne Metro Rail Project**

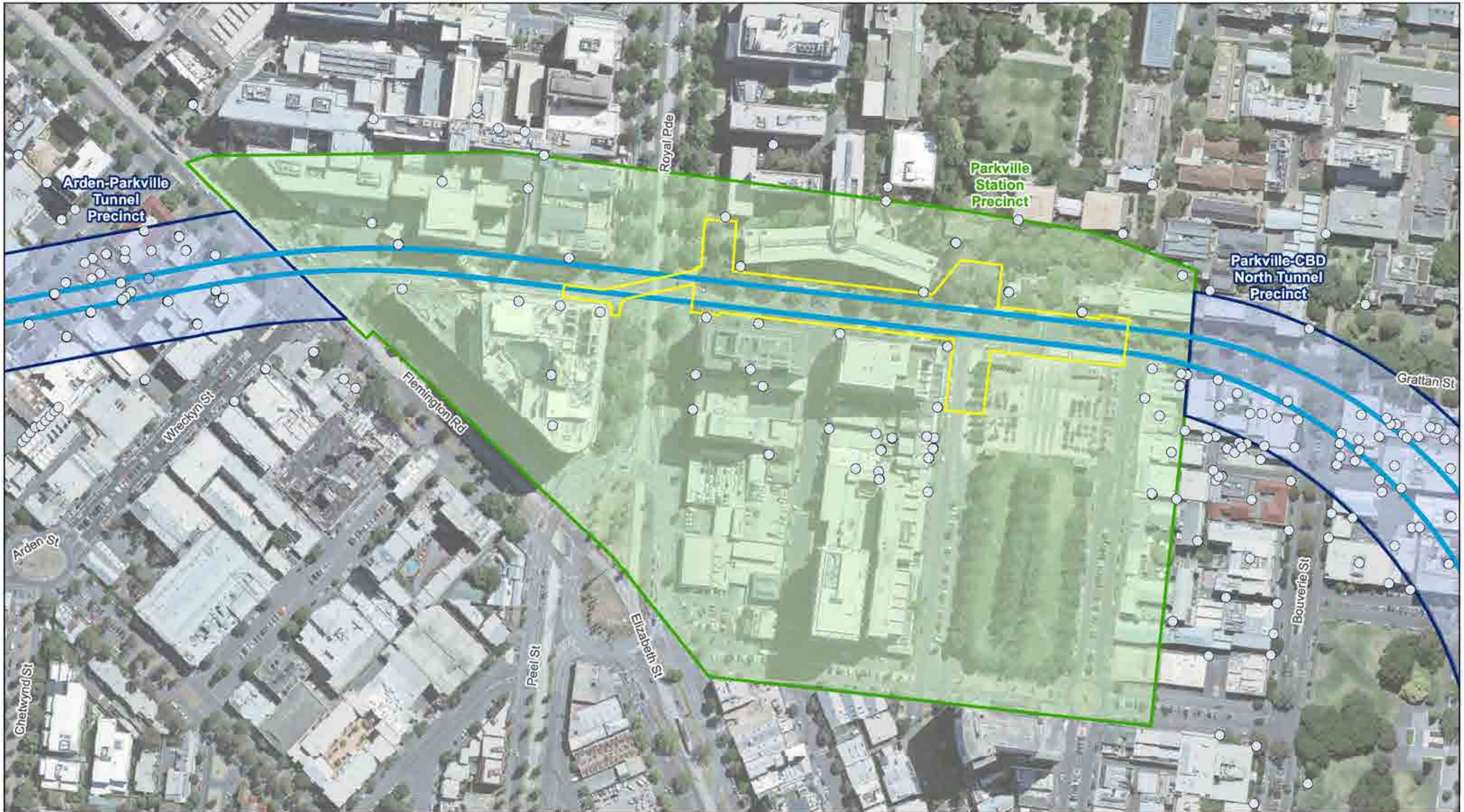
Title:
Unmitigated trackform vibration dosage value
- Arden to Parkville

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.13: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 1: Arden Station to Parkville Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd





**Legend**

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

**Map 5 of 13**

Data Sources:
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## Melbourne Metro Rail Project

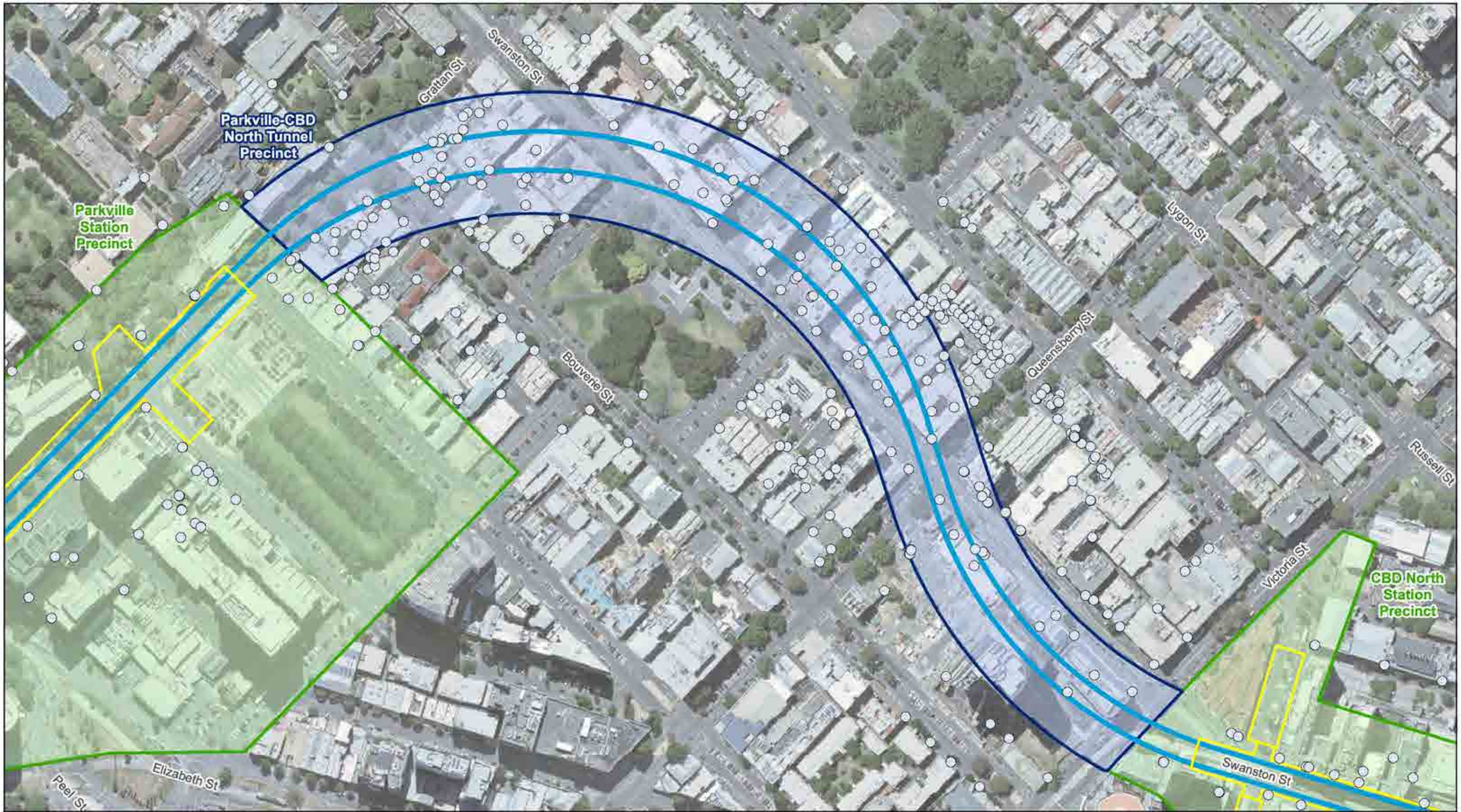
Title:
Unmitigated trackform vibration dosage value
- Parkville Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.14: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 4: Parkville Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd




Legend

Unmitigated VdV Rating

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 6 of 13


Data Sources:
Proposed Infrastructure: AJM 2016
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**Melbourne Metro Rail Project**

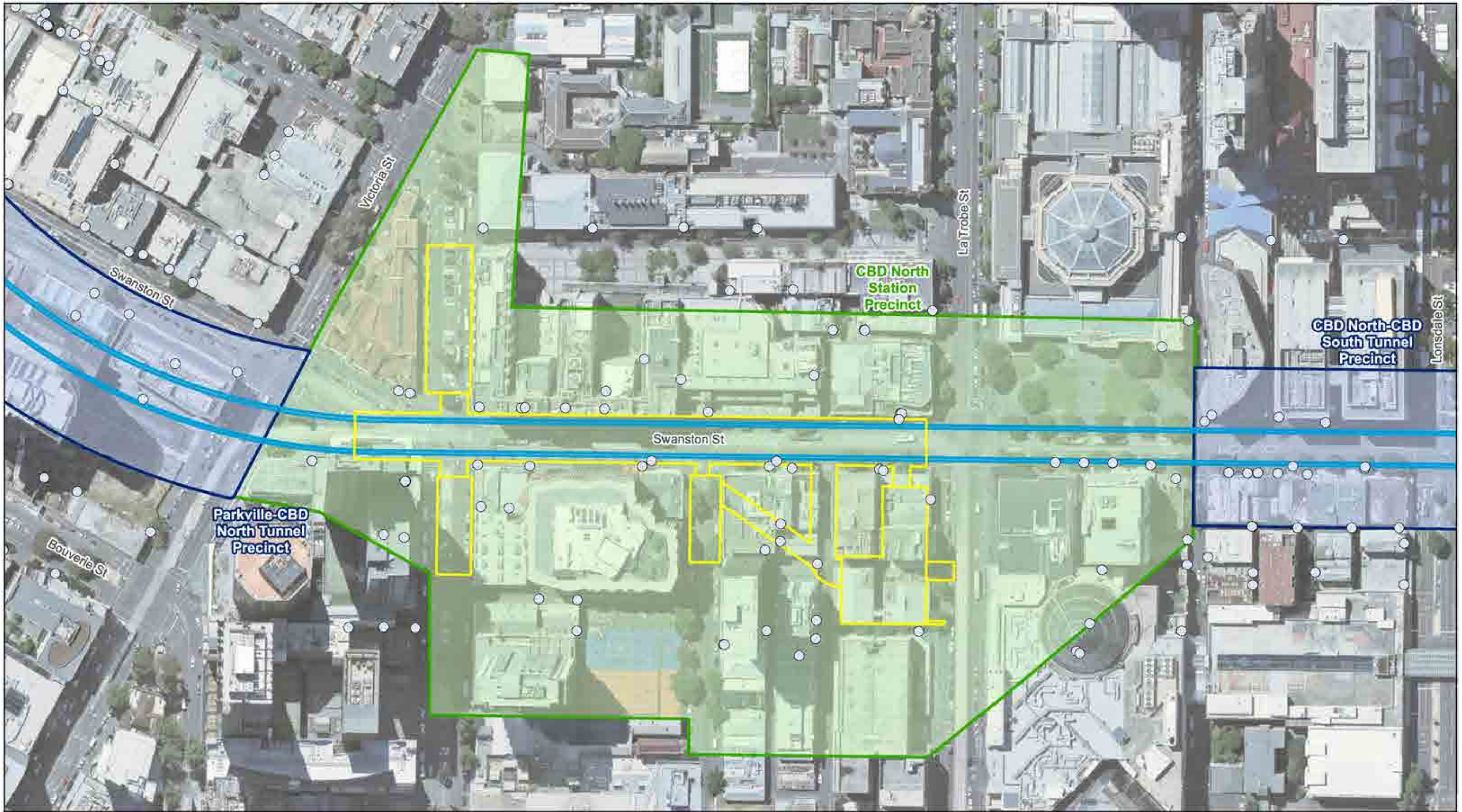
Title:
Unmitigated trackform vibration dosage value
- Parkville to CBD North

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100
Metres

**Figure E.15: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 1: Parkville Station to CBD North Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd




Legend

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 7 of 13


Data Sources:
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**Melbourne Metro Rail Project**

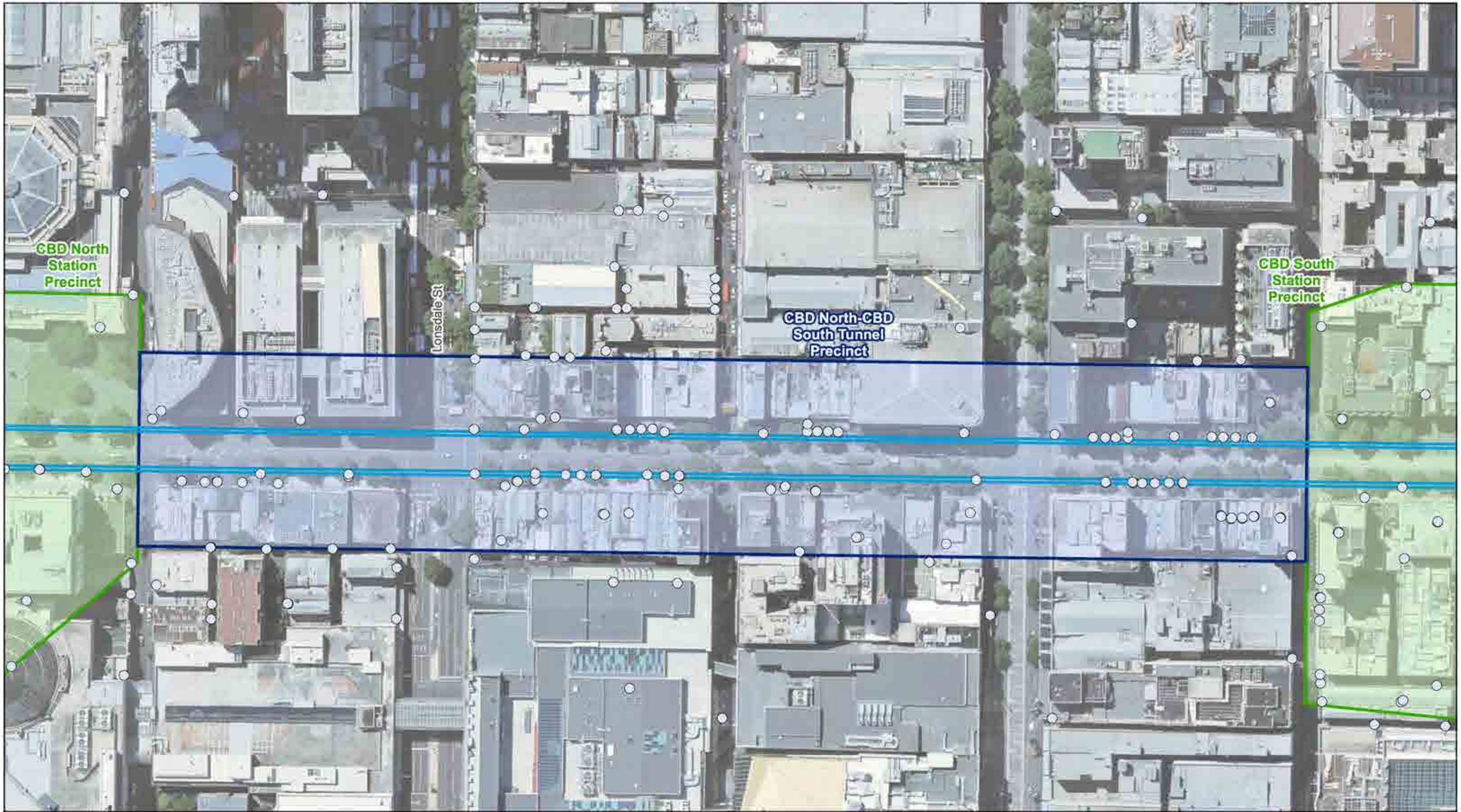
Title:
Unmitigated trackform vibration dosage value
- CBD North Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd

**Figure E.16: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 5: CBD North Station**




**Legend**

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 8 of 13


Data Sources:
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**Melbourne Metro Rail Project**

Title:
Unmitigated trackform vibration dosage value
- CBD North to CBD South

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.17: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 1: CBD North Station to CBD South Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd


**Legend**

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 9 of 13


Data Sources:
Proposed Infrastructure: AJM 2016
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**Melbourne Metro Rail Project**

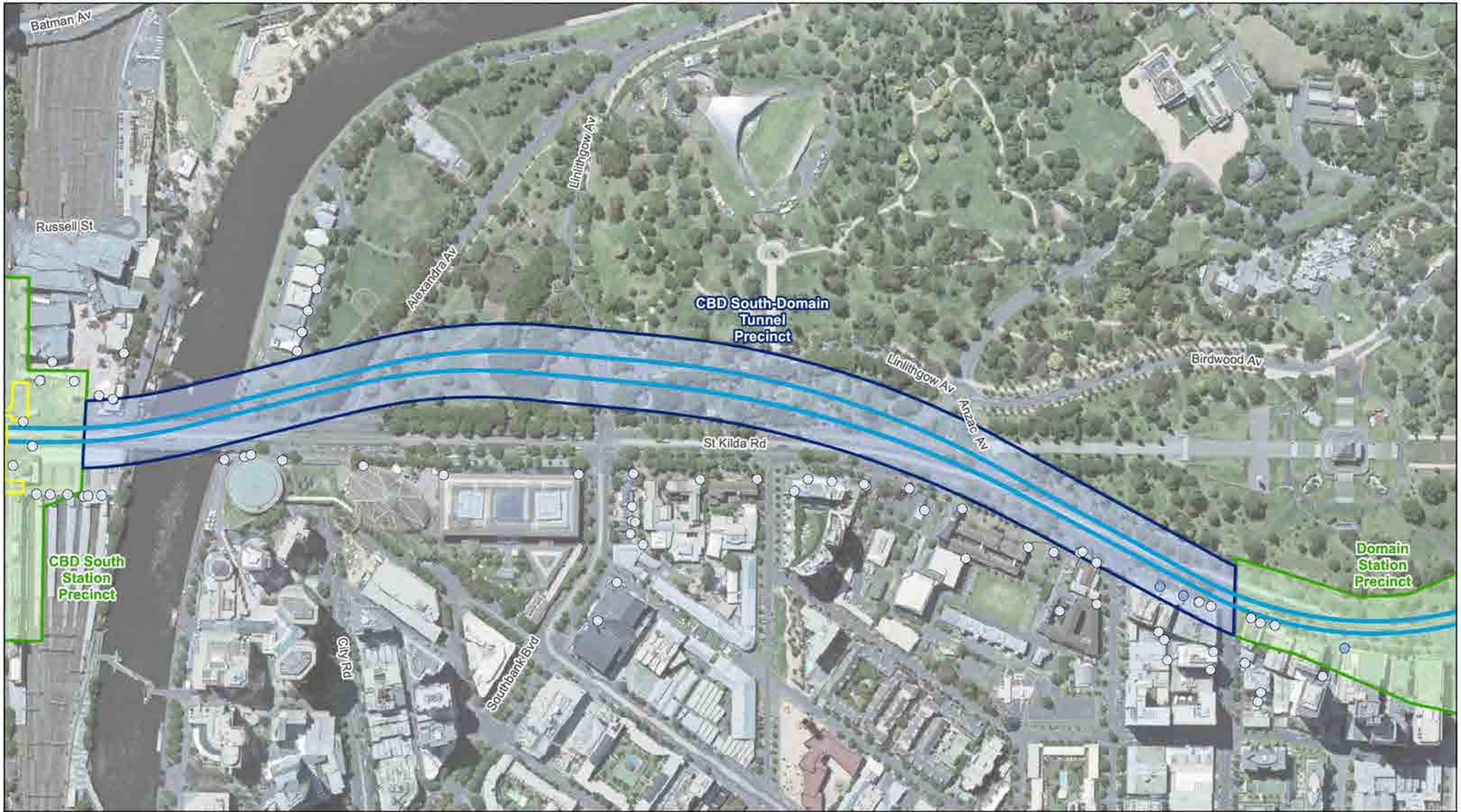
Title:
Unmitigated trackform vibration dosage value
- CBD South Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100
Metres

**Figure E.18: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 6: CBD South Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd




**Legend**

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

**Map 10 of 13**


Data Sources:
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## Melbourne Metro Rail Project

Title:
Unmitigated trackform vibration dosage value
- CBD South to Domain

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.19: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 1: CBD South Station to Domain Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd


**Legend**

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

**Map 11 of 13**


Data Sources:
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## Melbourne Metro Rail Project

Title:
Unmitigated trackform vibration dosage value - Domain Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.20: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 7: Domain Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd


**Legend**

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct

Map 12 of 13


Data Sources:
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**Melbourne Metro Rail Project**

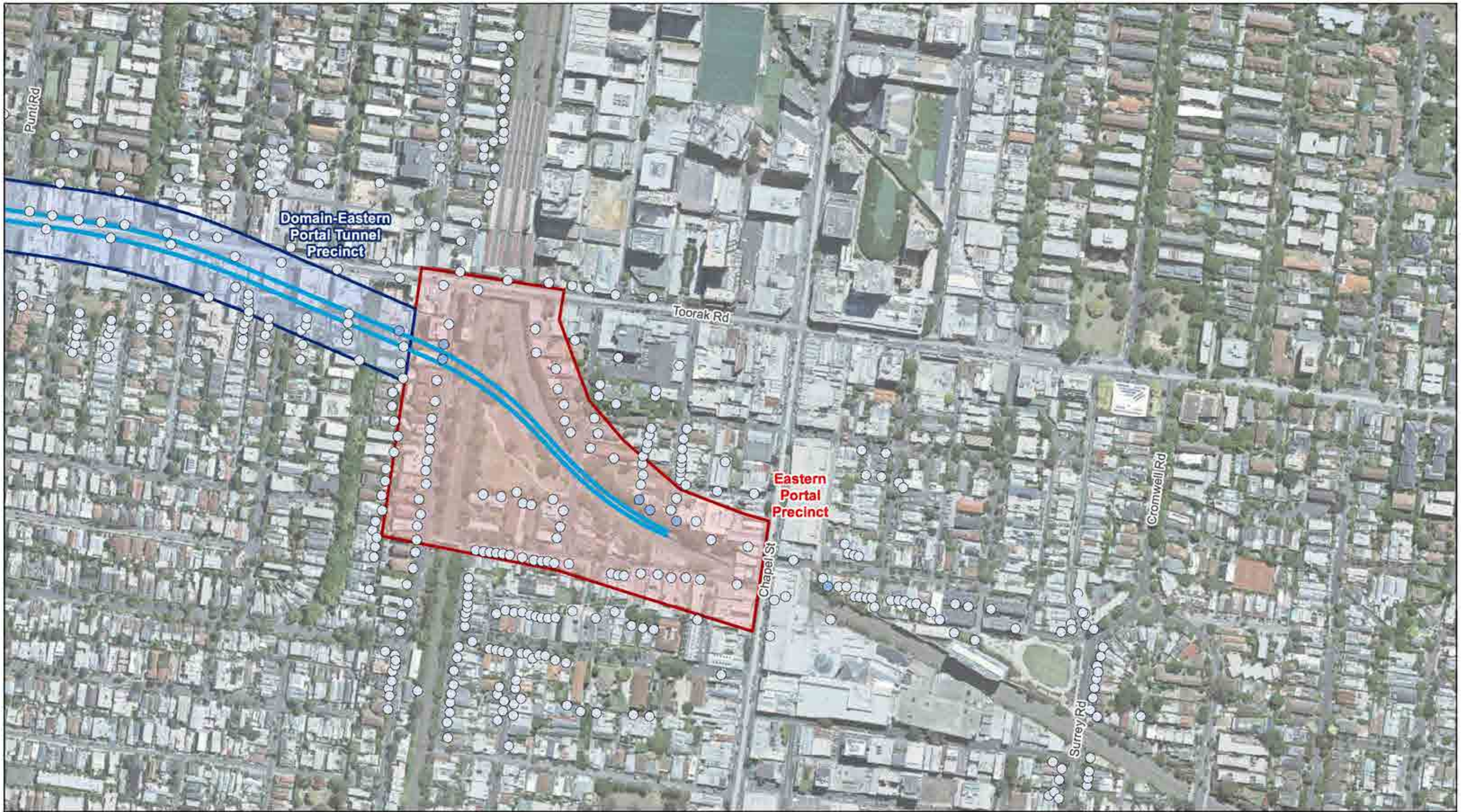
Title:
Unmitigated trackform vibration dosage value
- Domain to Eastern Portal

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100 Metres

**Figure E.21: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 1: Domain Station to Eastern Portal**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd




**Legend**

**Unmitigated VdV Rating**

- Below preferred criteria (adverse comment not expected)
- Below maximum criteria (low probability of adverse comment)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Portal Precinct

Map 13 of 13


Data Sources:
Proposed Infrastructure: AJM 2016
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**Melbourne Metro Rail Project**

Title:
Unmitigated trackform vibration dosage value
- Eastern Portal

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500334 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_VdV.mxd

**Figure E.22: Unmitigated Vibration Levels (VDV) for Human Comfort due to Trains in Precinct 8: Eastern Portal**


**Legend**

**Unmitigated GBN Rating**

- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Portal Precinct

**Map 1 of 13**


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## Melbourne Metro Rail Project

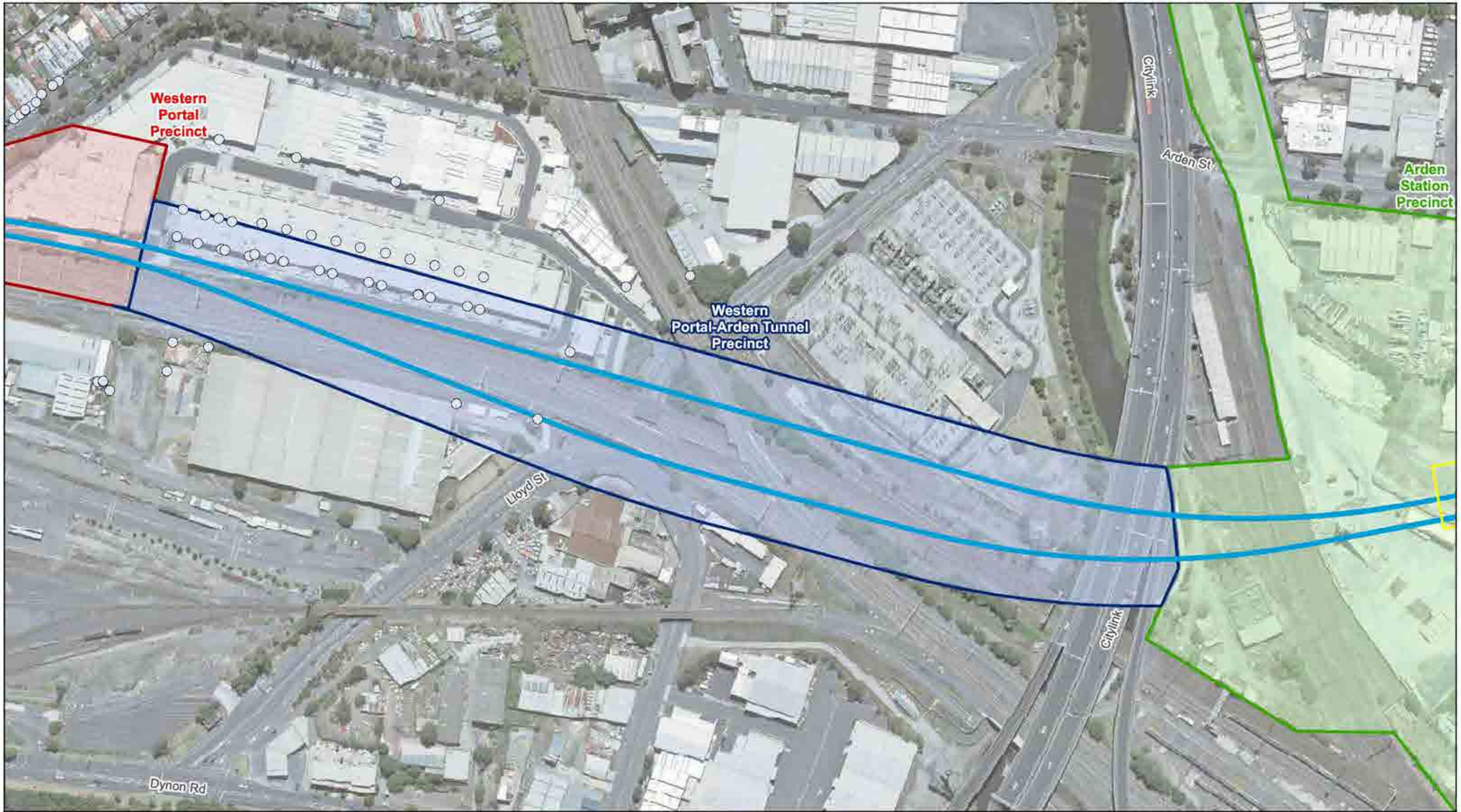
Title:
Unmitigated trackform ground-borne noise relative to night target - Western Portal

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.23: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 2: Western Portal**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd




**Legend**

**Unmitigated GBN Rating**
- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct

Map 2 of 13

Kensington
Melbourne
South Yarra
0 1 KM

Data Sources:
Proposed Infrastructure: AJM 2016
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AJM Joint Venture — aurecon JACOBS Mott MacDonald GRIMSHAW

## Melbourne Metro Rail Project

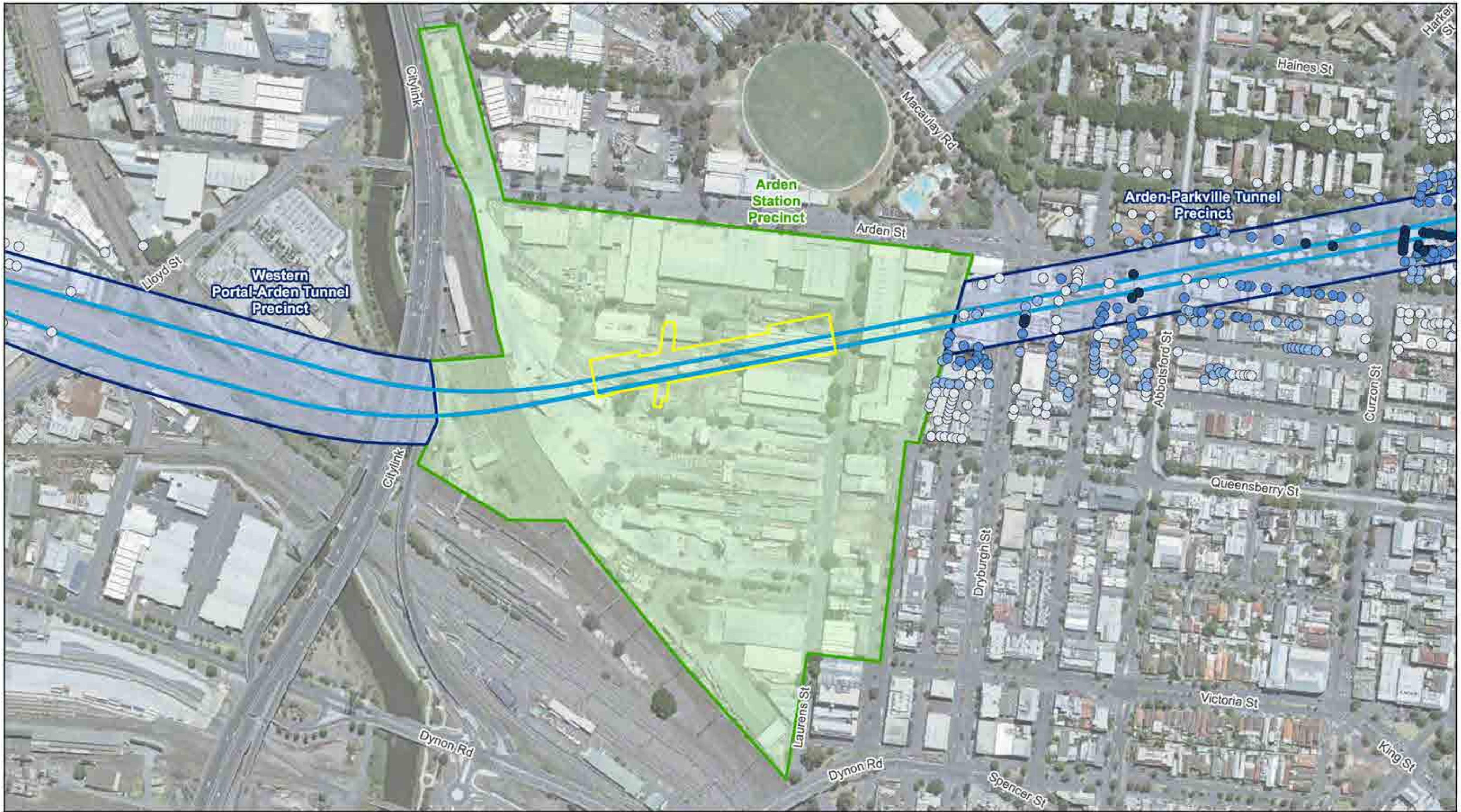
Title:
Unmitigated trackform ground-borne noise relative to night target - Western Portal to Arden

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100
Metres

**Figure E.24: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 1: Western Portal to Arden Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd




**Legend**

**Unmitigated GBN Rating**
- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 3 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
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**Melbourne Metro Rail Project**

Title:
Unmitigated trackform ground-borne noise relative to night target - Arden Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd

**Figure E.25: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 3 : Arden Station**

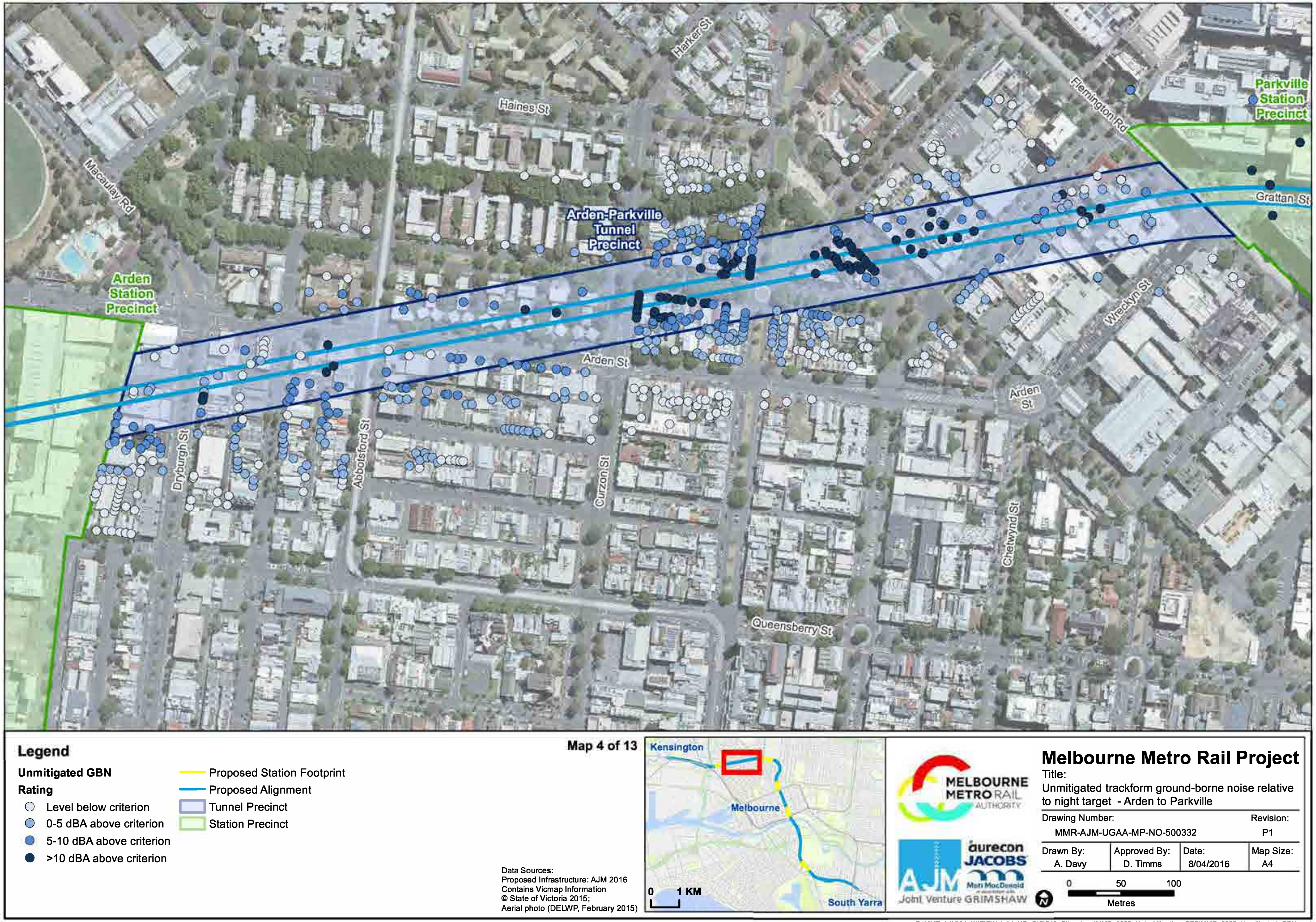



**Figure E.26: Unmitigated Ground-borne Noise Levels due to Trains to Precinct 1: Arden Station to Parkville Station**

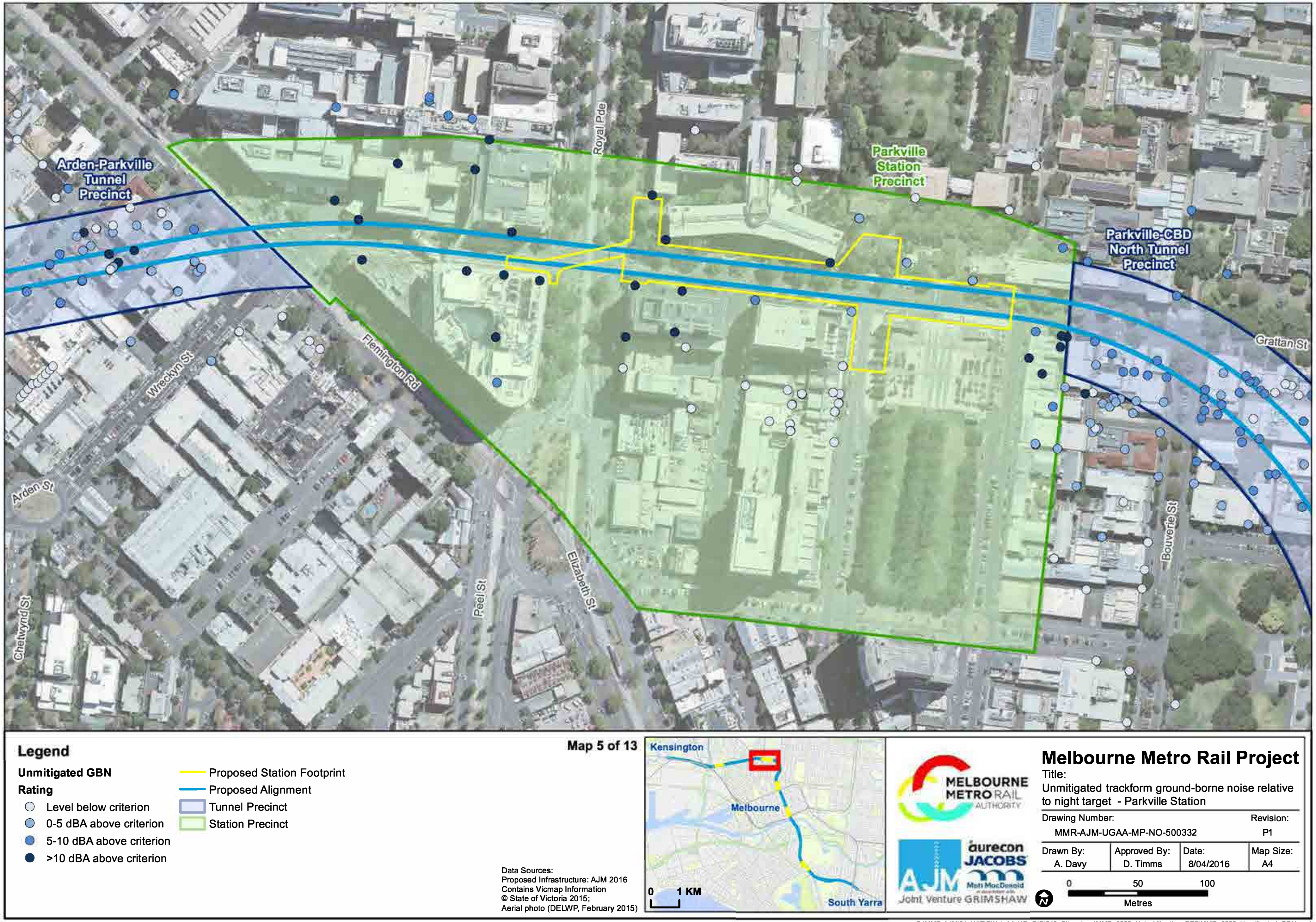
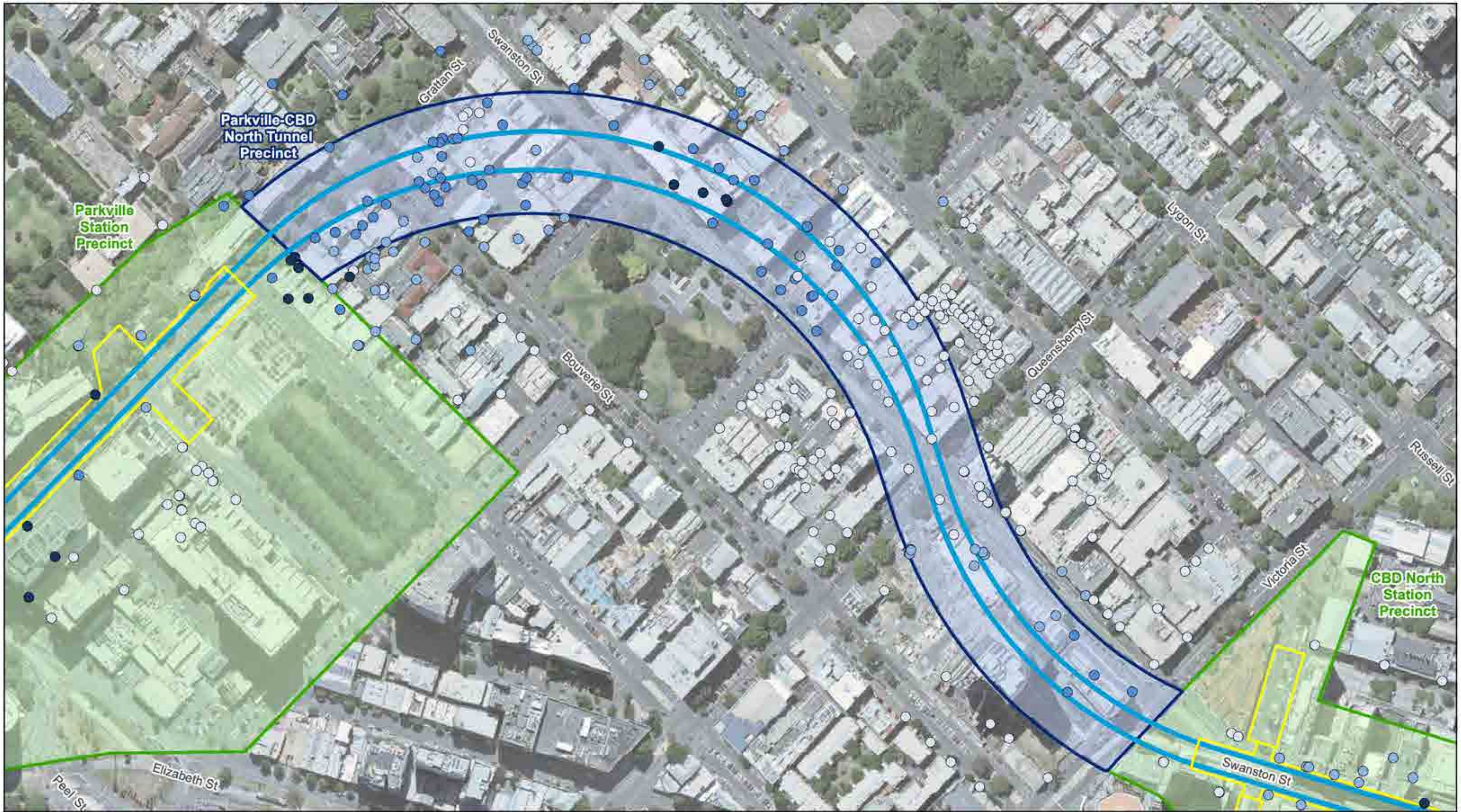



**Figure E.27: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 4: Parkville Station**




## Legend

**Unmitigated GBN Rating**

- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

**Map 6 of 13**


Data Sources:
Proposed Infrastructure: AJM 2016
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AJM Joint Venture: aurecon, JACOBS, Mott MacDonald, GRIMSHAW

# Melbourne Metro Rail Project

Title:
Unmitigated trackform ground-borne noise relative to night target - Parkville to CBD North

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.28: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 1: Parkville Station to CBD North Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd

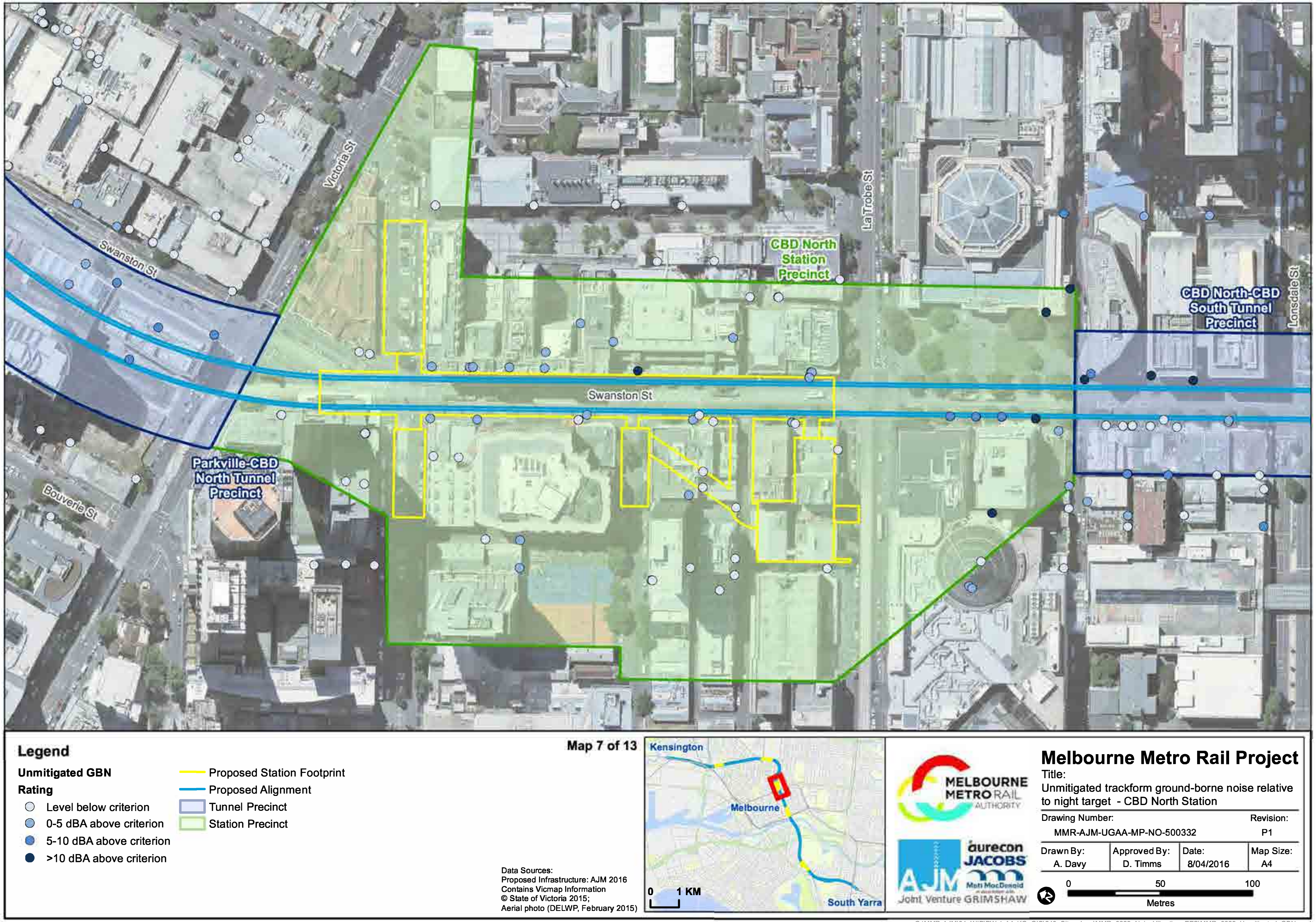
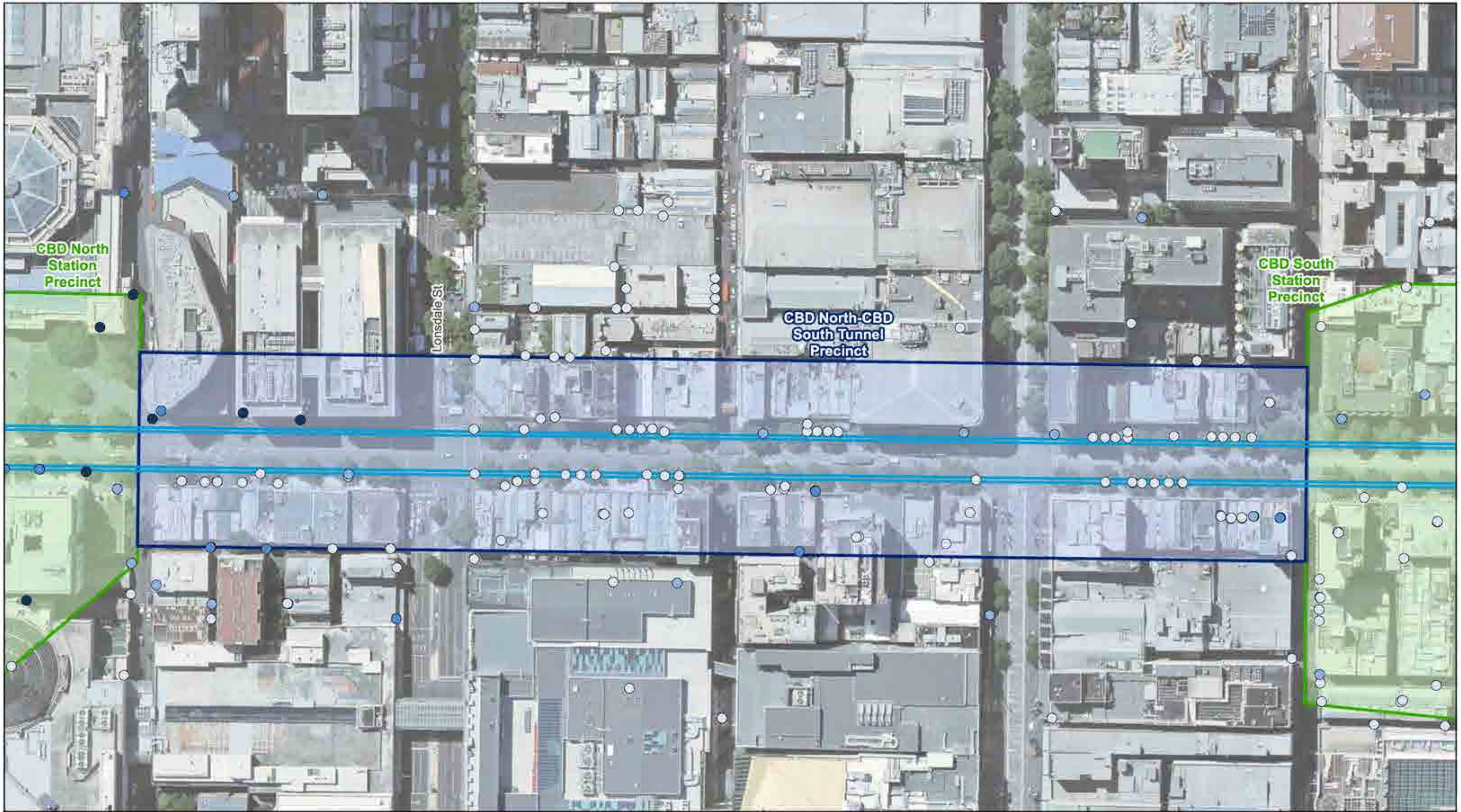



**Figure E.29: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 5: CBD North Station**




**Legend**

**Unmitigated GBN Rating**

- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 8 of 13


Data Sources:
Proposed Infrastructure: AJM 2016
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MELBOURNE METRO RAIL AUTHORITY

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AJM Joint Venture GRIMSHAW

## Melbourne Metro Rail Project

Title:
Unmitigated trackform ground-borne noise relative to night target - CBD North to CBD South

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100
Metres

**Figure E.30: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 1: CBD North Station to CBD South Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd


**Legend**

**Unmitigated GBN Rating**
- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 9 of 13


Data Sources:
Proposed Infrastructure: AJM 2016
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**Melbourne Metro Rail Project**

Title:
Unmitigated trackform ground-borne noise relative to night target - CBD South Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 8/04/2016 | Map Size: A4 |

0 50 100
Metres

**Figure E.31: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 6: CBD South Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd

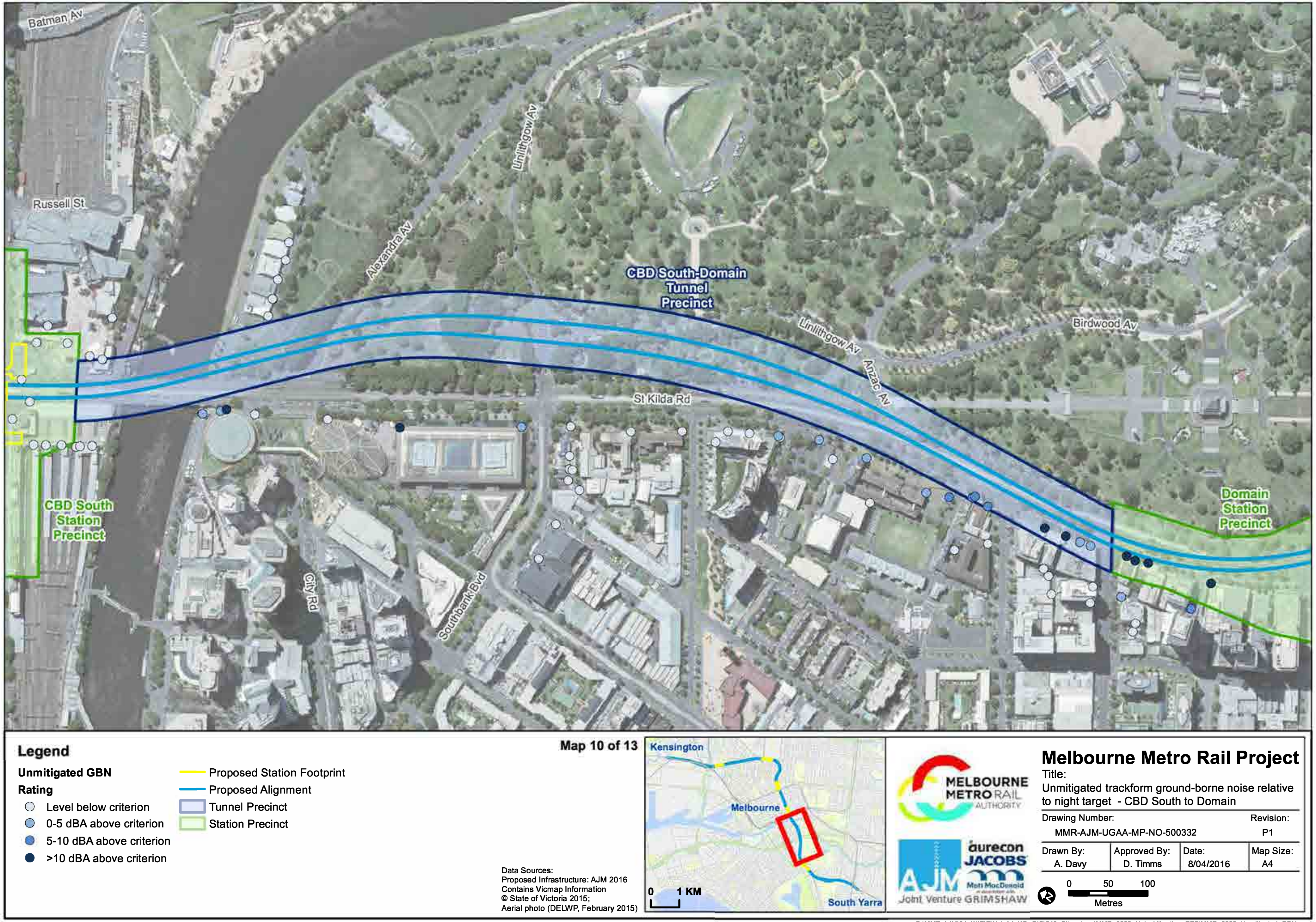
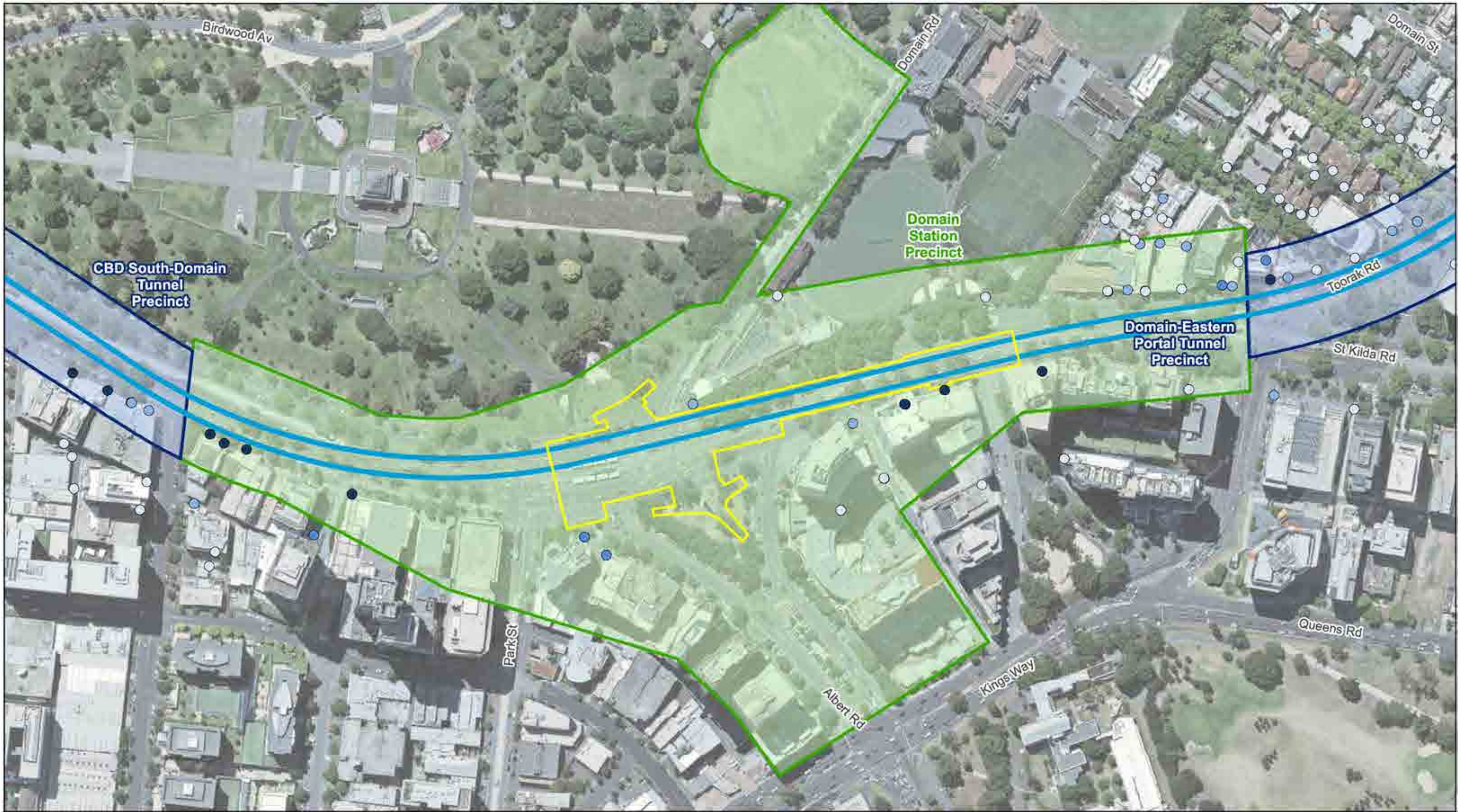



**Figure E.32: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 1: CBD South Station to Domain Station**




Legend

Unmitigated GBN Rating

- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct

Map 11 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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Aerial photo (DELWP, February 2015)


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**Melbourne Metro Rail Project**

Title:
Unmitigated trackform ground-borne noise relative to night target - Domain Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd

**Figure E.33: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 7: Domain Station**


**Legend**

**Unmitigated GBN Rating**

- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
© State of Victoria 2015;
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**Map 12 of 13**


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**Melbourne Metro Rail Project**

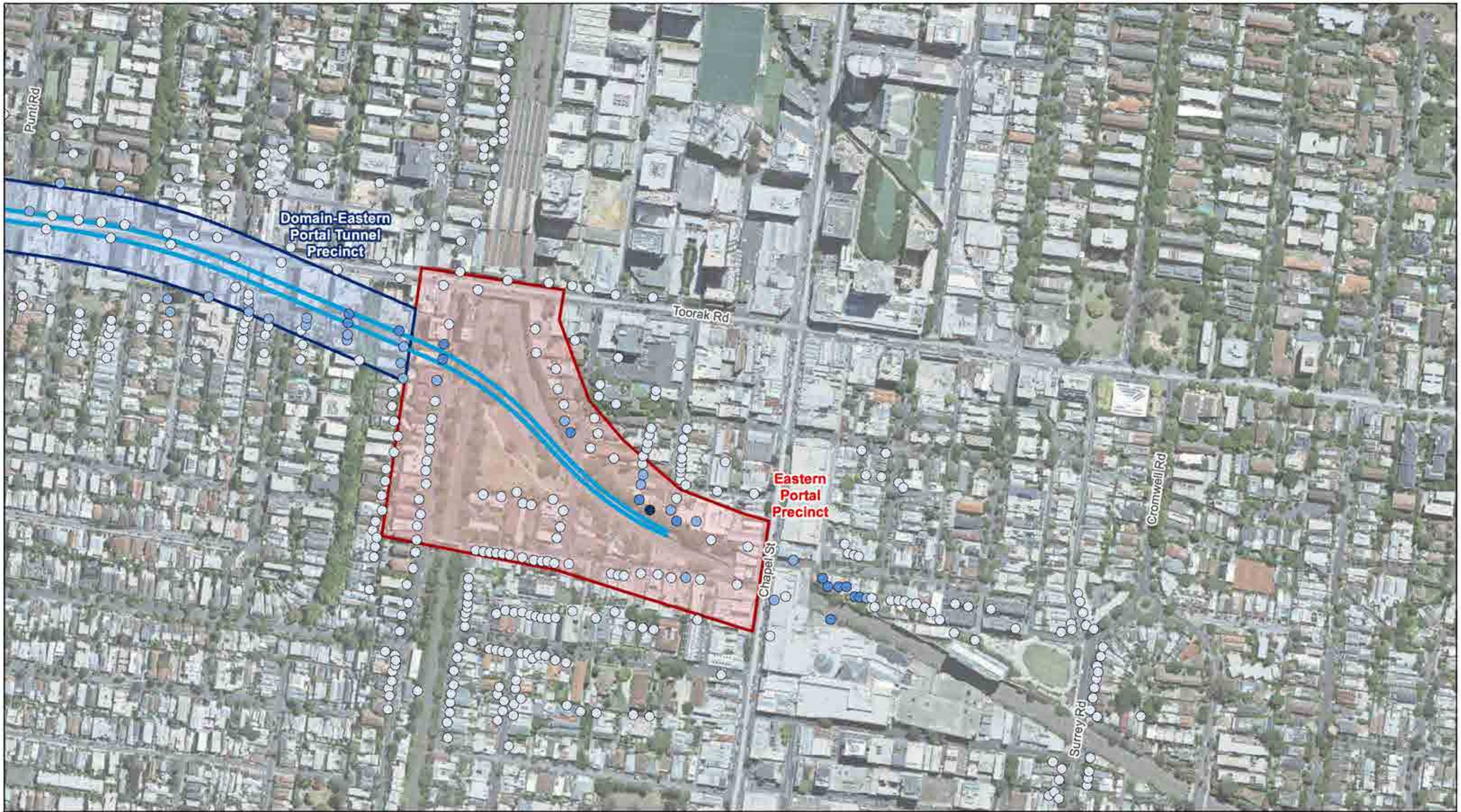
Title:
Unmitigated trackform ground-borne noise relative to night target - Domain to Eastern Portal

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.34: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 1: Domain Station to Eastern Portal**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd




**Legend**

**Unmitigated GBN Rating**
- Level below criterion
- 0-5 dBA above criterion
- 5-10 dBA above criterion
- >10 dBA above criterion

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Portal Precinct

Map 13 of 13


Data Sources:
Proposed Infrastructure: AJM 2016
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Title:
Unmitigated trackform ground-borne noise relative to night target - Eastern Portal

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500332 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 8/04/2016 | A4 |

0 50 100
Metres

**Figure E.35: Unmitigated Ground-borne Noise Levels due to Trains in Precinct 8: Eastern Portal**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Unmitigated_GBN.mxd

## E.5 Assessment of Impacts and Mitigation Requirements

The predicted VDV values generally comply with the Maximum VDV guideline targets for residential and other receivers throughout the alignment. However, a small number of receivers are predicted to exceed the Preferred VDV guideline targets and require mitigation.

Vibration impacts on sensitive equipment and highly sensitive areas are predicted to be non-compliant in the Parkville Precinct in the absence of mitigation and therefore mitigation is required (results for both unmitigated and mitigated cases are presented in Table E.9 - Table E.11).

The predicted ground-borne noise levels for the unmitigated case exceed the guideline targets in many locations for residential receivers and other occupancies and therefore mitigation is predicted to be required for ground-borne noise.

Mitigation of operational vibration and ground-borne noise impacts is expected to be achieved principally by the application of vibration isolating trackforms to reduce the amount of vibration transmitted to the ground and to receivers. In addition to 'standard attenuation' track, a mix of 'high attenuation' and 'very high attenuation' trackforms is expected to be required along the parts of the alignment to mitigate operational vibration and ground-borne noise impacts. The predictions for the mitigated case are shown in Figure E.36 to Figure E.48.

In order to meet the mitigation requirements the vibration isolating trackforms are designed to work in conjunction with:

- The use of continuously welded rail
- Any switches and crossings to be located remote from sensitive receivers
- A good wheel-rail maintenance regime to minimise dynamic inputs to the track.

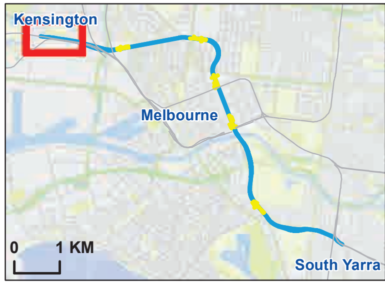
The vibration mitigation trackforms must be carefully integrated into the design to ensure a safe, reliable, maintainable and cost-effective railway and therefore the designs may be reviewed and alternatives selected during the detailed design stage providing that it can be demonstrated that ground-borne noise and vibration guideline targets would be met.


**Legend**

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Portal Precinct

Map 1 of 13




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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Aerial photo (DELWP, February 2015)

**Melbourne Metro Rail Project**

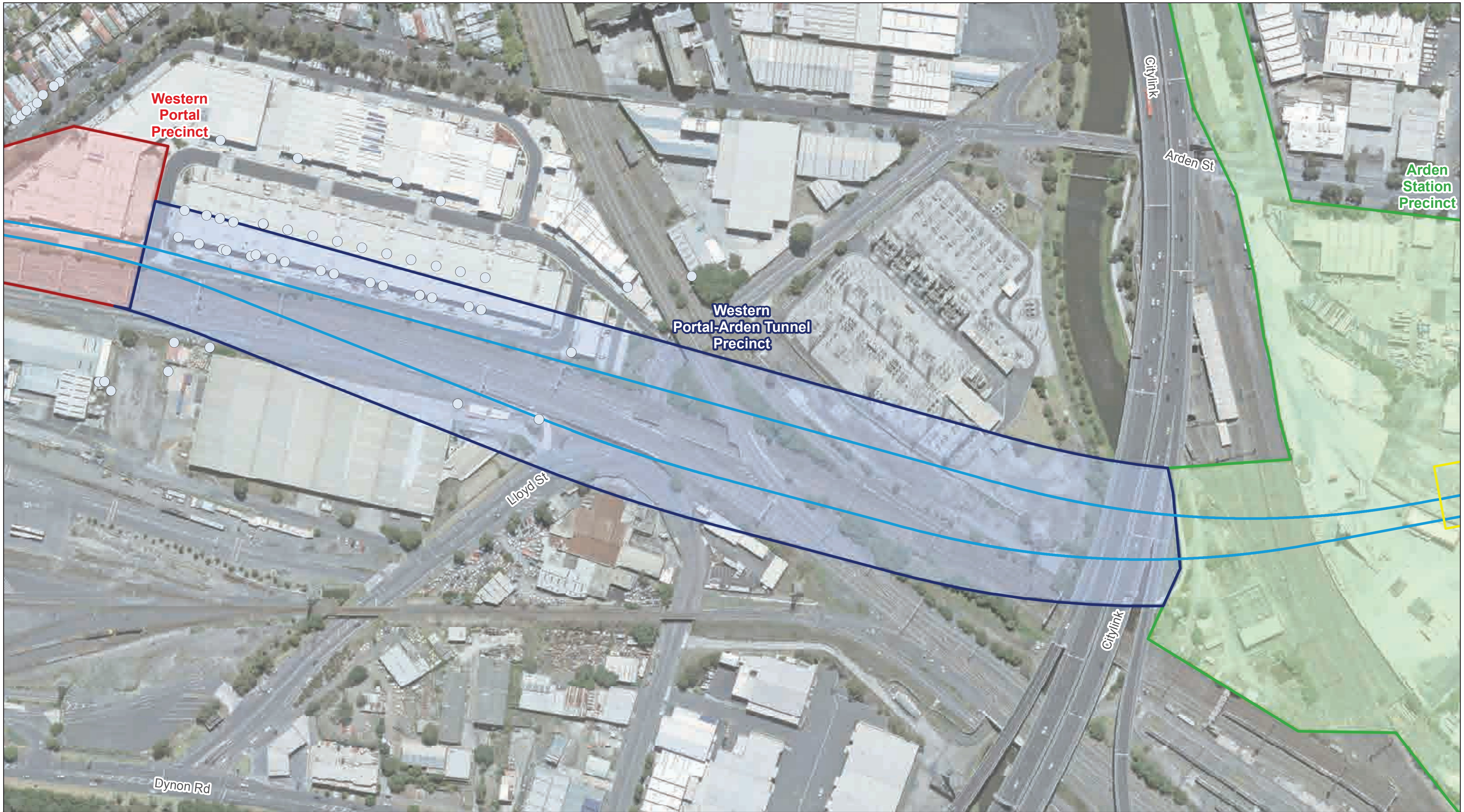
Title:
Mitigated trackform ground-borne noise relative to night target - Western Portal

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 7/04/2016 | Map Size: A4 |

0 50 100
Metres

**Figure E.36: Mitigated Ground-borne Noise Levels due to Trains in Precinct 2: Western Portal**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd




Legend

Mitigated GBN

Rating

Below preferred guideline target (adverse comment not expected)

Proposed Station Footprint

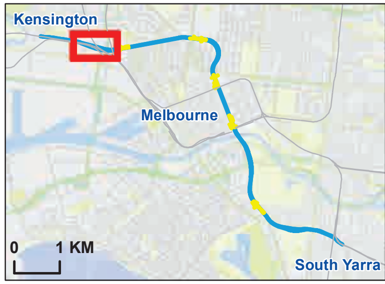
Proposed Alignment

Tunnels Precinct

Station Precinct

Portal Precinct

Map 2 of 13




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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**Melbourne Metro Rail Project**

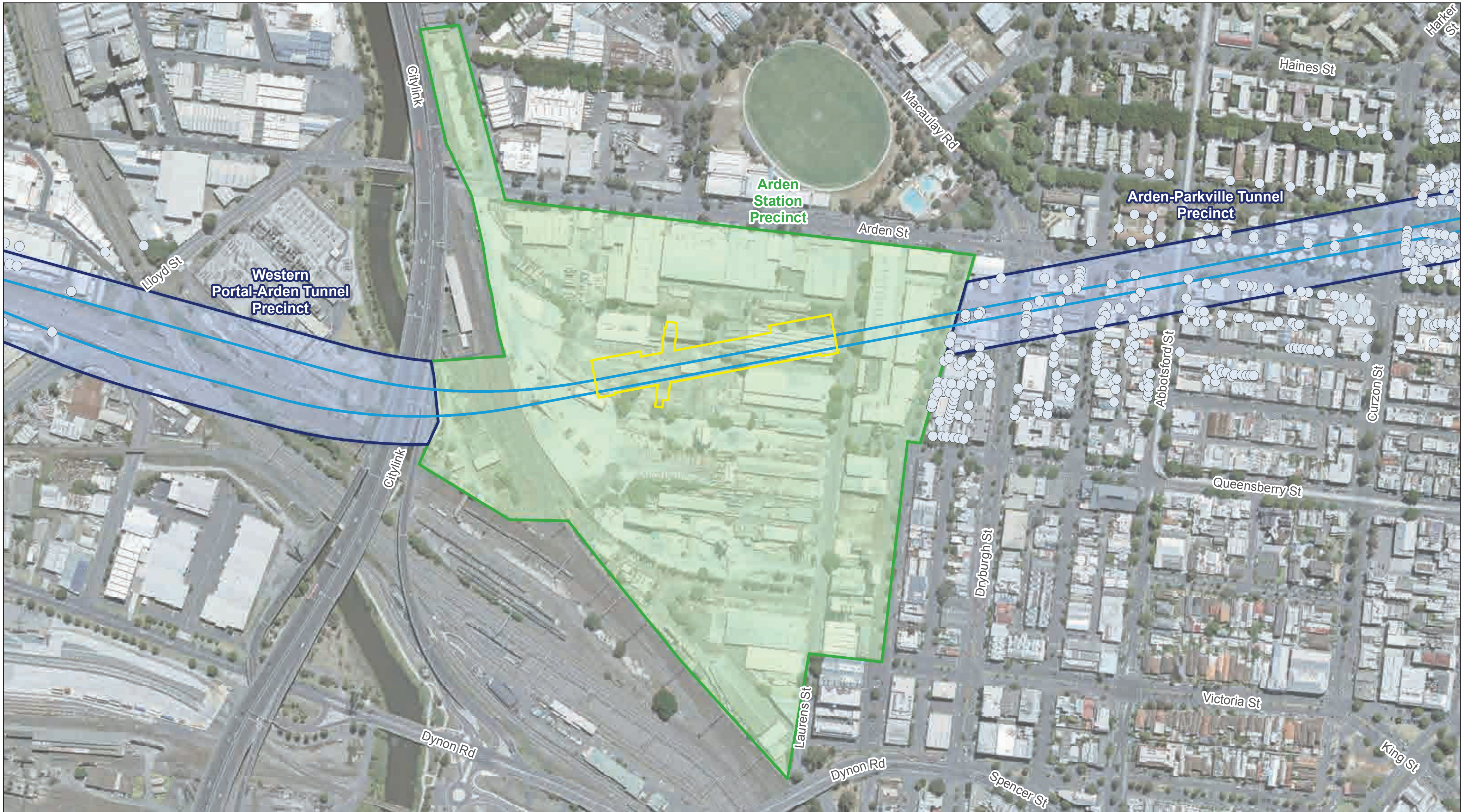
Title:
Mitigated trackform ground-borne noise relative to night target - Western Portal to Arden

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

**Figure E.37: Mitigated Ground-borne Noise Levels due to Trains in Precinct 1: Western Portal to Arden Station**

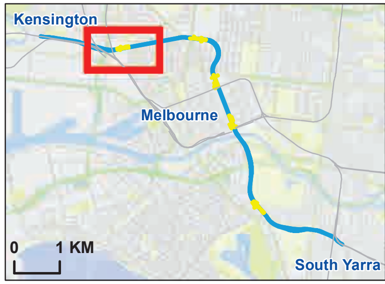



## Legend

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

Map 3 of 13




Data Sources:
Proposed Infrastructure: AJM 2016
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**Melbourne Metro Rail Project**

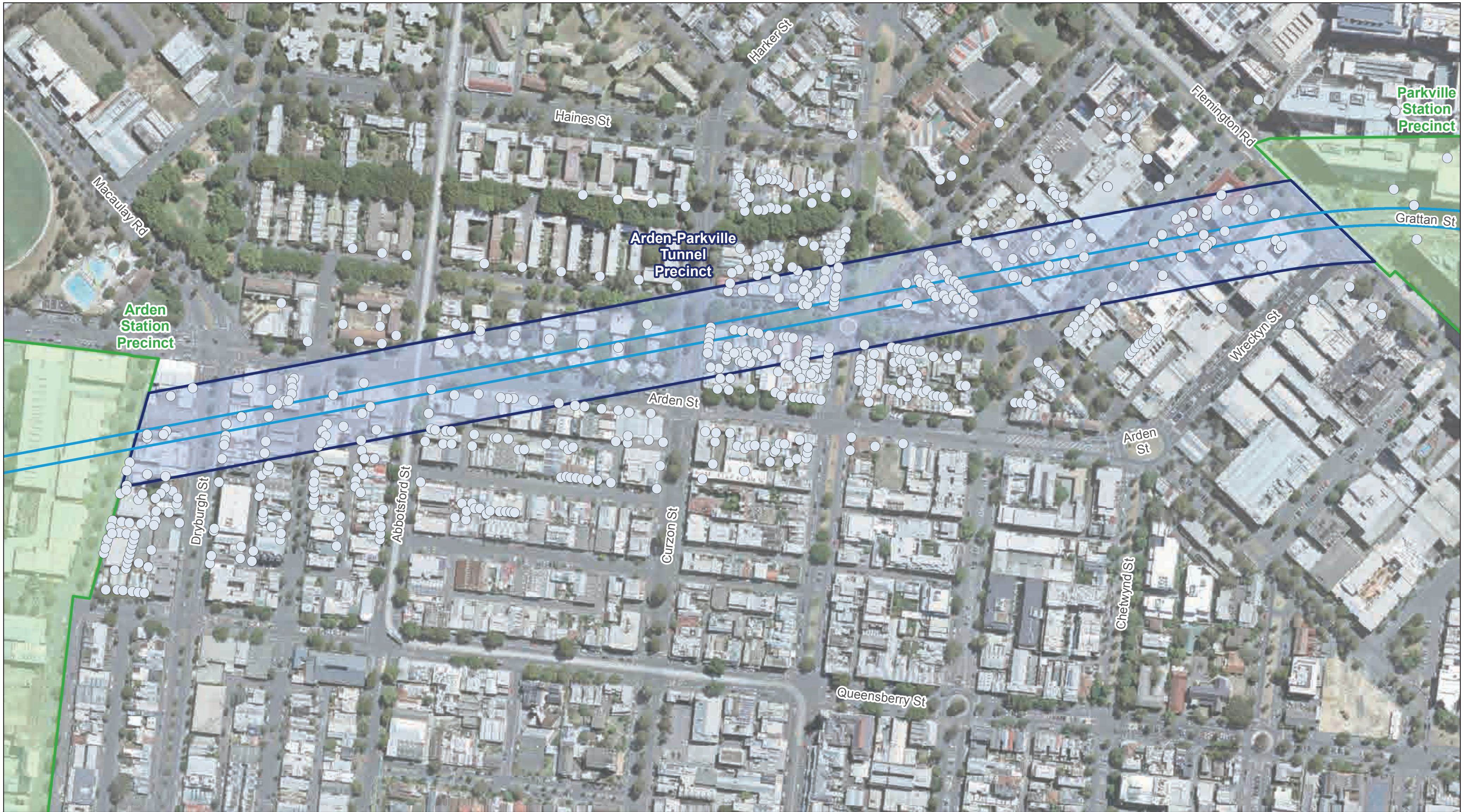
Title:
Mitigated trackform ground-borne noise relative to night target - Arden Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

**Figure E.38: Mitigated Ground-borne Noise Levels due to Trains in Precinct 3: Arden Station**




## Legend

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

Map 4 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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**Melbourne Metro Rail Project**

Title:
Mitigated trackform ground-borne noise relative to night target - Arden to Parkville

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

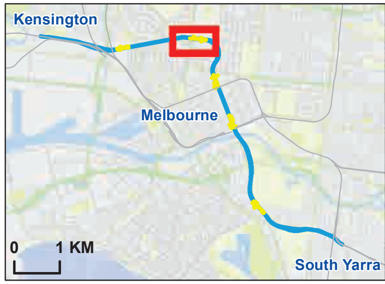
**Figure E.39: Mitigated Ground-borne Noise Levels due to Trains in Precinct 1: Arden Station to Parkville Station**


**Legend**

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

**Map 5 of 13**




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
© State of Victoria 2015;
Aerial photo (DELWP, February 2015)

**Melbourne Metro Rail Project**

Title:
Mitigated trackform ground-borne noise relative to night target - Parkville Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

Joint Venture GRIMSHAW

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

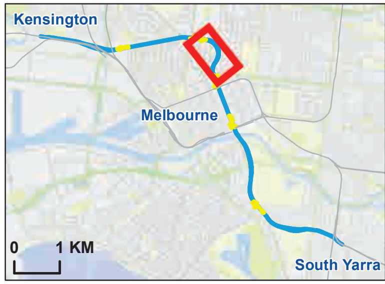
**Figure E.40: Mitigated Ground-borne Noise Levels due to Trains in Precinct 4: Parkville Station**


**Legend**

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

Map 6 of 13




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
© State of Victoria 2015;
Aerial photo (DELWP, February 2015)

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AJM Joint Venture aurecon JACOBS Mott MacDonald GRIMSHAW

## Melbourne Metro Rail Project

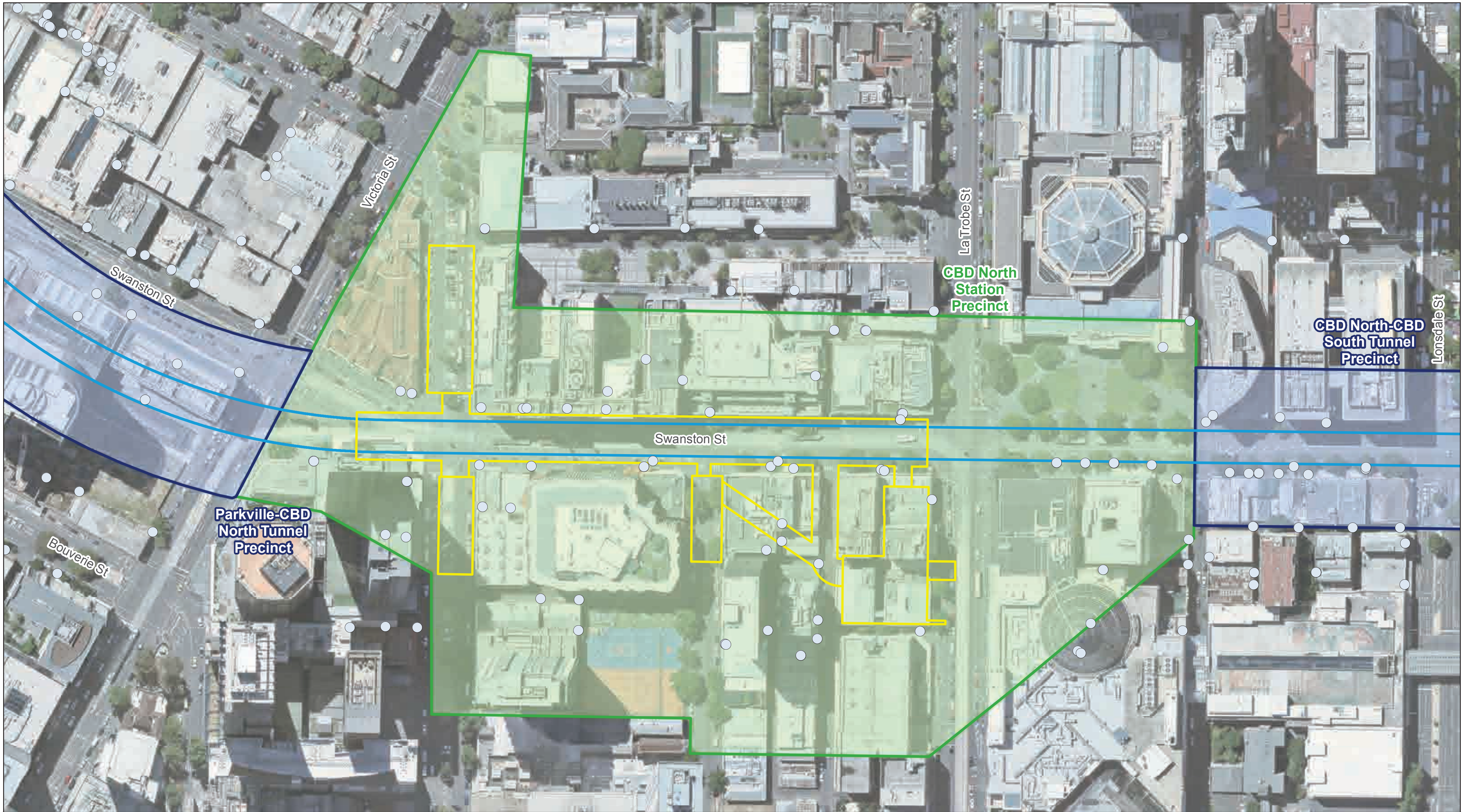
Title:
Mitigated trackform ground-borne noise relative to night target - Parkville to CBD North

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

**Figure E.41: Mitigated Ground-borne Noise Levels due to Trains in Precinct 1: Parkville Station to CBD North Station**

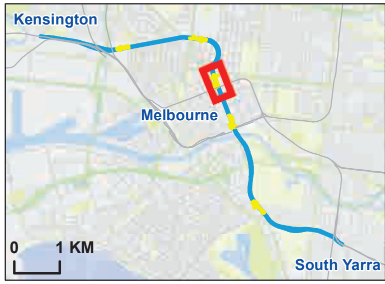



## Legend

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct






Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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Aerial photo (DELWP, February 2015)

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# Melbourne Metro Rail Project

Title:
Mitigated trackform ground-borne noise relative to night target - CBD North Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

**Figure E.42: Mitigated Ground-borne Noise Levels due to Trains in Precinct 5: CBD North Station**

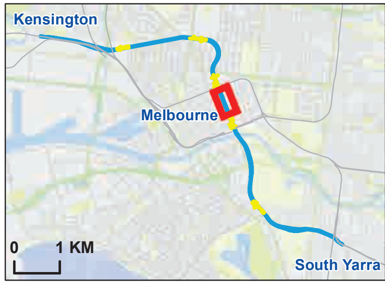
G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd


## Legend

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

Map 8 of 13




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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## Melbourne Metro Rail Project

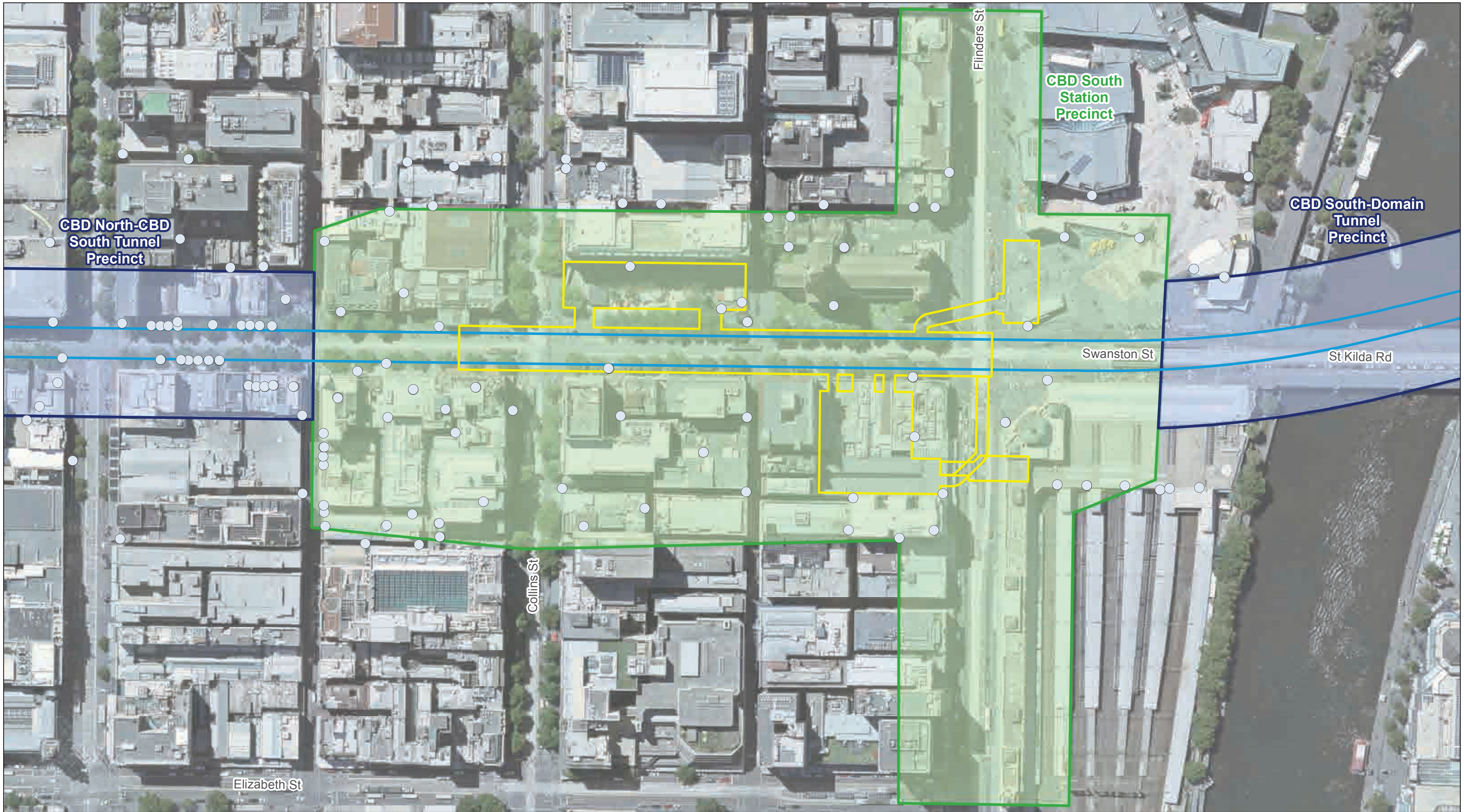
Title:
Mitigated trackform ground-borne noise relative to night target - CBD North to CBD South

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

**Figure E.43: Mitigated Ground-borne Noise Levels due to Trains in Precinct 1: CBD North Station to CBD South Station**

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

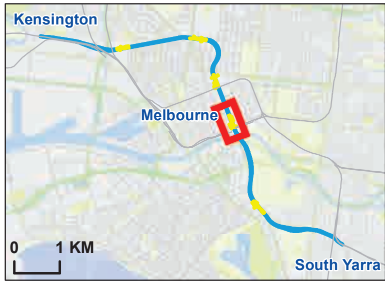



## Legend

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

Map 9 of 13




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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**Melbourne Metro Rail Project**

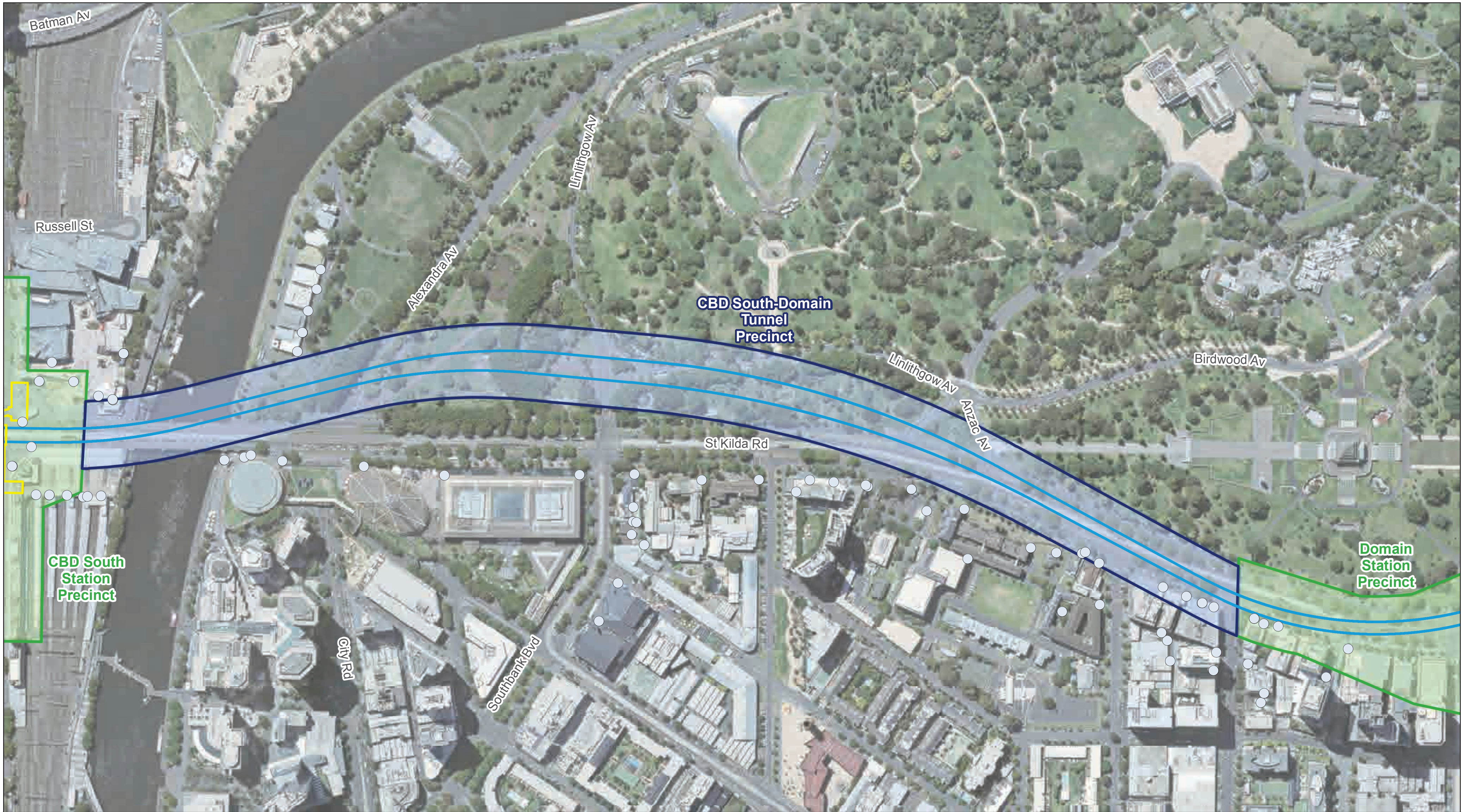
Title:
Mitigated trackform ground-borne noise relative to night target - CBD South Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 7/04/2016 | Map Size: A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

**Figure E.44: Mitigated Ground-borne Noise Levels due to Trains in Precinct 6: CBD South Station**

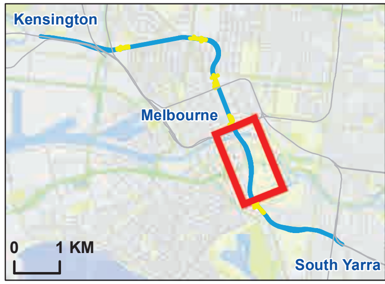



**Legend**

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

**Map 10 of 13**




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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## Melbourne Metro Rail Project

Title:
Mitigated trackform ground-borne noise relative to night target - CBD South to Domain

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

**Figure E.45: Mitigated Ground-borne Noise Levels due to Trains in Precinct 1: CBD South Station to Domain Station**

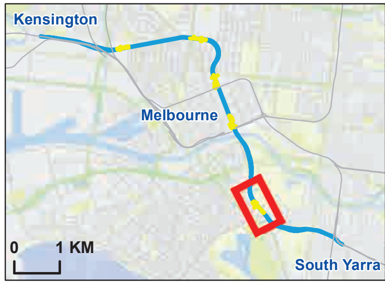
G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd


**Legend**

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct

**Map 11 of 13**




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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## Melbourne Metro Rail Project

Title:
Mitigated trackform ground-borne noise relative to night target - Domain Station

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: A. Davy | Approved By: D. Timms | Date: 7/04/2016 | Map Size: A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

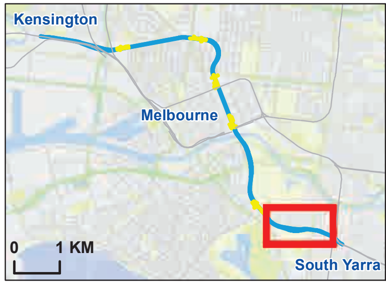
**Figure E.46: Mitigated Ground-borne Noise Levels due to Trains in Precinct 7: Domain Station**


## Legend

**Mitigated GBN Rating**

- Below preferred guideline target (adverse comment not expected)
- Proposed Station Footprint
- Proposed Alignment
- Tunnels Precinct
- Station Precinct
- Portal Precinct

Map 12 of 13




Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
© State of Victoria 2015;
Aerial photo (DELWP, February 2015)

**Melbourne Metro Rail Project**

Title:
Mitigated trackform ground-borne noise relative to night target - Domain to Eastern Portal

| Drawing Number: | | | Revision: |
|---|---|---|---|
| MMR-AJM-UGAA-MP-NO-500333 | | | P1 |
| Drawn By: | Approved By: | Date: | Map Size: |
| A. Davy | D. Timms | 7/04/2016 | A4 |

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Mitigated_GBN.mxd

**Figure E.47: Mitigated Ground-borne Noise Levels due to Trains in Precinct 1: Domain Station to Eastern Portal**

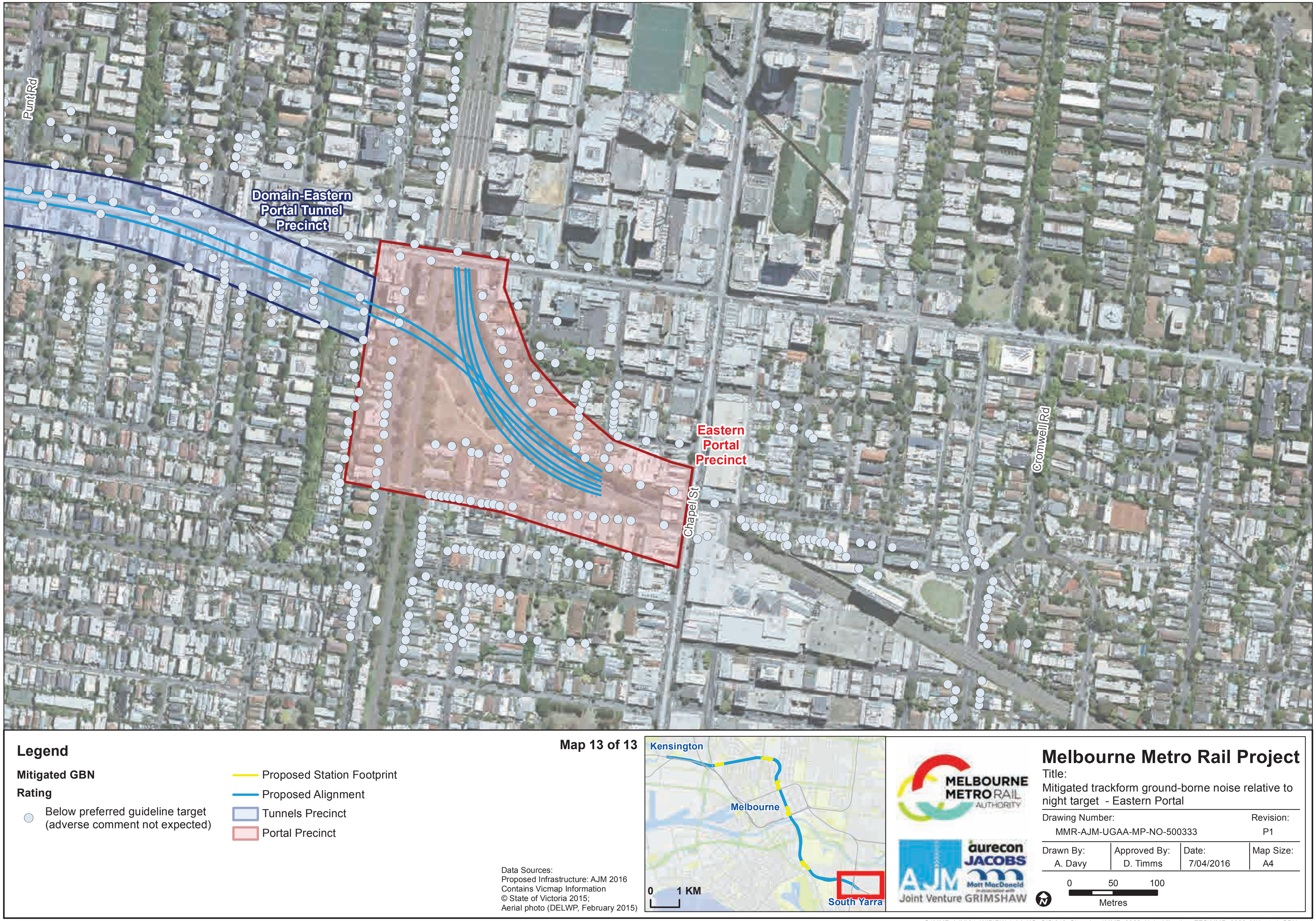



Figure E.48: Mitigated Ground-borne Noise Levels due to Trains in Precinct 8: Eastern Portal

There is also a significant extent of vibration-sensitive equipment and highly sensitive areas in the vicinity of the alignment at Parkville and at RMIT. These have been assessed separately and the results are provided in Table E.9 - Table E.11. Note that the guideline target for the vibration assessment is taken to be the greater of the VC-curve and baseline measurement (where available). The vibration predictions relate the impact of the rail operation only.

**Table E.9: Vibration predictions for vibration-sensitive equipment and highly sensitive areas**

| Location | Vibration-sensitive Equipment | Vibration criteria curve (better than) | Baseline measurements (better than or equal to) | Vibration predictions | | Comments |
|---|---|---|---|---|---|---|
| | | | | Unmitigated (predicted level) | Mitigated (predicted level) | |
| **Royal Women's Hospital** | | | | | | |
| **Level 1 adjacent to Grattan Street** | CT Scanner<br>MRI | VC-A *50 µm/s*<br>VC-C *12.5 µm/s* | VC-B *17 µm/s* | Exceeds (70 µm/s) | Complies (5 µm/s) | Equipment was not impacted upon by VCCC construction |
| **Level 2: Infertility** | Microscopy | VC-A *50 µm/s* | N/A | Exceeds (56 µm/s) | Complies (4 µm/s) | |
| **Level 3: Theatres** | Typical equipment | Operating Room *100 µm/s* | N/A | Complies (44 µm/s) | Complies (3 µm/s) | |
| **Royal Melbourne Hospital, Building** | | | | | | |
| **Ground Level** | MRI (1.5 T), MRI (1 T)<br>CT<br>Ultra sound, Mammography | VC-C *12.5 µm/s*<br>VC-A *50 µm/s*<br>100 *µm/s* | N/A | Exceeds (83 µm/s) | Complies (6 µm/s) | Private Medical Centre Radiology |
| **Ground Level** | Gamma cameras, PET Scanner | VC-A *50 µm/s* | N/A | Complies (46 µm/s) | Complies (4 µm/s) | Adjacent to Royal Parade RMH Nuclear medicine department |
| **Ground Level** | CT scanner, X-ray equipment | VC-A *50 µm/s* | N/A | Complies (36 µm/s) | Complies (3 µm/s) | Emergency Department |
| **Level 1** | MRI (1.5 T, MRI (1 T)<br>CT Scanner | VC-C *12.5 µm/s*<br>VC-A *50 µm/s* | VC-B *13 µm/s* | Exceeds (103 µm/s) | Complies (7 µm/s) | |
| **Level 1** | Sensitive equipment | VC-A *50 µm/s* | N/A | Complies (37 µm/s) | Complies (3 µm/s) | Micro Biology Lab, Haematology |
| **Level 3** | MRI | VC-C *12.5 µm/s* | N/A | Exceeds (35 µm/s) | Complies (3 µm/s) | Cardio and neurology surgery<br>General and Angiography theatres |
| **Level 3** | Operating Theatre | 100 *µm/s* | N/A | Complies (71 µm/s) | Complies (5 µm/s) | Cardio and neurology surgery<br>General and Angiography theatres |
| **Level 5 (north corner)** | MRIs | VC-C *12.5 µm/s* | VC-B *20 µm/s* | Complies (11 µm/s) | Complies (1 µm/s) | |
| **Level 8 East Wing Main Block** | Instrument Lab | VC-A *50 µm/s* | N/A | Complies (13 µm/s) | Complies (1 µm/s) | Belonging to WEHI |
| **Melbourne Private Hospital** | | | | | | |
| **Level 7** | Brain navigation systems | Operating Room *100 µm/s* | Operating Room<br>*63 µm/s* | Complies (11 µm/s) | Complies (1 µm/s) | Operating theatres, Cath lab, Use radiology at RMH |
| **Victorian Comprehensive Cancer Centre** | | | | | | |
| **Basement 2 (Haymarket corner of the building)** | Cyclotron | VC-C *12.5 µm/s* | N/A | Exceeds (53 µm/s) | Complies (4 µm/s) | |
| **Basement 1 (adjacent to Grattan Street)** | Linear accelerators | VC-C *12.5 µm/s* | N/A | Exceeds (152 µm/s) | Complies (10 µm/s) | |
| **Basement 1 (towards Flemington Road)** | CT Scanners | VC-A *50 µm/s* | N/A | Exceeds (74 µm/s) | Complies (5 µm/s) | |
| **Level 4** | MRIs | VC-C *50 µm/s* | N/A | Complies (25 µm/s) | Complies (2 µm/s) | MRIs located in the VCCC have a limit of 50µm/s as specified in *Victorian Comprehensive Cancer Centre Project, Volume 2, Part C,8.13 Technical Specification* (DH-PDOC-F84-C-000_04-150525-rm.docx). |

| Location | Vibration-sensitive Equipment | Vibration criteria curve (better than) | Baseline measurements (better than or equal to) | Vibration predictions | | Comments |
|---|---|---|---|---|---|---|
| | | | | Unmitigated (predicted level) | Mitigated (predicted level) | |
| **Level 5** | MRI,<br>X-ray, Ultrasounds,<br>PET, CT | VC-C *50 µm/s*<br>100 *µm/s*<br>VC-A *50 µm/s* | N/A | Complies (44 µm/s) | Complies (3 µm/s) | |
| **Level 6** | Operating theatre<br>Future MRI | 100 *µm/s*<br>VC-C *50 µm/s* | N/A | Complies (36 µm/s) | Complies (2 µm/s) | |
| **Peter Doherty Institute** | | | | | | |
| **Basement** | Electron microscope for VIDRL | VC-A *50 µm/s*<br>(on floor slab) | VC-C *7 µm/s* | Exceeds (109 µm/s) | Complies (7 µm/s) | Located on independent concrete inertia block with pneumatic isolation.<br>Criterion is based on information from Marshall Day Acoustics Report dated 13 February 2011 Reference SP0032010065. |
| **Level 1** | Genomics room | VC-C *12.5 µm/s* | N/A | Exceeds (64 µm/s) | Complies (4 µm/s) | |
| **Level 7** | Microscopy | VC-A *50 µm/s* | N/A | Complies (24 µm/s) | Complies (2 µm/s) | |
| **Level 8** | Photon | VC-C *12.5 µm/s* | N/A | Complies (22 µm/s) | Complies (1 µm/s) | |
| **University of Melbourne** | | | | | | |
| **Ground, Bio21 Institute** | Electron microscope | VC-D *6 µm/s* | *VC-B 20 µm/s* | Exceeds (21 µm/s) | Complies (2 µm/s) | Electron microscope isolated from structure. |
| **Ground, Building 170** | Laser diagnostics equipment | VC-A *50 µm/s* | N/A | Exceeds (98 µm/s) | Complies (7 µm/s) | |
| **Level 1, Building 170** | Fluoroscopes and Robotic Gantry Equipment | 100 *µm/s* | N/A | Complies (81 µm/s) | Complies (6 µm/s) | |
| **Ground, Building 261** | Helium Ion Microscope | VC-D 6 *µm/s* | N/A | Exceeds (8 µm/s) | Complies (0 µm/s) | |
| **Basement, Building 175** | Network Analysers and Dielectric Permittivity Probes | 200 *µm/s* | N/A | Complies (68 µm/s) | Complies (5 µm/s) | |
| **Ground, Building 165** | Thermal Gravity Analysis | 100 *µm/s* | N/A | Complies (52 µm/s) | Complies (4 µm/s) | |
| **Ground, Building 165** | Sorption Analyser | VC-A *50 µm/s* | N/A | Exceeds (52 µm/s) | Complies (4 µm/s) | |
| **Ground, Building 165** | Nanomaterials Nanoindenter | VC-C *12.5 µm/s* | N/A | Exceeds (52 µm/s) | Complies (4 µm/s) | On air isolated table |
| **Level 1, Building 165** | JPK Nanowizard | VC-C *12.5 µm/s* | N/A | Exceeds (41 µm/s) | Complies (3 µm/s) | |
| **Level 1, Building 165** | 3D Atomic Force Microscope | VC-D 6 *µm/s* | N/A | Exceeds (41 µm/s) | Complies (3 µm/s) | |
| **Level 1, Building 165** | 20nm Resolution Microscope | VC-B *25 µm/s* | N/A | Exceeds (40 µm/s) | Complies (3 µm/s) | On air isolated table |
| **Level 1, Building 165** | 200nm Resolution Microscope | VC-B *25 µm/s* | N/A | Exceeds (42 µm/s) | Complies (3 µm/s) | |
| **Level 2, Building 165** | 3D Atomic Force Microscope | VC-D 6 *µm/s* | N/A | Exceeds (33 µm/s) | Complies (2 µm/s) | On isolation table |
| **Level 3, Building 181** | Confocal Microscope (LEICA SP2) | VC-C 12.5 *µm/s* | VC-B 24 *µm/s* | Complies (2 µm/s) | Complies (1 µm/s) | Vibration Limit from supplier data<br>On isolation table |
| **Ground, Building 181** | Confocal Microscope + UPS | 300 *µm/s* on floor | VC-B 28 *µm/s* | Complies (5 µm/s) | Complies (2 µm/s) | Vibration Limit from supplier data<br>On isolation table |

| Location | Vibration-sensitive Equipment | Vibration criteria curve (better than) | Baseline measurements (better than or equal to) | Vibration predictions | | Comments |
|---|---|---|---|---|---|---|
| | | | | Unmitigated (predicted level) | Mitigated (predicted level) | |
| **RMIT** | | | | | | |
| **Basement, Building 100** | Robotics lab | 100 *µm/s* | N/A | Complies (3 µm/s) | Complies (1 µm/s) | |
| **Level 7, Building 14** | Electron microscope | VC-D *6 µm/s* | N/A | Exceeds (26 µm/s) | Complies (1 µm/s) | |
| **Ground, Building 12** | Acoustic Chambers | *200 µm/s* | N/A | Complies (40 µm/s) | Complies (2 µm/s) | |
| **Ground, Building 7** | The Fib (Ion beam manufacturing tool) | VC-C 12.5 *µm/s* | N/A | Exceeds (18 µm/s) | Complies (1 µm/s) | |
| **RMIT** | Confocal Microscope | VC-C 12.5 *µm/s* | N/A | Complies (9 µm/s) | Complies (1 µm/s) | |
| **RMIT** | NMR Spectrometer | VC-C 12.5 *µm/s* | N/A | Complies (2 µm/s) | Complies (0 µm/s) | |
| **Howard Florey Laboratories** | | | | | | |
| **Basement** | MRI | VC-C *12.5 µm/s* | VC-C *11 µm/s* | Exceeds (51 µm/s) | Complies (4 µm/s) | At Northern end of the building |
| **Walter and Eliza Hall Institute (WEHI)** | | | | | | |
| **Ground Level, WEHI 1** | | VC-C *12.5 µm/s* | N/A | Exceeds (37 µm/s) | Complies (3 µm/s) | Potential Crystallography facility |
| **Level 3C WEHI 1** | Laser and analysis equipment | VC-A *50 µm/s* | N/A | Complies (18 µm/s) | Complies (2 µm/s) | |
| **Level 4C WEHI 1** | High sensitivity microscopes | VC-B *25 µm/s* | VC-A 58 µm/s | Complies (15 µm/s) | Complies (1 µm/s) | |
| **Level 7W WEHI 2** | | VC-A *50 µm/s* | N/A | Complies (9 µm/s) | Complies (1 µm/s) | Structural Biology Crystal Store |
| **Kenneth Myer Building** | | | | | | |
| **Basement Level** | Small bore MRI (4.7 T) | VC-B *25 µm/s* | N/A | Exceeds (26 µm/s) | Complies (2 µm/s) | |
| **Ground Level** | MRI (7 T), PET<br>CT Camera | VC-C *12.5 µm/s*<br>VC-A *50 µm/s* | N/A | Exceeds (26 µm/s) | Complies (2 µm/s) | |
| **All Levels** | Extremely sensitive equipment | VC-C *12.5 µm/s* | N/A | Exceeds (26 µm/s) | Complies (2 µm/s) | Equipment that is extremely sensitive to vibration |
| **Level 1** | Nano PET | VC-C *12.5 µm/s* | N/A | Exceeds (21 µm/s) | Complies (2 µm/s) | Some equipment is pneumatically isolated |
| **Level 2** | 2 photon microscopes | VC-C *12.5 µm/s* | N/A | Exceeds (17 µm/s) | Complies (2 µm/s) | Equipment pneumatically isolated |
| **Level 3** | Advanced microscopy | VC-B *25 µm/s* | N/A | Complies (13 µm/s) | Complies (1 µm/s) | Advance microscopy<br>Equipment pneumatically isolated |
| **Level 4** | Mass spectroscopy | VC-C *12.5 µm/s* | N/A | Complies (10 µm/s) | Complies (1 µm/s) | Mass spectroscopy |
| **Level 7** | Sensitive equipment | VC-A *50 µm/s* | N/A | Complies (7 µm/s) | Complies (1 µm/s) | Equipment pneumatically isolated |
| **University High School** | | | | | | |
| **Gene Technology Access Centre** | Scanning Electron Microscope | VC-C *25 µm/s* | N/A | Exceeds (27 µm/s) | Complies (3 µm/s) | In the Pittard Room (desk-mounted teaching resource) |

List in Table E.9 is representative of the most sensitive equipment at closest proximity to the alignment.  Other vibration-sensitive equipment may also be present at some sites.
AHSRAE does not provide vibration criteria for all of the sensitive equipment that is listed in this table.  The following assumptions have been made with regards to equipment that is not listed in AHSRAE:

1. It is assumed that bio-resource facilities must comply with the VC curve for laboratories VC-A curve *50 µm/s*
2. It is assumed that X-Rays, Ultrasound, Mammography, Gamma Cameras must comply with the VC curve for laboratories VC-A curve *50 µm/s*
3. It is assumed that generally sensitive equipment must comply with VC-A curve *50 µm/s*
4. It is assumed that PET scanners and Mass Spectroscopy machines have similar vibration requirements to MRI machines (VC-C *12.5 µm/s*).  Information has been provided in DH-PDOC-F84-C-000_04-150525-rm VCCC Technical Specification Volume 2 part C that MRI facilities in the VCCC would be assessed to VC-A.
5. It is assumed that CT scanners must comply with the VC-A curve *50 µm/s*
6. It is assumed that hospital operating rooms are **not** used for microsurgery, eye surgery, or neurosurgery (i.e. they can be classified as a standard "Operating Room" *100 µm/s*)
7. It is assumed that all electron microscopes have a magnification of 30,000 x or greater (VC-D *6 µm/s*)
8. It is assumed that Photon Microscopes, Crystallography sites, Linear accelerators and Cyclotrons have similar vibration requirements to Electron microscopes and MRIs (VC-C *12.5 µm/s*)
9. It is assumed that general microscopes (for which the magnification is not listed are assumed) must comply with VC-A curve *50 µm/s*
10. It is assumed that advanced or sensitive microscopes (for which the magnification is not listed are assumed) must comply with VC-B curve *25 µm/s*

**Table E.10: Operational vibration and ground-borne noise predictions for highly sensitive areas**

| Location | Highly Sensitive Area | VDV Guideline Target ($m/s^{1.75}$) | Ground-borne Noise Guideline Target (dBA) | Unmitigated Trackform | | | Mitigated Trackform | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Vibration - Day VDV ($m/s^{1.75}$) | Vibration - Night VDV ($m/s^{1.75}$) | Ground-borne Noise (dBA) | Vibration - Day VDV ($m/s^{1.75}$) | Vibration - Night VDV ($m/s^{1.75}$) | Ground-borne Noise (dBA) | |
| **Royal Women's Hospital** | | | | | | | | | | |
| **Level 4** | Wards | 0.1 | 35 | Complies (0.02) | Complies (0.03) | Exceeds (39) | Complies (0.00) | Complies (0.01) | Complies (<20) | |
| **Level 5** | Staff Accommodation | 0.1 | 35 | Complies (0.02) | Complies (0.03) | Exceeds (37) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Level 7** | Maternity | 0.1 | 35 | Complies (0.02) | Complies (0.02) | Complies (35) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Royal Melbourne Hospital** | | | | | | | | | | |
| **Level 2** | ICU | 0.1 | 35 | Complies (0.04) | Complies (0.05) | Exceeds (45) | Complies (0.01) | Complies (0.01) | Complies (<20) | |
| **Level 3** | Ward 3S | 0.1 | 35 | Complies (0.03) | Complies (0.04) | Exceeds (43) | Complies (0.01) | Complies (0.01) | Complies (<20) | |
| **Level 5** | Ward 5S | 0.1 | 35 | Complies (0.02) | Complies (0.03) | Exceeds (39) | Complies (0.00) | Complies (0.01) | Complies (<20) | |
| **Level 6** | Ward 6S | 0.1 | 35 | Complies (0.02) | Complies (0.02) | Exceeds (38) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Level 7** | Ward 7S | 0.1 | 35 | Complies (0.01) | Complies (0.02) | Exceeds (37) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Level 2** | Cardiology ward 2b | 0.1 | 35 | Complies (0.04) | Complies (0.05) | Exceeds (46) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Level 2** | Ward 2W | 0.1 | 35 | Complies (0.02) | Complies (0.02) | Exceeds (36) | Complies (0.00) | Complies (0.01) | Complies (<20) | |
| **Level 5** | Ward 5E | 0.1 | 35 | Complies (0.01) | Complies (0.01) | Complies (30) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Level 7** | Ward 7W | 0.1 | 35 | Complies (0.01) | Complies (0.01) | Complies (28) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Level 9** | Ward 9E & 9W | 0.1 | 35 | Complies (0.01) | Complies (0.01) | Complies (26) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Victorian Comprehensive Cancer Centre** | | | | | | | | | | |
| **Level 1** | Country Patient Accommodation | 0.1 | 35 | Complies (0.05) | Complies (0.06) | Exceeds (47) | Complies (0.01) | Complies (0.01) | Complies (<20) | |
| **Level 3** | Medical Ward | 0.1 | 35 | Complies (0.03) | Complies (0.04) | Exceeds (43) | Complies (0.01) | Complies (0.01) | Complies (<20) | |
| **Level 5** | Haematology Ward | 0.1 | 35 | Complies (0.02) | Complies (0.02) | Exceeds (39) | Complies (0.00) | Complies (0.01) | Complies (<20) | |
| **Level 6** | Surgical Ward | 0.1 | 35 | Complies (0.02) | Complies (0.02) | Exceeds (38) | Complies (0.00) | Complies (0.00) | Complies (<20) | |
| **Peter Doherty Institute** | | | | | | | | | | |
| **Ground** | Auditorium | 0.4 | 40 | Complies (0.04) | Complies (0.06) | Exceeds (46) | Complies (0.01) | Complies (0.01) | Complies (<20) | |

Table E.11: Operational vibration and ground-borne noise predictions for highly sensitive areas containing biological resources

| Location | Ground-borne Noise Guideline Target | Measured Ground-borne Noise ($L_{eq}$) | Unmitigated Trackform | | Mitigated Trackform | | Comments |
|---|---|---|---|---|---|---|---|
| | | | Vibration | Ground-borne Noise | Vibration | Ground-borne Noise | |
| **Walter and Eliza Hall Institute** | | | | | | | |
| **Level 1C, WEHI 1** | 50 dBL (>500Hz) | N/A | Complies (14 µm/s) | Complies (<50 dBL) | Complies (3 µm/s) | Complies (<50 dBL) | |
| **Level 2, WEHI 2** | 50 dBL (>500Hz) | N/A | Complies (11 µm/s) | Complies (<50 dBL) | Complies (2 µm/s) | Complies (<50 dBL) | |
| **Level 4C, WEHI 1** | 50 dBL (>500Hz) | 61 dBL | Complies (7 µm/s) | Complies (<50 dBL) | Complies (1 µm/s) | Complies (<50 dBL) | |
| **Royal Melbourne Hospital** | | | | | | | |
| **Basement** | 50 dBL | 78 dBL | Complies (39 µm/s) | Complies (68 dBL) | Complies (6 µm/s) | Complies (52 dBL) | |
| **Level 6** | 50 dBL (>500Hz) | 60 dBL | Complies (6 µm/s) | Complies (<50 dBL) | Complies (1 µm/s) | Complies (<50 dBL) | |
| **Peter Doherty Institute** | | | | | | | |
| **Level 8** | 50 dBL (>500Hz) | N/A | Complies (10 µm/s) | Complies (<50 dBL) | Complies (1 µm/s) | Complies (<50 dBL) | |
| **Level 9** | 50 dBL (>500Hz) | N/A | Complies (8 µm/s) | Complies (<50 dBL) | Complies (1 µm/s) | Complies (<50 dBL) | |
| **Level 9** | 50 dBL | 70 dBL | Complies (8 µm/s) | Complies (54 dBL) | Complies (1 µm/s) | Complies (37 dBL) | |
| **Howard Florey Laboratories** | | | | | | | |
| **Ground Floor** | 50 dBL (>500Hz) | N/A | Complies (24 µm/s) | Complies (<50 dBL) | Complies (4 µm/s) | Complies (<50 dBL) | |
| **Level 3** | 50 dBL (>500Hz) | N/A | Complies (12 µm/s) | Complies (<50 dBL) | Complies (2 µm/s) | Complies (<50 dBL) | |
| **Level 4** | 50 dBL (>100Hz) | N/A | Complies (10 µm/s) | Complies (46 dBL) | Complies (2 µm/s) | Complies (13 dBL) | |
| **Level 5** | 50 dBL (>100Hz) | N/A | Complies (8 µm/s) | Complies (44 dBL) | Complies (1 µm/s) | Complies (12 dBL) | |
| **Level 7** | 50 dBL (>500Hz) | N/A | Complies (6 µm/s) | Complies (<50 dBL) | Complies (1 µm/s) | Complies (<50 dBL) | |
| **University of Melbourne Faculty of Medicine** | | | | | | | |
| **Level 9** | 50 dBL (>500Hz) | 49 dBL | Complies (9 µm/s) | Complies (<50 dBL) | Complies (1 µm/s) | Complies (<50 dBL) | |
| **Level 9** | 50 dBL (>500Hz) | 45 dBL | Complies (9 µm/s) | Complies (<50 dBL) | Complies (1 µm/s) | Complies (<50 dBL) | |
| **Victorian Comprehensive Cancer Centre** | | | | | | | |
| **Level 4** | 50 dBL (>500Hz) | N/A | Complies (26 µm/s) | Complies (<50 dBL) | Complies (4 µm/s) | Complies (<50 dBL) | |
| **Level 8** | 50 dBL (>500Hz) | N/A | Complies (14 µm/s) | Complies (<50 dBL) | Complies (2 µm/s) | Complies (<50 dBL) | |

The following guideline targets have been used to assess biological resources:

1. Vibration guideline target is 50µm/s
2. Ground-borne noise guideline target is the maximum of 50dBL with a frequency limit specific to each site/biological resource and the measured ambient noise level with the same frequency restriction

## E.6 Mitigation

The operational vibration and ground-borne noise levels for the project are predicted to exceed guideline target levels for much of the alignment using 'standard attenuation' track. Higher performing track vibration isolation is proposed in order to achieve compliance with the guideline targets. The resultant trackform mitigation is a mix of 'standard attenuation', 'high attenuation' and 'very high attenuation' track with properties as described in Section E.3.3. The extent of the three trackforms predicted to be required in order to achieve compliance with vibration and ground-borne noise guideline targets is presented graphically in Figure E.49. Areas of the alignment shown in red represent 'standard attenuation' track (direct fix track with standard resilient fasteners or 'booted' sleepers with standard resilience), green represents 'high attenuation' track (direct fix track with highly resilient fasteners or 'booted' sleepers with highly resilient boot). The blue areas indicate 'very high attenuation' track (floating track slab or equivalent). The chainages relating to each trackform type in the Concept Design are summarised in Table E.12 along with the geotechnical conditions and approximate cover above the tunnel crown relating to each interval.

Based on the results presented in Section E.4 approximately 14 per cent of the alignment is expected to require 'standard attenuation' track, approximately 45  of the alignment is expected to require 'high attenuation' track and 41 per cent is expected to require 'very high attenuation' track. It is noted that these percentages may change during the detailed design stage as vibration models are refined.

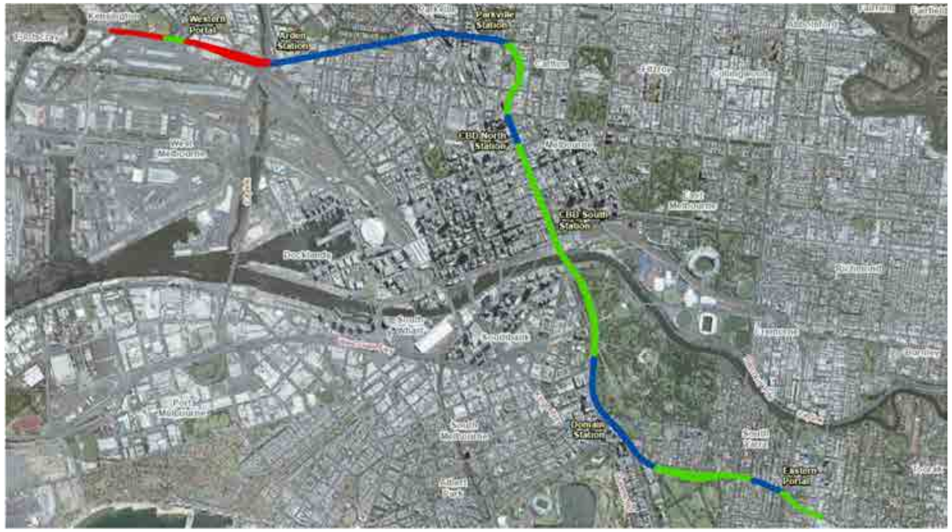



**Figure E.49: Graphical representation of the extent of trackform mitigations (red - 'standard attenuation', green - 'high attenuation', blue - 'very high attenuation')**

**Table E.12: Extent of trackform mitigation by chainage**

| Tunnel Precinct and Approximate Chainage | Geotechnical Conditions | Cover Above Tunnel Crown (m) | Standard Attenuation Track (m) | High Attenuation Track (m) | Very High Attenuation Track (m) |
|---|---|---|---|---|---|
| **Western Portal** | | | | | |
| **94,580 – 95,100** | Fill / Coode Island Silt | 0 | 520 | | |
| **95,100 – 95,300** | Tertiary Older Volcanoes | 0 - 10 | | 200 | |
| **95,300 – 96,150** | Tertiary Older Volcanoes / Werribee Formation | 10 - 22 | 850 | | |
| **Arden** | | | | | |
| **96,150 – 96,800** | Coode Island Silt / Fisherman's Bend Silt/ Alluvium | 11 - 15 | | | 650 |
| **96,800 – 98,150** | Werribee Formation and Tertiary Older Volcanoes transitioning to Highly Weathered to Moderately Weathered Melbourne Formation | 12 - 20 | | | 1350 |
| **Parkville** | | | | | |
| **98,150 – 98,450** | Highly Weathered to Moderately Weathered Melbourne Formation | 16 - 22 | | | 300 |
| **98,450 – 99,200** | Highly Weathered to Moderately Weathered Melbourne Formation Overlaying Slightly Weathered to Fresh Melbourne Formation | 23 - 38 | | 750 | |
| **99,200 – 99,400** | Highly Weathered to Moderately Weathered Melbourne Formation Overlaying Slightly Weathered to Fresh Melbourne Formation | 33 - 34 | | | 200 |
| **CBD North** | | | | | |
| **99,400 – 99,500** | Highly Weathered to Moderately Weathered Melbourne Formation Overlaying Slightly Weathered to Fresh Melbourne Formation | 33 | | | 100 |
| **99,500 – 100,350** | Highly Weathered to Moderately Weathered Melbourne Formation Overlaying Slightly Weathered to Fresh Melbourne Formation | 23 - 33 | | 850 | |
| **CBD South** | | | | | |
| **100,350 – 101,700** | Highly Weathered to Moderately Weathered Melbourne Formation Overlaying Slightly Weathered to Fresh Melbourne Formation transitioning though complex silts at the Yarra River  to Tertiary Brighton Group | 7 - 23 | | 1350 | |

| Tunnel Precinct and Approximate Chainage | Geotechnical Conditions | Cover Above Tunnel Crown (m) | Standard Attenuation Track (m) | High Attenuation Track (m) | Very High Attenuation Track (m) |
|---|---|---|---|---|---|
| **101,700 – 102,350** | Residual to Extremely Weathered Melbourne Formation overlaying Highly Weathered to Moderately Weathered Melbourne Formation | 5 | | | 650 |
| **Domain** | | | | | |
| 102,350 – 103,000 | Tertiary Brighton Group Formation overlaying Residual to Extremely Weathered Melbourne Formation | 7 - 18 | | | 650 |
| 103,000 – 103,950 | Tertiary Brighton Group and Highly Weathered to Moderately Weathered Melbourne Formation | 12 | | 950 | |
| 103,950 – 104,250 | Tertiary Brighton Group overlaying Highly Weathered to Moderately Weathered Melbourne Formation | 10 | | | 300 |
| **Eastern Portal** | | | | | |
| 104,250 – 104,700 | Tertiary Brighton Group overlaying Devonian Granite | 0 | | 450 | |
| **Total** | | | **1370** | **4550** | **4200** |

## E.7 Discussion

Modelling predicts that for 'standard attenuation' trackform there is compliance across the alignment with respect to the 'Maximum' VDV human comfort vibration guideline target, but a small number of exceedances of the 'Preferred' VDV human comfort guideline target. Using 'standard attenuation' track there are predicted to be wide-spread exceedances of ground-borne noise guideline targets. By using a mix of 'standard attenuation', 'high attenuation' and 'very high attenuation' track the human comfort related vibration and ground-borne noise guideline targets are predicted to be met throughout the alignment.

Exceedances of vibration and ground-borne noise guideline targets are predicted for vibration-sensitive equipment and highly sensitive areas in the Parkville Station Precinct when using 'standard attenuation' track. Mitigation of vibration impacts for vibration-sensitive equipment and highly sensitive areas at Parkville is predicted to require a floating slab track with 'very high attenuation' properties. With mitigation the vibration and ground-borne noise levels predicted at all sensitive instrumentation and highly sensitive area receivers at Parkville comply with the guideline targets.

Further optimisation of vibration mitigation may be possible with refinement of the prediction model during detailed design. A range of trackform solutions having equivalent vibration isolation performance to those used in this assessment may be selected during detailed design in order to account for buildability, maintenance and other parameters.

It is recommended that the ground vibration propagation characteristics be verified by direct measurement at the construction stage following development of the tunnel.

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