Appendix B. Construction: Vibration and Ground-borne Noise

B.1 Introduction

B.1.1 Description of the Construction Works that are Relevant to Vibration

Construction activities on the Melbourne Metro Rail Project (Melbourne Metro) have been divided into two broad categories: 1) Tunnelling, and 2) Additional Construction Works.

The Tunnelling and Additional Construction Works are described below.

B.1.1.1 Tunnelling Works

Underground tunnelling activities are proposed to occur along the Melbourne Metro alignment and consist of:

- Tunnel Boring Machines (TBM) for tunnelling along the alignment between the western portal and CBD North station as well between CBD South station and the Eastern Portal. The TBMs are large cylindrical machines with a rotating cutting wheel at the head of the machine. TBMs typically produce less vibration and fewer disturbances than traditional drilling and blasting techniques
- Road headers for mining the section of tunnel between CBD North and CBD South stations. Road headers consist of a cutting head which is mounted on a boom
- Road headers for excavating the two cavern stations; CBD North and CBD South.

When viewing the results of the vibration assessment, it is important to note that the “Tunnelling works” include the road header excavation of the CBD North and South station caverns. Results contained under the heading of “Tunnelling works” do not relate to excavation works that are to be completed using piling rigs, excavators, rippers and rock breakers.

The alignment of the Melbourne Metro tunnel is shown in Figure B.1 in blue. The red dots show buildings that are above or near to the tunnel alignment.

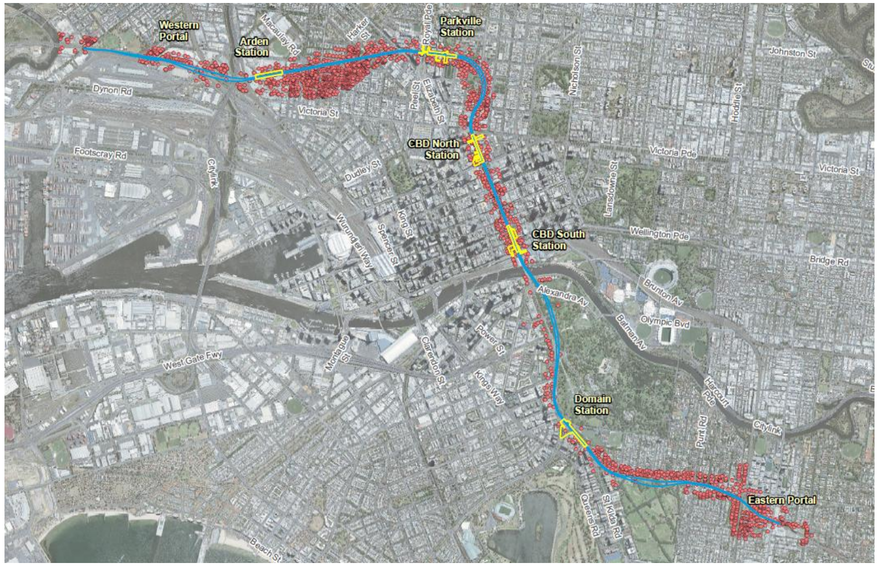


Figure B.1: Melbourne Metro Tunnel Alignment. The Tunnel alignment is shown in blue. The receiver sites are represented by red dots.

B.1.1.2 Additional Construction Works

The Additional Construction Works include all non-tunnelling construction activities (for example they include construction of the stations and construction of TBM launch / recovery sites). The locations where the Additional Construction Works are to take place are shown in Figure B.2.

The equipment that is relevant to vibration as part of the Additional Construction Works is listed in Table B.1

Most of the above ground equipment (e.g. piling rigs, hydromills) would be operated during Normal Working Hours of 7 am to 6 pm week days and 8 am to 1 pm Saturdays. At many of the construction sites it is expected that underground works (including excavation and rockbreaking) would occur 24 hours a day and 7 days a week once the station roofs have been constructed. Exceptions to this are the Western Portal, Fawkner Park and Eastern Portal construction sites where works are anticipated to occur during Normal Working Hours.

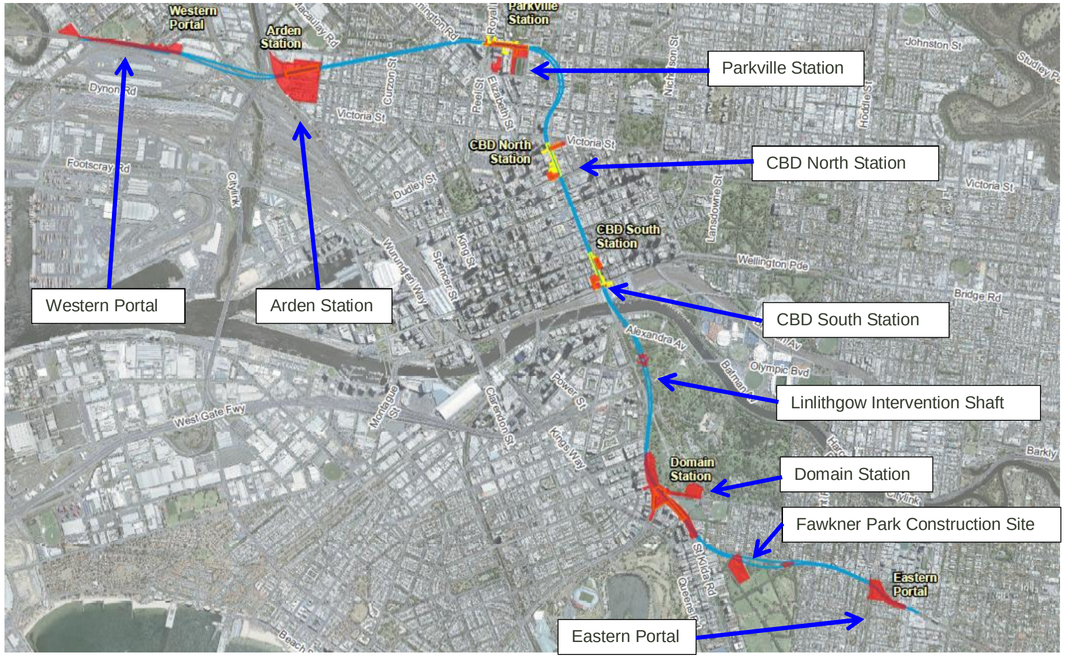


Figure B.2: Melbourne Metro Additional Construction Work sites. Construction sites are marked in red. The tunnel alignment is shown in blue.

Table B.1: Construction equipment that is relevant to vibration.

Location / Precinct	Key vibration generating equipment							
	Excavator with hydraulic rock breaker	**Piling Rig (bored)**	**Clam shovel (diaphragm walls)**	**Hydromill (diaphragm walls)**	**Excavator with ripper attachment**	**Excavator**	**Heavy vehicles** (eg concrete trucks, spoil removal trucks, material delivery trucks)	**Fixed plant** (eg water treatment, concrete batching, de-sanding plant)
Western Portal	o	o				o	o	o
Arden Station		o				o	o	o
Parkville Station	o	o			o	o	o	o
CBD North	o	o			o	o	o	o
CBD South	o	o	o	o	o	o	o	o
Linlithgow Avenue Emergency Access Shaft	o	o				o	o	o
Domain	o	o	o	o		o	o	o
Fawkner Park construction site	o	o				o	o	o
Eastern Portal	o	o				o	o	o

B.1.2 Overview of the Potential Impacts of Vibration Caused by the Construction Works

The construction equipment used for tunnelling and station excavation is predicted to cause ground vibration. Some construction activities are predicted to cause vibration which at times would be perceptible to receivers that are located near to the construction activities and tunnels. At other times the vibration may not be perceptible.

Ground vibration during construction may have a number of potential impacts on receiver locations that are situated near to the construction activities. Potential impacts of ground vibration are:

- **Building damage:** Major structural damage is rarely a concern from construction activities. Damage to building structures only occurs when buildings are exposed to intense shock loads from blasting or driven piling from within a few meters. Some of the equipment that would be used on the Melbourne Metro has the potential to cause minor cosmetic damage such as cracking of plaster and rattling of windows and other fragile objects. Predictions have been undertaken to estimate ground vibration levels in buildings and structures that are located near to construction activities to identify locations where there is potential for minor cosmetic damage to buildings. In those instances where there is a potential for minor cosmetic damage to buildings, lower vibration construction techniques have been recommended. In the assessment of building damage, particular emphasis has been placed on heritage listed sites.
- **Human comfort:** There is potential for ground vibration to have an impact on the comfort of people living or working near to construction activities. When ground vibrations exceed the threshold of perception people may experience some level of annoyance. The potential for impact on human comfort from construction vibration has been assessed. Mitigation steps have been identified where construction activities are predicted to impact on human comfort.
- **Ground-borne noise:** Ground-borne noise can also have an impact upon human comfort. Ground-borne noise is noise caused by ground vibration and is typically characterised as low frequency "rumbling" noise. Potential sources of ground-borne noise include trains, buses on rough roads, and vibration intensive construction activities. There is a distinction between ground-borne noise and airborne noise. Ground-borne noise is caused by ground vibration and is typically characterised as low frequency "rumbling" noise (as mentioned above). Airborne noise on the other hand describes noise transmitted through the air. This section of the report deals with ground-borne noise only. An airborne noise impact assessment has been completed for the Melbourne Metro and details of that assessment may be found in the main body of this report and in Appendix A.

  The potential for human discomfort due to ground-borne noise during the Melbourne Metro construction works has been assessed and additional mitigation has been recommended where ground-borne noise is predicted to impact upon the comfort of receivers in the vicinity of the construction sites.
- **Impacts on vibration-sensitive equipment:** There is potential for ground vibration to impact upon vibration-sensitive equipment. Vibration-sensitive equipment includes medical equipment such as MRI machines and research laboratory equipment such as high power microscopes. The functionality of vibration-sensitive equipment may be degraded if ground vibration and building vibrations exceed certain levels. The vibration levels specified for these items of equipment can be many times lower than the level of human perception. This means that vibration-sensitive equipment can be affected by low levels of vibration that people cannot detect.

  There are a number of research laboratories and medical facilities in the Parkville and CBD North station precincts that house vibration-sensitive equipment. The potential exists for sensitive equipment to be affected by vibration from the construction works that are to be undertaken in Parkville and CBD North (RMIT) and this has been assessed.

B.1.3 Overview of the Vibration and Ground-borne Noise Assessment Methodology

Details of a desktop study that has been undertaken to predict the vibration and ground-borne noise levels at buildings in the vicinity of the tunnel alignment and station construction sites are provided. Management actions have been recommended where receivers are predicted to be impacted.

An overview of the desktop assessment methodology is given as follows:

1. Guideline targets for vibration and ground-borne noise were established using Australian and international standards and guidelines
2. Vibration source levels were determined for the most vibration intensive equipment that is proposed to be used during construction
3. Predictions were undertaken to determine the reduction of vibration with distance. Predictions were also undertaken to determine how much vibration is transmitted from the ground into buildings. The vibration predictions were completed at approximately 3000 buildings that are located in the vicinity of the rail alignment and construction sites
4. Detailed vibration assessments were completed at receiver locations where the predicted vibration and/or ground-borne noise levels were higher than the guideline targets. The detailed assessments considered additional factors such as existing vibration and ground-borne noise levels and the anticipated duration of the construction works. The detailed assessments aided in determining appropriate management actions for these receivers.

The predictions are based upon the “worst case” vibration levels that are expected to occur during the period of construction. Therefore vibration levels are expected to be lower than the predicted levels for the majority of construction works. The vibration levels that are predicted relate to the point in time at which the most vibration intensive equipment is operating at the minimum distance from each receiver. It is important to note that equipment would not always be operating at that minimum distance. For example, the distance from the tunnelling equipment to a receiver would vary as the tunnelling machines move along the alignment. There would also be changes in the types of construction equipment that are used throughout the construction. For example, rockbreakers would only be required for a portion of the station excavation works (rather than throughout the entire period of construction).

Further details on the guideline targets and the vibration prediction methodology are provided in Sections B.2 and B.3.

B.2 Guideline Targets used to Assess the Potential Impact of Construction Vibration on Structures, Human Comfort and Sensitive Equipment

The guideline targets provided below. These guideline targets were used as a trigger for detailed assessment and development of management actions.

B.2.1 Vibration

Guideline targets for vibration are provided below for:

(i) Damage to Buildings

(ii) Damage to Utilities (eg. sewers, drains)

(iii) Human Comfort

(iv) Vibration-sensitive Equipment.

(i) Damage to Buildings

There are no Victorian or national Australian documents that provide guidance with respect to potential vibration damage to buildings.

DIN 4150-3 Structural Vibration Part 3: Effects of vibration on structures, February 1999, (DIN 4150) has been chosen for the assessment of construction vibration.

DIN 4150 sets vibration levels which *when complied with would not result in damage that would have an adverse effect of the structures 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 and if the risk of damage is determined to be low then higher levels of vibration may be approved. The DIN 4150 values are provided in Table B.2 and Table B.3 for short term and long term vibration respectively.

Table B.2: Guideline values 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 mm/s (Peak Component Particle Velocity)
	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 B.3: Guideline values 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) Damage to Utilities

Table B.4: Guideline values for vibration velocity to be used when evaluating the effects of long-term vibration on structures

Utility / Service	Vibration Velocity, mm/s (Peak Component Particle Velocity) at all frequencies
All utilities (unless specified below)	20
Melbourne Water unreinforced structures and pipework	10
South Yarra sewer main	2

(iii) Human Comfort

There is no Victorian or current national Australian 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 not 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 (*NSW Vibration*).

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

NSW 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 *NSW Vibration* (Sections 2.3 and 2.4) has been used, together with the updated vibration targets 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).

The vibration guideline targets (trigger levels for management actions) for continuous (as for TBMs and road headers), intermittent, or impulsive (other than blasting) vibration are provided in Table B.5 and are proposed to be applied for the Melbourne Metro project within the Victorian assessment framework for addressing construction impacts.

Table B.5: Guideline targets for Human Comfort (trigger levels for management actions)

Location	Vibration Dose Value, VDV ($m/s^{1.75}$)			
	Day 7:00 am to 10:00 pm		Night 10:00 pm to 7:00 am	
	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. Guideline vibration targets for Highly Sensitive areas such as hospital operating theatres or precision laboratories are provided below.

(iv) Sensitive Equipment

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 vibration criteria (VC) curves provided by 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 to set targets on the basis of precedent. The VC curves are presented in Figure B.3 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 provided in Table B.6.

The location and type of vibration-sensitive equipment have been identified for the project and site-specific vibration targets derived.

Where targets cannot be achieved, management approaches would need to be implemented so that construction activities do not interfere with the use of vibration-sensitive equipment.

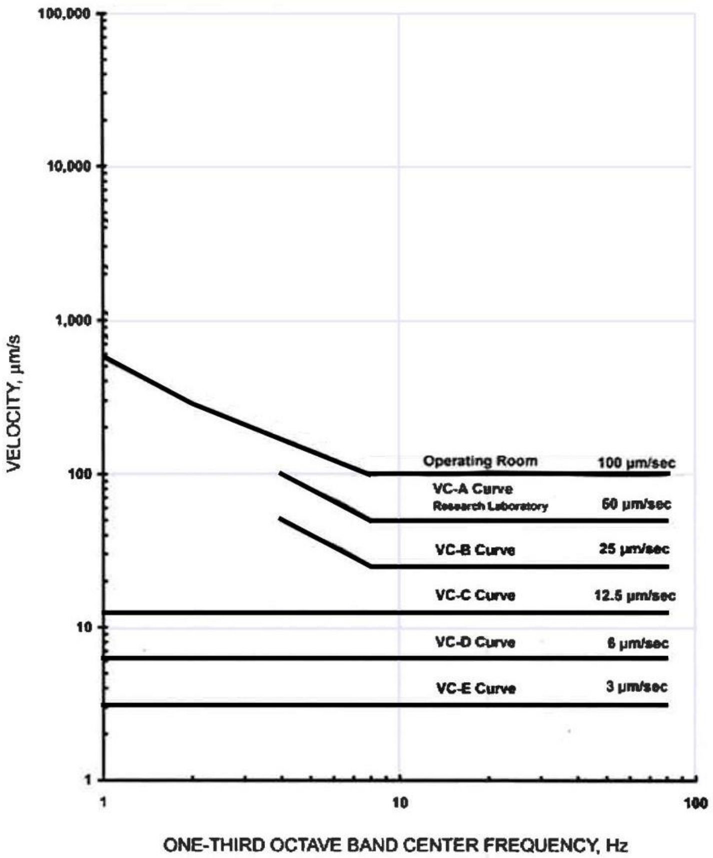


Figure B.3: VC Curves from ASHRAE

Table B.6: Equipment Vibration Guideline Targets - ASHRAE

Equipment Requirements	VC 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 3mm 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 photo-lithography with line widths of ½ micro m; includes electron beam systems	VC-D
Un-isolated 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

B.2.2 Ground-borne Noise

There is no Victorian or national Australian document that provides guidance with respect to construction ground-borne noise. The following guideline which addresses ground-borne noise has been developed in NSW:

- NSW Interim Construction Noise Guideline, Department of Environment and Climate Change, July 2009 (*the Guideline*).

This document has been successfully applied on recent projects in NSW which are similar to the Melbourne Metro. It has been developed by the Department of Environment and Climate Change NSW, the NSW Department of Planning, Roads and Traffic Authority NSW, Work Cover NSW, Health NSW and the Local Government and Shires Associations of NSW. Preparation of the document included extensive public consultation and the view of industry stakeholders were considered along with the Standards Australia committee.

The relevant section of *The Guideline* is Section 4.2. It presents the ground-borne noise trigger levels which indicate when management actions should be implemented. These levels recognise the temporary nature of construction and are to protect the amenity and sleep of people when they are home. It is also proposed that for the Melbourne Metro they be applied to sleeping areas in hospital wards, student accommodation and hotel rooms. The levels are reproduced in Table B.7. It is proposed that the values in Table B.7 (from Section 4.2 of the Guideline) apply for the Melbourne Metro. These are to be applied within the Victorian assessment framework for addressing construction impacts.

Table B.7: Guideline targets for ground-borne noise (trigger levels for management actions)

Time Period	Internal $L_{Aeq,15min}$, dB
Evening, 6pm to 10pm	40
Night, 10 pm to 7am	35

Note:

1. Levels are only applicable when ground-borne noise levels are higher than airborne noise levels
2. The noise levels are assessed at the centre of the most affected habitable room
3. Management Actions include extensive community consultation to determine acceptable level of disruption and provision of respite accommodation in some circumstances.

The Department of Primary Industry Code of Practice for the Housing and Care of Laboratory Mice, Rats, Guinea Pigs and Rabbits provides noise recommends that background noise levels are kept below 50 dBL. Ground-borne noise at locations where biological resources are housed has been compared with either a guideline target of 50 dBL or with existing noise level measurements. In making these assessments, the frequency range relevant to each type of biological resource has been considered.

B.3 Method used to predict vibration and ground-borne noise

B.3.1 Approach

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

- The type of occupancy (residential, commercial, other sensitive use) has been identified for each of the receivers
- A sophisticated spreadsheet modelling tool has been developed based on the Federal Transit Administration (FTA) predictive methodology (the US Department of Transportation FTA document, *Transit Noise and Vibration Impact Assessment* FTA-VA-90-1003-06, FTA 2006) (FTA Guideline)
- Vibration source spectra (one third octave vibration levels) for the TBM and road header have been estimated using a combination of literature-based data along with AJM JV's library of test data
- 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
- The model has been used to predict vibration and ground-borne noise levels for receivers in the vicinity of the rail alignment For the purpose of calculation of Vibration Dose Values (VDV) day has been defined as 7:00 am to 10:00 pm and night has been defined as 10:00 pm to 7:00 am as per BS6472-1:2008
- The predicted vibration and ground-borne noise levels have been compared to the guideline targets for each occupancy type
- Where guideline targets are exceeded, a further analysis has been carried out at one or more of the worst affected receivers to quantify the duration of the exceedance for tunnelling activities.

B.3.2 Vibration Source Levels and Propagation Functions

Tunnelling equipment

Vibration source levels and spectral characteristics are dependent on machine type and size and the ground conditions through which tunnelling is proposed to occur. TBM and road header vibration source levels and spectral characteristics have been determined based on literature and test results for similar size and type machines in comparable soil/rock conditions.

The frequency spectra defined for the TBM and road header are based on the assumption that the majority of vibration is in the 16 to 80 Hz frequency bands.

The ground vibration at the receiver location has been estimated using the formula:

$$PPV = k\frac{d_{ref}}{d}e^{-\alpha(d-d_{ref})}$$

Where PPV = peak particle velocity, in mm/s
k = site/machine specific constant
d_{ref} = reference distance for source vibration data (m)
d = slope distance from the receiver location to the closest edge of the tunnel (m)
α = site specific ground attenuation constant (varies with frequency)

The site/machine specific constants have been selected based on international literature and AJM JV's library of test data, taking into account the expected ground conditions in the Melbourne Metropolitan Area along with machine types and sizes. The mathematical models used are represented graphically in Figure B.4.

These equations are a best fit vibration estimate and vibration measurements should be undertaken at the commencement of work to confirm the mathematical prediction model.

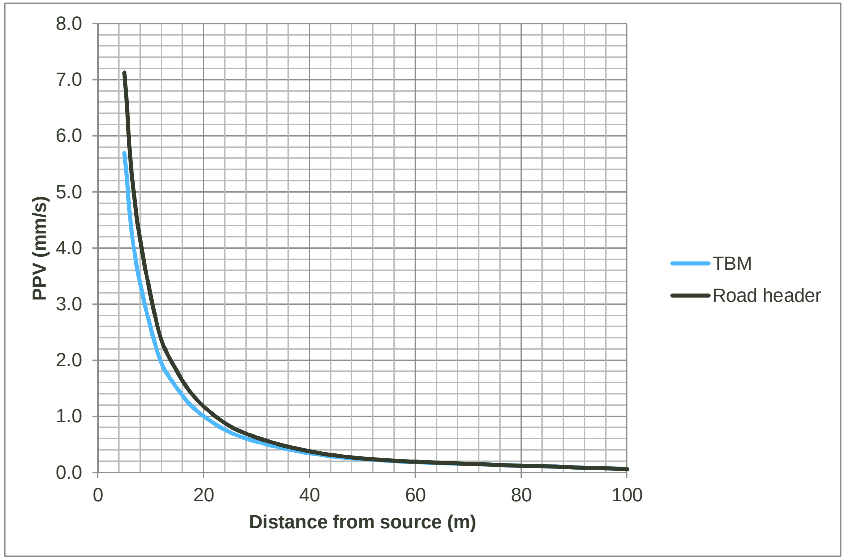


Figure B.4: Ground-borne Vibration Attenuation Models for TBM and Road headers

The vibration adjacent to the receiver location has been estimated by calculating the minimum slope distance from each receiver to the top of the tunnel alignment, as shown in

Figure B.5.

In the minimum slope distances calculations the tunnel diameter has been taken as 5.7 m and the station cavern roof height as 13.5 m above rail height.

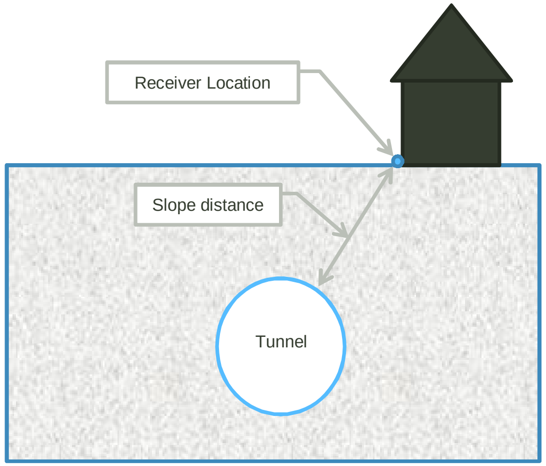


Figure B.5: Slope Distance between Tunnel and Receiver

Additional Construction Works Equipment

Source vibration levels used to model the Additional Construction Works equipment are presented in Table B.8.

Table B.8: Source vibration levels for equipment for Additional Construction Works

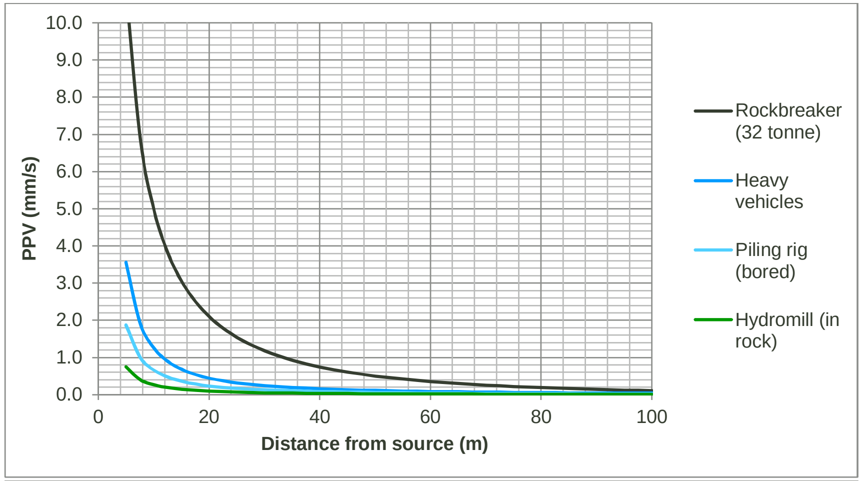
Description of vibration source	PPV at 7.6 m (mm/s)	Reference/Comment
32 tonne excavator with hydraulic rockbreaker	6.9	Based on representative data
20 tonne excavator with hydraulic rockbreaker	4.7	Based on representative data
12-15 tonne excavator with hydraulic rockbreaker	3.3	Based on representative data
7 tonne excavator with hydraulic rockbreaker	2.4	Based on representative data
Excavator with ripper	1.3	Based on representative data
Hydromill in rock (diaphragm wall construction)	0.4	FTA Guideline
Piling rig (bored)	1.0	British Standard BS5228.
Heavy vehicle traffic	1.9	FTA Guideline
Fixed plant	1.9	Expected to be better than or equal to heavy vehicle traffic

For the rockbreakers, the ground vibration at each receiver (adjacent to the building foundation) has been estimated using a relationship similar to that which was used for the tunnelling equipment. Equipment other than rockbreakers has been using the formula from the FTA Guideline:

$$PPV_{Receiver} = PPV_{Ref} \times \left(\frac{d_{ref}}{d}\right)^{1.5}$$

Where $PPV_{Receiver}$ = peak particle velocity at the receiver in mm/s
$PPV_{Equipment\ Ref}$ = peak particle velocity of the source, measured at the reference distance (7.6 m)
d_{ref} = reference distance for the vibration source (7.6 m)
d = horizontal distance from the source to the receiver (m)

The vibration attenuation models are presented graphically in Figure B.6:



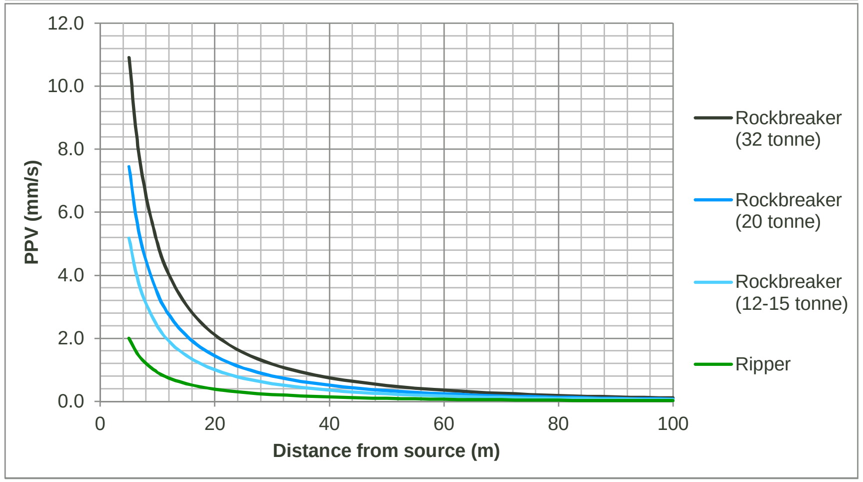


Figure B.6: Vibration attenuation models for equipment associated with Additional Construction Works

At each construction site, vibration has been assessed for the "worst case" (highest vibration) machine. For each receiver, vibration has been assessed with the equipment operating in the "worst case" position (i.e. with the machine positioned as closely as possible to the receiver). In other words, the distance "d" has been predicted as the distance from the location of the receiver to the nearest boundary of the nominated work area.

For most machines, the horizontal distance was used in the prediction. However, the slope distance was used for rockbreakers in order to reflect reductions in vibration that occur when rockbreakers are working deeper underground. The assumed depths of operation for rockbreakers are summarised in Table B.9.

It is important to note that the vibration prediction results are less accurate when machines are extremely close to receiver locations (e.g. less than 5 m). Therefore the Proponent would need to undertake vibration measurements to ensure that the guideline targets are met when vibration critical construction machinery is less than 5 m from the nearest building.

Table B.9: Rockbreaker sizes and depths of operation

Precinct	Assumed geology	Rockbreaker excavator size (tonnes)	Depth (m)
Western Portal	Older Volcanics	12	-
Arden	Coode Island Silt	Not required	-
Parkville	Melbourne Formation (MF4-3)	20	>25
CBD North (Franklin St Excavation)	Melbourne Formation (MF2)	20	10 – 25
CBD North (A'Beckett and Southern Entrance Excavations)	Melbourne Formation (MF2)	20	15 – 25
	Melbourne Formation (MF1)	32	>25
CBD South (City Square and Flinders/Swanston Excavations)	Melbourne Formation (MF2)	20	>20
CBD South (Federation Square Excavation)	Melbourne Formation (MF4-2)	12	>15
Fawkner Park	Melbourne Formation (HW)	Not required	0 – 20
	Melbourne Formation (MW)	20	> 20
Domain	Brighton Group	Not required	0 – 10
	Melbourne Formation (HW)	20	> 10
Eastern portal	Brighton Group	Not required	0 – 10
	Melbourne Formation (HW)	7	> 10

B.3.3 Model

Construction vibration and ground-borne noise levels for the tunnelling have been predicted using the modelling and assessment methodology described in the FTA Guideline (as referenced above), with modifications to allow for the use of point sources such as are typical for the TBM cutting face, road headers, piling equipment etc. The general and detailed FTA Guideline approaches have been used to create a model for the entire alignment.

The overall modelling process has been summarized in the flowchart shown in Figure B.7.

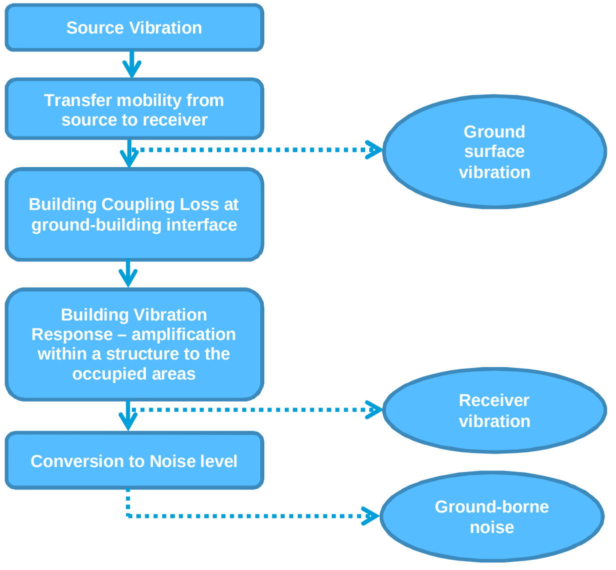


Figure B.7: Construction vibration and ground-borne noise modelling process (based on FTA guideline with modifications)

B.3.4 Vibration Predictions

Predicted levels of vibration at each sensitive receiver have been based on relevant vibration source spectra and vibration propagation functions as presented above, and adjusted for building coupling loss factors and vibration response.

Building Damage

At each receiver point the overall Peak Particle Vibration (PPV) has been calculated for comparison with the guideline targets for structural damage.

Human Comfort

The VDV is dependent on three key parameters:

- Level of vibration
- Spectral content of the vibration
- Duration of operation

VDVs for the TBM have been calculated based on continual operation and VDVs for road headers have been based on 60% operating time. Vibration spectra for these machines is based on data from the literature. The VDV for tunnelling works has been calculated based on the methodology presented in BS6472-1:2008 using weighting Wb (for vertical motion) and the predictions compared to the human comfort vibration trigger for management action.

Where spectral data for the Additional Construction Equipment is not known, the VDV was estimated using the following formula:

$$VDV = 1.4 \times V_{RMS\ Receiver} \times \left(\frac{2 \times \pi \times 31.5 \times 0.49}{1000}\right) \times t^{0.25}$$

Where $V_{RMS\ Receiver}$ = RMS vibration level at the receiver location in mm/s and 't' is the duration of operation in seconds.

This was calculated from the PPV vibration using a crest factor of 4 (consistent with the crest factor used in the FTA guideline). The calculation also included coupling loss factors for the building and amplifications due to building resonance.

This equation assumes that the dominant vibration is at 31.5 Hz (where the BS6472 Wb frequency weighting is 0.49). It is noted that this calculation can lead to conservative VDV estimates.

Sensitive Equipment

For sensitive receivers, the receiver vibration frequency spectrum has been inspected and compared with the relevant VC curve from ASHRAE (and baseline measurements where applicable).

B.3.5 Ground-borne Noise Impact Predictions

For the tunnelling works, the ground-borne noise model is based on the method outlined above for 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 publication – *Measurement and assessment of ground-borne noise and vibration* (Association of Noise Consultants 2012).

Vibration levels for this methodology are RMS (Root Mean Square) values. The relationship between the peak value calculated in the vibration prediction and the RMS level required for the ground-borne noise prediction is a function of the shape of the vibration pulse. For a true sinusoidal vibration the peak vibration must be divided by a factor of 1.4 to obtain RMS units, however for vibration which contains elevated peaks (higher crest factors) this factor may increase to more than 5.

TBM and road header vibration is considered to be continuous in nature, but is not necessarily sinusoidal. A factor of 2.5 has been used for the conversion of peak to RMS vibration levels for the road header, while a factor of 1.4 has been used in the case of the TBM. These factors are considered conservative and therefore likely to produce conservative RMS values as well as conservative results for ground-borne noise.

The calculated 1/3 octave band interior sound pressure levels have been A-weighted, logarithmically summed and converted to overall noise levels for comparison with the guideline ground-borne noise targets for the different occupancy types.

A simplification of this method has been used to predict ground-borne noise for the Additional Construction Works (where estimates of the vibration spectra were not available). The formula used to compute ground-borne noise is (FTA Guideline, Table 10.1):

$$L_{Aeq\ 15min} = 20 \times LOG_{10}\left(\frac{L_V}{2.54^{-5}}\right) - 35$$

Where $L_{Aeq\ 15min}$ = the equivalent noise level over a 15 minute period in dB

L_V = the RMS vibration level in the occupied area (mm/s). The RMS vibration level was calculated from the PPV using a crest factor of 4 (FTA guideline).

Note: This $L_{Aeq\ 15min}$ calculation assumes that that equipment (including heavy vehicle traffic) operates continually. It is expected that actual $L_{Aeq\ 15min}$ values would be lower at construction sites where equipment operates intermittently and vehicular traffic is light.

B.4 Results of Initial Vibration and Ground-borne Noise Assessment for Tunnelling works

Vibration and ground-borne noise has been predicted across the Melbourne Metro alignment. The predictions relate to the highest vibration levels that are predicted to occur at any point in time during the construction. For multiple story buildings, the predictions relate to the vibration levels on the ground floor where vibration levels are expected to be highest. Vibration levels would be lower on higher floors of the multi-story buildings.

The results of the predictions are plotted against tunnel chainage as follows:

- Figure B.8: Predicted vibration levels due to tunnelling at commercial receivers
- Figure B.9: Predicted vibration levels due to tunnelling at residential receivers
- Figure B.10: Predicted VDV – Day levels for Human Comfort due to tunnelling at residential receivers
- Figure B.11: Predicted VDV – Night levels for Human Comfort due to tunnelling at residential receivers
- Figure B.12: Predicted VDV – Day levels for Human Comfort due to tunnelling at commercial & educational receivers
- Figure B.13: Predicted VDV – Night levels for Human Comfort due to tunnelling at commercial & educational receivers
- Figure B.14: Predicted VDV – Day levels for Human Comfort due to tunnelling at workshop receivers
- Figure B.15: Predicted VDV – Night levels for Human Comfort due to tunnelling at workshop receivers
- Figure B.16: Predicted ground-borne noise levels for Human Comfort due to tunnelling at residential receivers

VDV levels and ground-borne noise levels due to the TBM and road header tunnelling are presented as colour coded levels on the Melbourne Metro precinct maps as follows:

- Figure B.17: Colour coded tunnelling VDV (day) levels for Human Comfort for Western Portal Precinct
- Figure B.18: Colour coded tunnelling VDV (day) levels for Human Comfort for Western Portal to Arden Tunnel Precinct
- Figure B.19: Colour coded tunnelling VDV (day) levels for Human Comfort for Arden Station Precinct
- Figure B.20: Colour coded tunnelling VDV (day) levels for Human Comfort for Arden to Parkville Precinct
- Figure B.21: Colour coded tunnelling VDV (day) levels for Human Comfort for Parkville Station Precinct
- Figure B.22: Colour coded tunnelling VDV (day) levels for Human Comfort for Parkville to CBD North Tunnel Precinct
- Figure B.23: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD North Station Precinct
- Figure B.24: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD North and CBD South Tunnel Precinct
- Figure B.25: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD South Station Precinct
- Figure B.26: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD South to Domain Tunnel Precinct
- Figure B.27: Colour coded tunnelling VDV (day) levels for Human Comfort for Domain Station Precinct
- Figure B.28: Colour coded tunnelling VDV (day) levels for Human Comfort for Domain to Eastern Tunnel Precinct
- Figure B.29: Colour coded tunnelling VDV (day) levels for Human Comfort for Eastern Portal Precinct
- Figure B.30: Colour coded tunnelling VDV (night) levels for Human Comfort for Western Portal Precinct
- Figure B.31: Colour coded tunnelling VDV (night) levels for Human Comfort for Western Portal to Arden Tunnel Precinct
- Figure B.32: Colour coded tunnelling VDV (night) levels for Human Comfort for Arden Station Precinct
- Figure B.33: Colour coded tunnelling VDV (night) levels for Human Comfort for Arden to Parkville Tunnel Precinct
- Figure B.34: Colour coded tunnelling VDV (night) levels for Human Comfort for Parkville Station Precinct
- Figure B.35: Colour coded tunnelling VDV (night) levels for Human Comfort for Parkville to CBD North Tunnel Precinct
- Figure B.36: Colour coded tunnelling VDV (night) levels for Human Comfort for CBD North Station Precinct
- Figure B.37: Colour coded tunnelling VDV (night) levels for Human Comfort CBD North and CBD South Tunnel Precinct
- Figure B.38: Colour coded tunnelling VDV (night) levels for Human Comfort for CBD South Station Precinct
- Figure B.39: Colour coded tunnelling VDV (night) levels for Human Comfort for CBD South to Domain Tunnel Precinct
- Figure B.40: Colour coded tunnelling VDV (night) levels for Human Comfort for Domain Station Precinct
- Figure B.41: Colour coded tunnelling VDV (night) levels for Human Comfort for Domain to Eastern Tunnel Precinct
- Figure B.42: Colour coded tunnelling VDV (night) levels for Human Comfort for Eastern Portal Precinct
- Figure B.43: Colour coded tunnelling ground-borne noise levels for Western Portal Precinct
- Figure B.44: Colour coded tunnelling ground-borne noise levels for Western Portal to Arden Tunnel Precinct
- Figure B.45: Colour coded tunnelling ground-borne noise levels for Arden Station Precinct
- Figure B.46: Colour coded tunnelling ground-borne noise levels for Western Portal to Parkville Tunnel Precinct
- Figure B.47: Colour coded tunnelling ground-borne noise levels for Parkville Station Precinct
- Figure B.48: Colour coded tunnelling ground-borne noise levels for Parkville to CBD North Tunnel Precinct
- Figure B.49: Colour coded tunnelling ground-borne noise levels for CBD North Station Precinct
- Figure B.50: Colour coded tunnelling ground-borne noise levels for CBD North and CBD South Tunnel Precinct
- Figure B.51: Colour coded tunnelling ground-borne noise levels for CBD South Station Precinct
- Figure B.52: Colour coded tunnelling ground-borne noise levels for CBD South to Domain Tunnel Precinct
- Figure B.53: Colour coded tunnelling ground-borne noise levels for Domain Station Precinct
- Figure B.54: Colour coded tunnelling ground-borne noise levels for Domain to Eastern Tunnel Precinct
- Figure B.55: Colour coded tunnelling ground-borne noise levels for Western Portal Precinct

VDV levels and ground-borne noise levels due to the road header mining of the CBD North and CBD South station caverns are presented as colour coded levels on the Melbourne Metro precinct maps as follows:

- Figure B.56: Colour coded station cavern mining VDV (day) levels for Human Comfort for CBD North Station Precinct
- Figure B.57: Colour coded station cavern mining VDV (day) levels for Human Comfort for CBD South Station Precinct
- Figure B.58: Colour coded station cavern mining VDV (night) levels for Human Comfort for CBD North Station Precinct
- Figure B.59: Colour coded station cavern mining VDV (night) levels for Human Comfort for CBD South Station Precinct
- Figure B.60: Colour coded station cavern mining ground-borne noise levels for CBD North Station Precinct
- Figure B.61: Colour coded station cavern mining ground-borne noise levels for CBD South Station Precinct

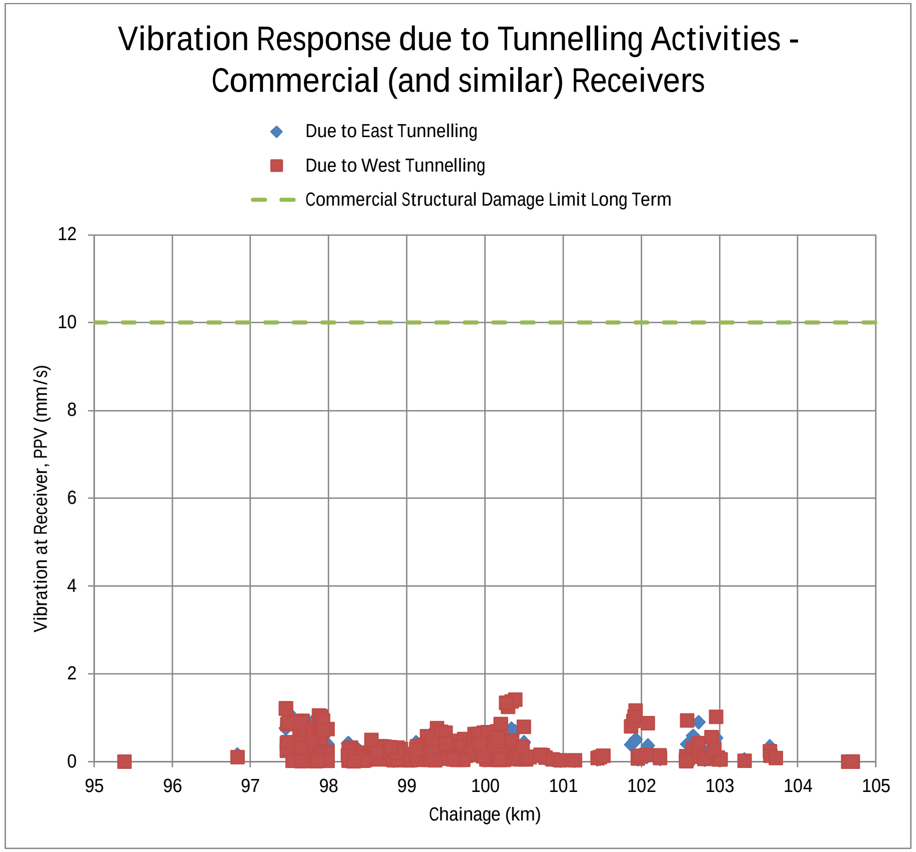


Figure B.8: Predicted vibration levels due to tunnelling at commercial receivers

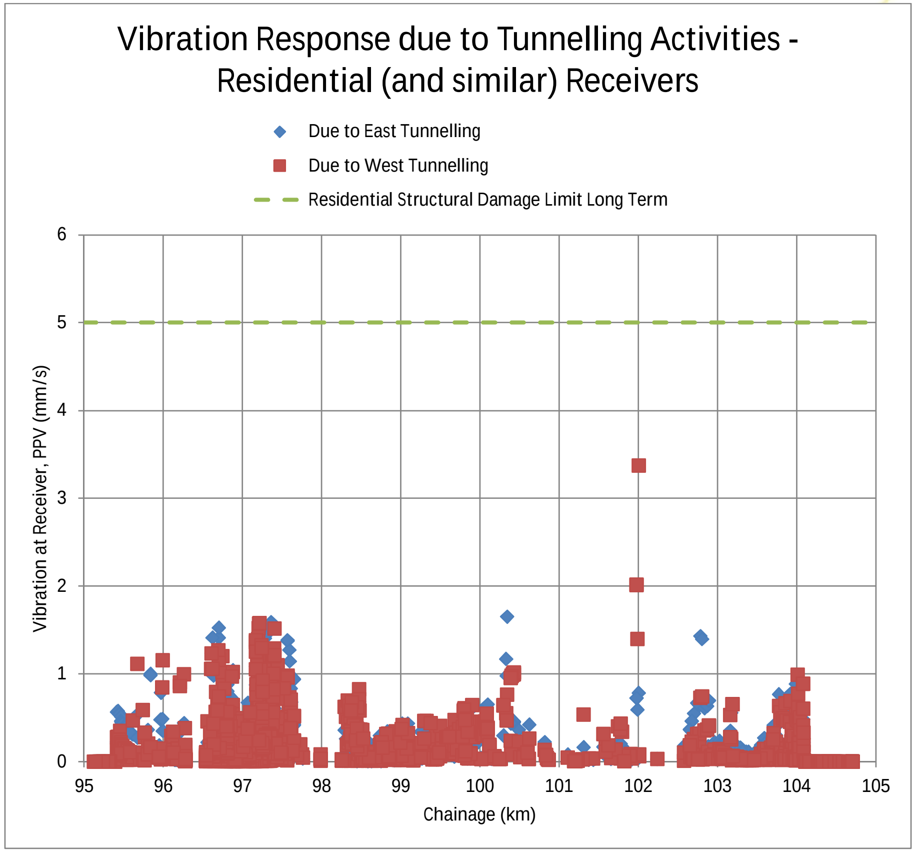


Figure B.9: Predicted vibration levels due to tunnelling at residential receivers

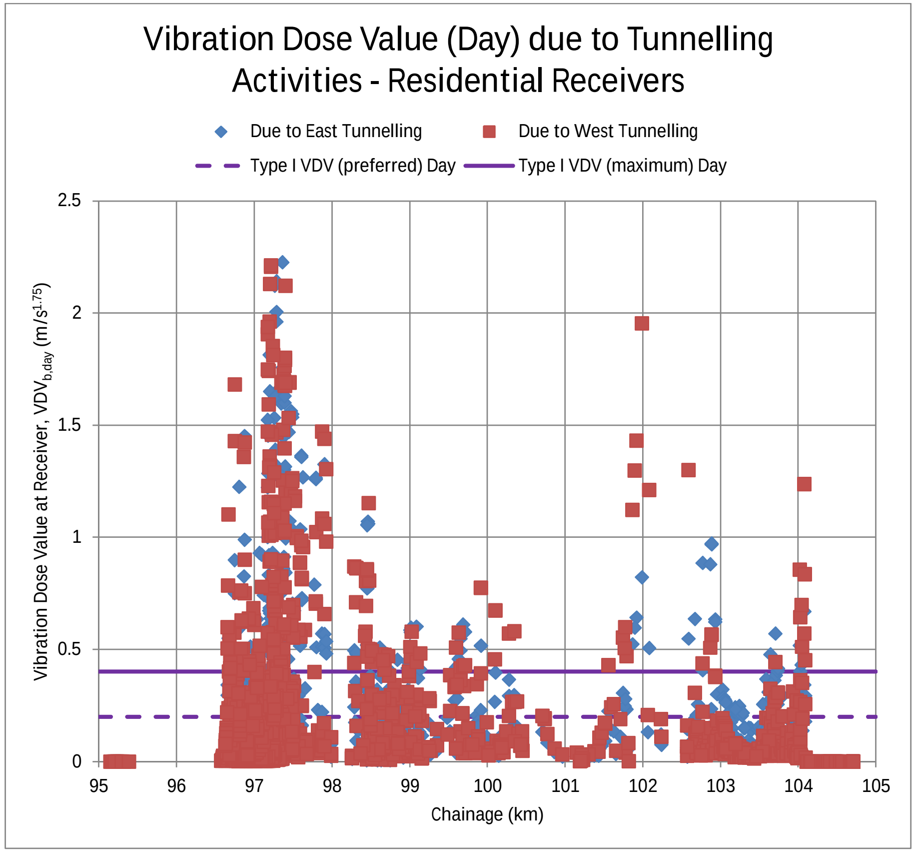


Figure B.10: Predicted VDV – Day levels for Human Comfort due to tunnelling at residential receivers

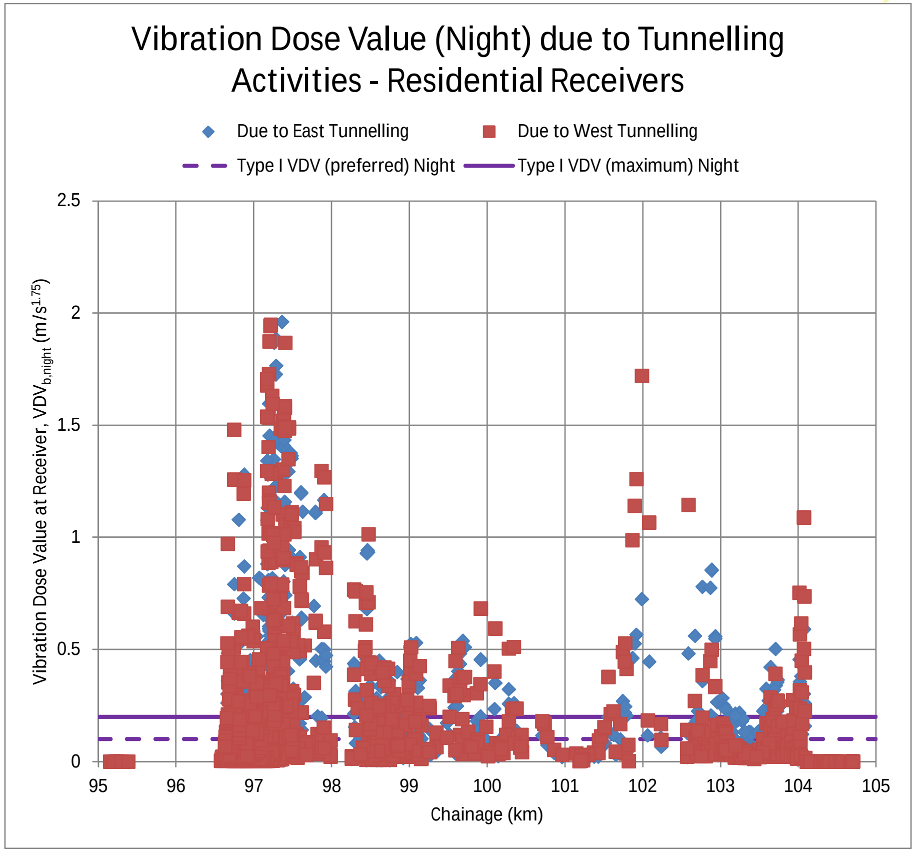


Figure B.11: Predicted VDV – Night levels for Human Comfort due to tunnelling at residential receivers

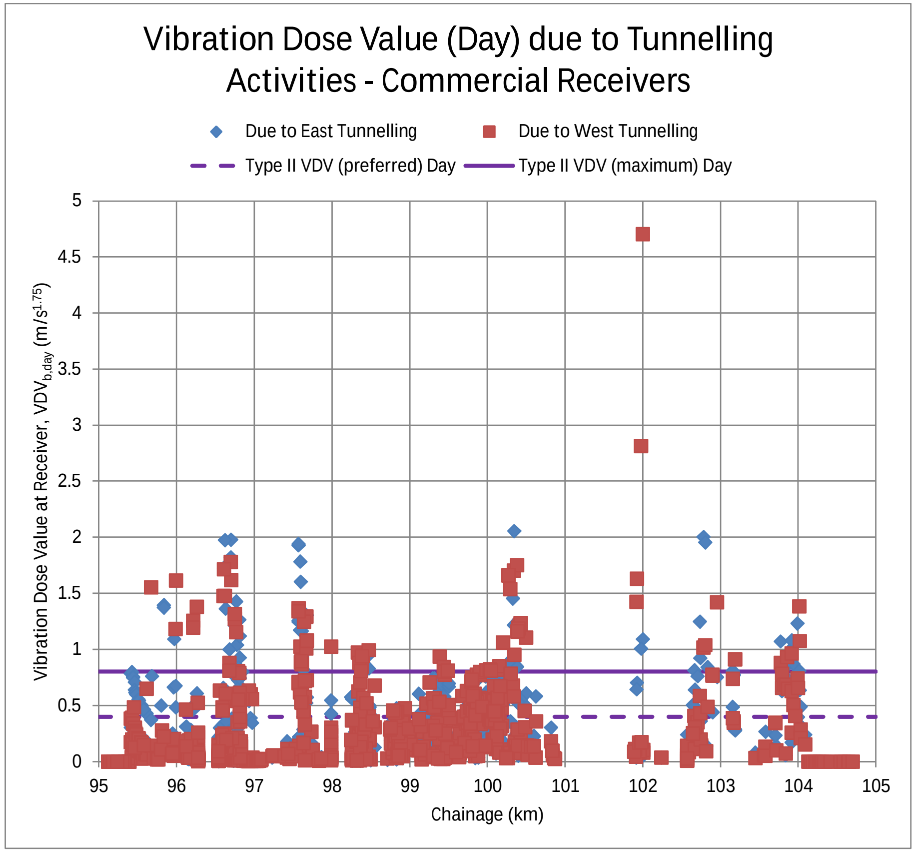


Figure B.12: Predicted VDV – Day levels for Human Comfort due to tunnelling at commercial & educational receivers

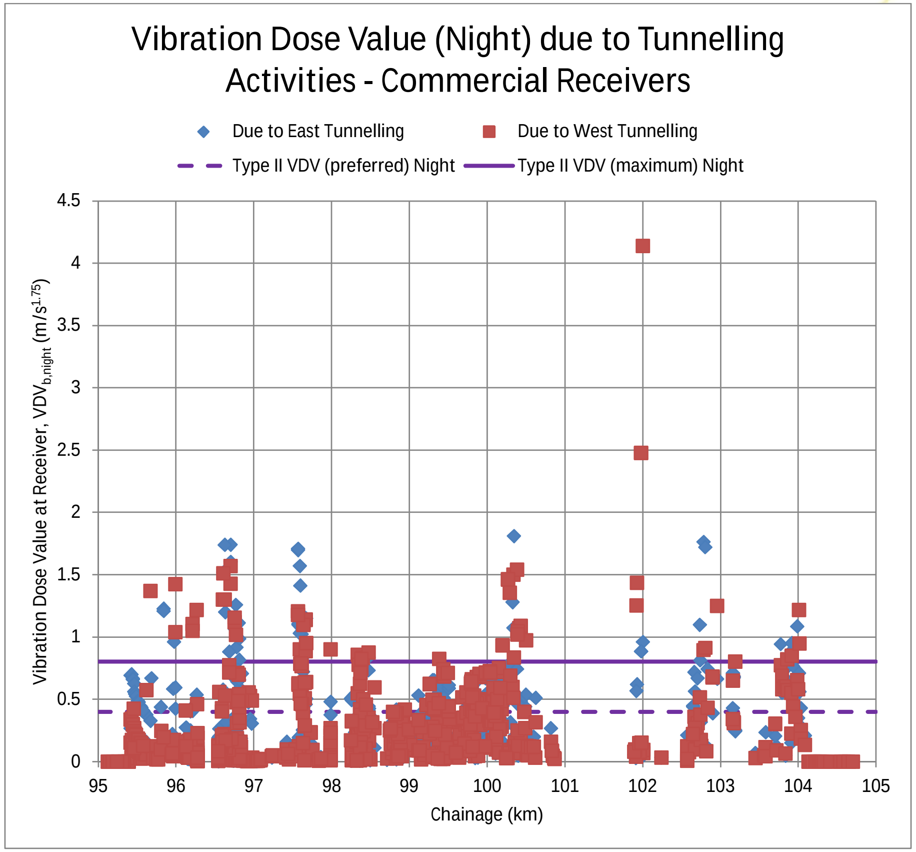


Figure B.13: Predicted VDV – Night levels for Human Comfort due to tunnelling at commercial & educational receivers

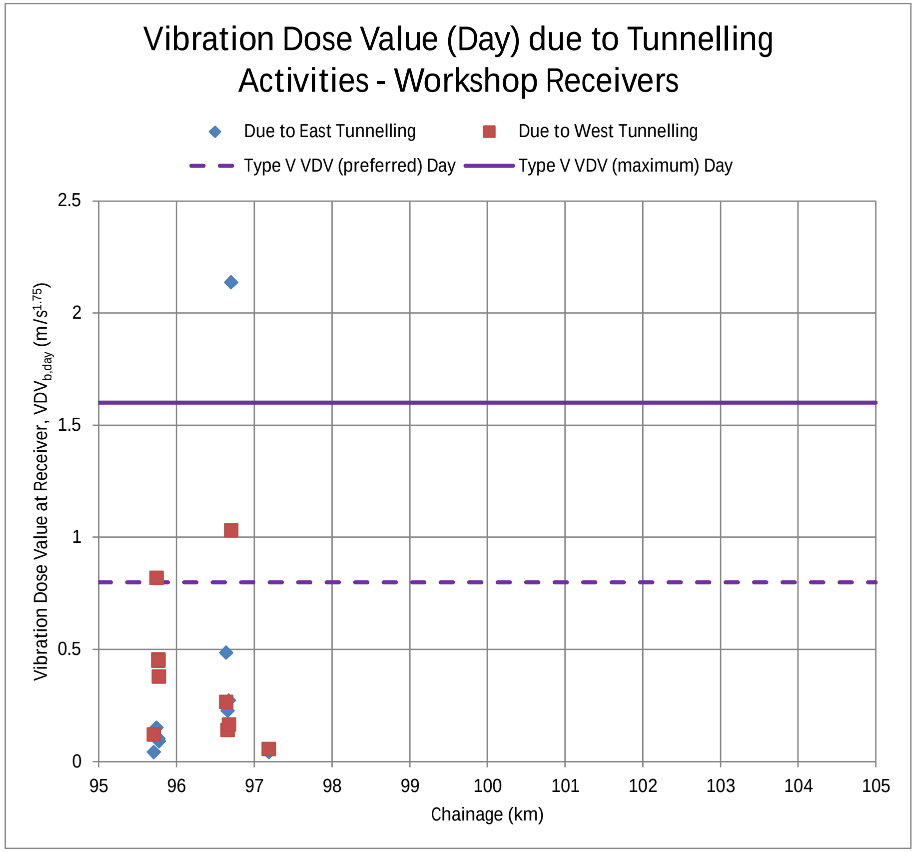


Figure B.14: Predicted VDV – Day levels for Human Comfort due to tunnelling at workshop receivers

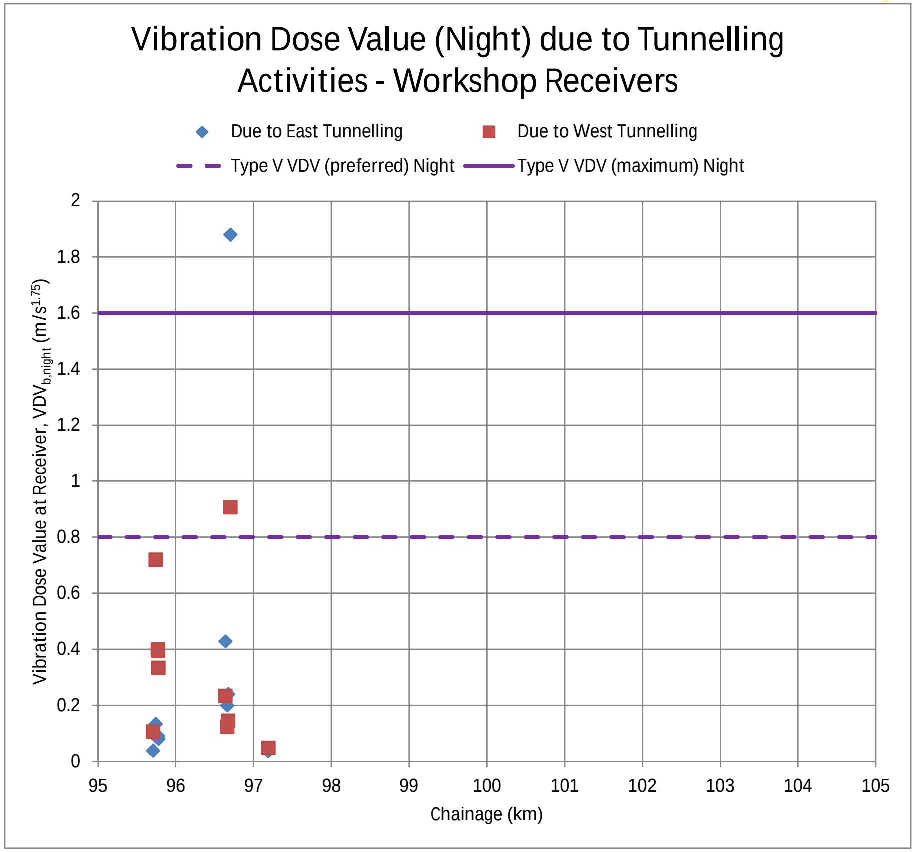


Figure B.15: Predicted VDV – Night levels for Human Comfort due to tunnelling at workshop receivers

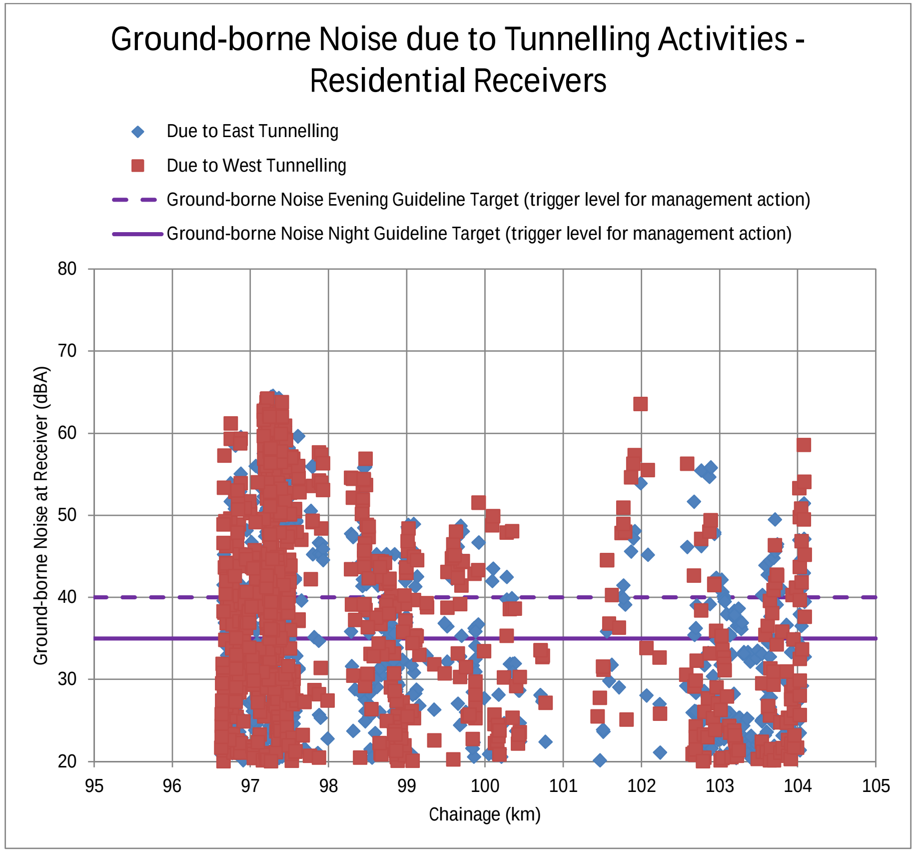


Figure B.16: Predicted ground-borne noise levels for Human Comfort due to tunnelling at residential receivers

Legend

Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 1 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information

Aerial photo (DELWP, February 2015)

Melbourne Metro Rail Project

Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Western Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.17: Colour coded tunnelling VDV (day) levels for Human Comfort for Western Portal Precinct

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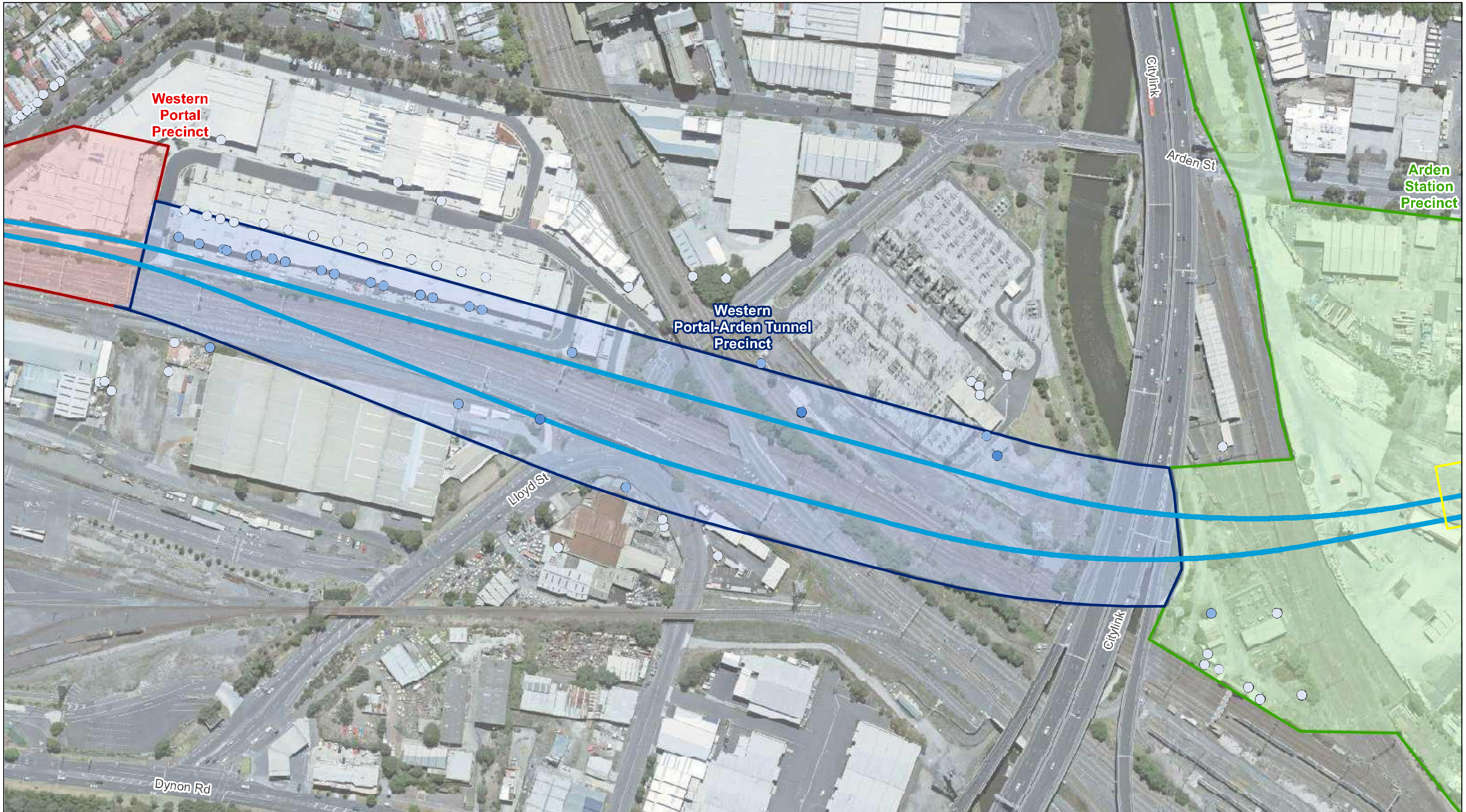

Legend

Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 2 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
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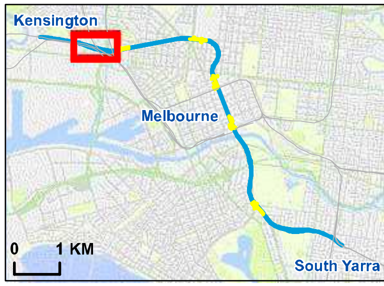

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Melbourne Metro Rail Project

Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Western Portal to Arden

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By: A. Davy	Approved By: D. Timms	Date: 11/04/2016	Map Size: A4

0 50 100
Metres

Figure B.18: Colour coded tunnelling VDV (day) levels for Human Comfort for Western Portal to Arden Tunnel Precinct

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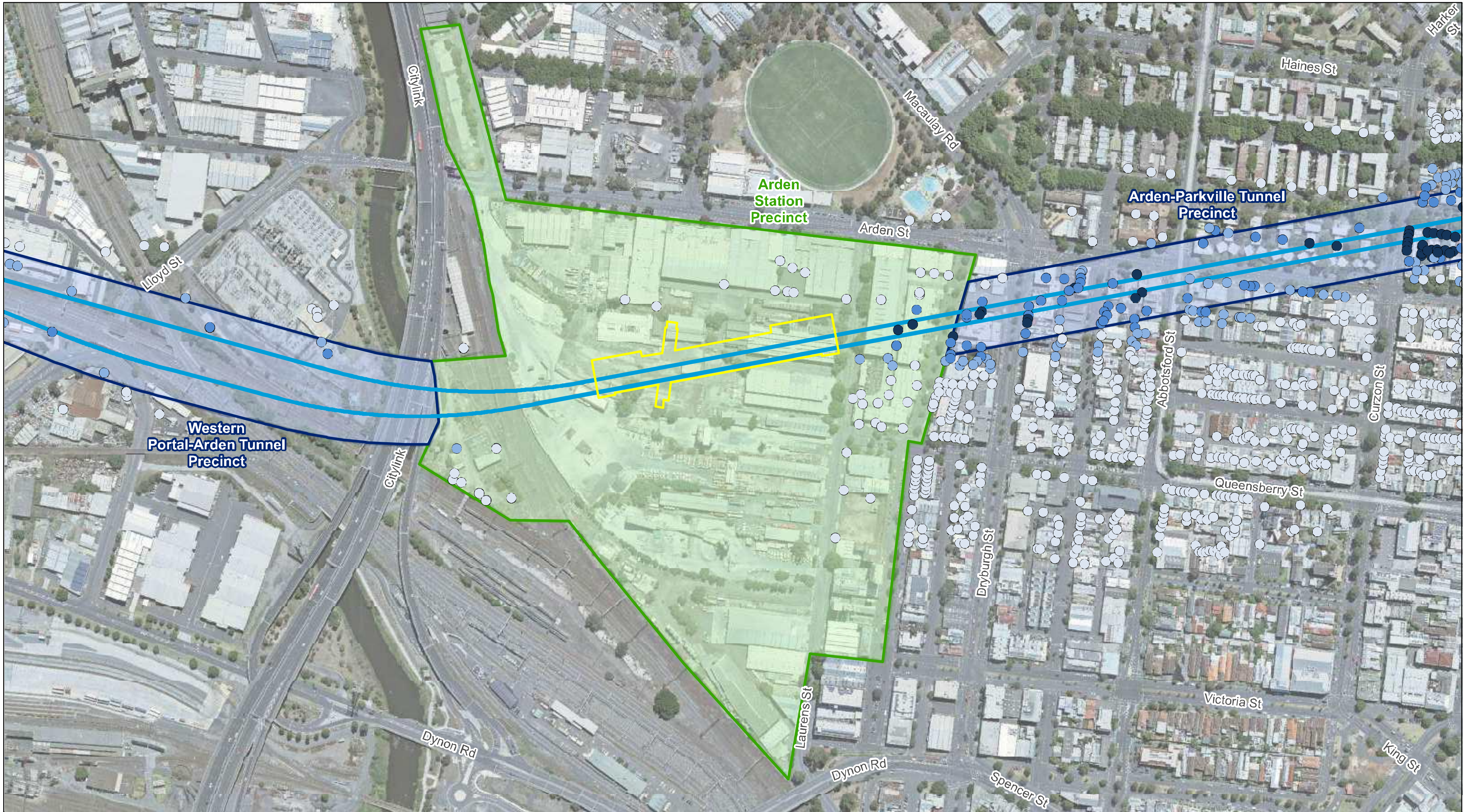


Legend

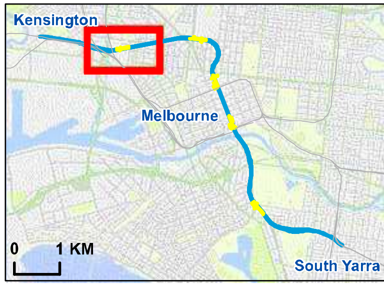
Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 3 of 13



Data Sources:
Proposed Infrastructure: AJM 2016
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Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Arden Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.19: Colour coded tunnelling VDV (day) levels for Human Comfort for Arden Station Precinct

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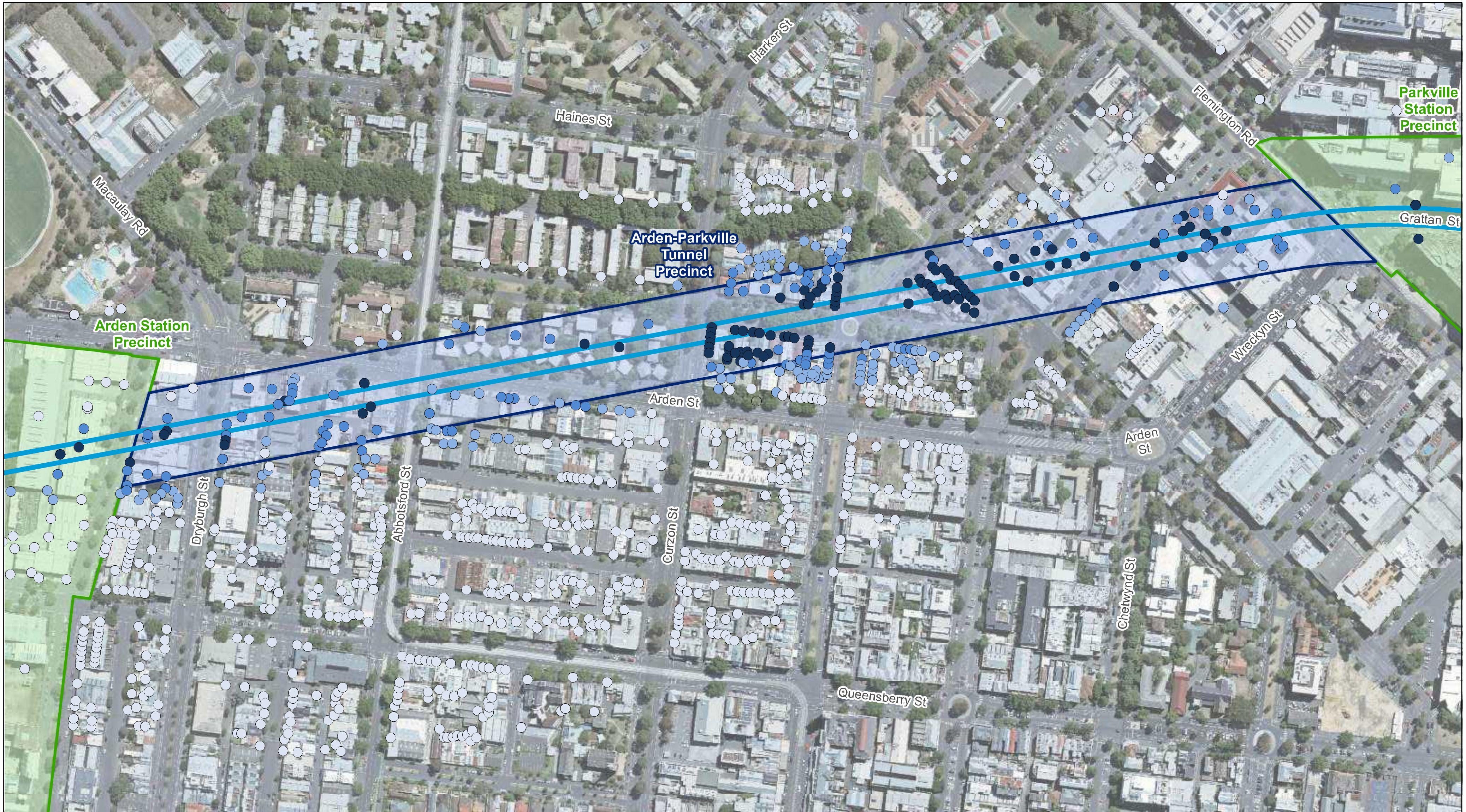


Legend

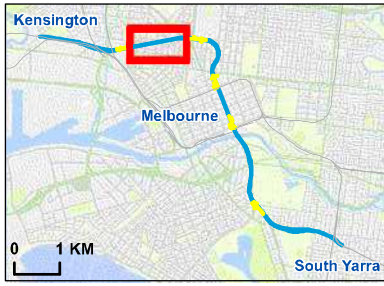
Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 4 of 13



Data Sources:
Proposed Infrastructure: AJM 2016
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Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Arden to Parkville

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.20: Colour coded tunnelling VDV (day) levels for Human Comfort for Arden to Parkville Precinct

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Legend

Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 5 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
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Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Parkville Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_1.mxd

Figure B.21: Colour coded tunnelling VDV (day) levels for Human Comfort for Parkville Station Precinct

Legend

Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 6 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
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Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Parkville to CBD North

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_1.mxd

Figure B.22: Colour coded tunnelling VDV (day) levels for Human Comfort for Parkville to CBD North Tunnel Precinct

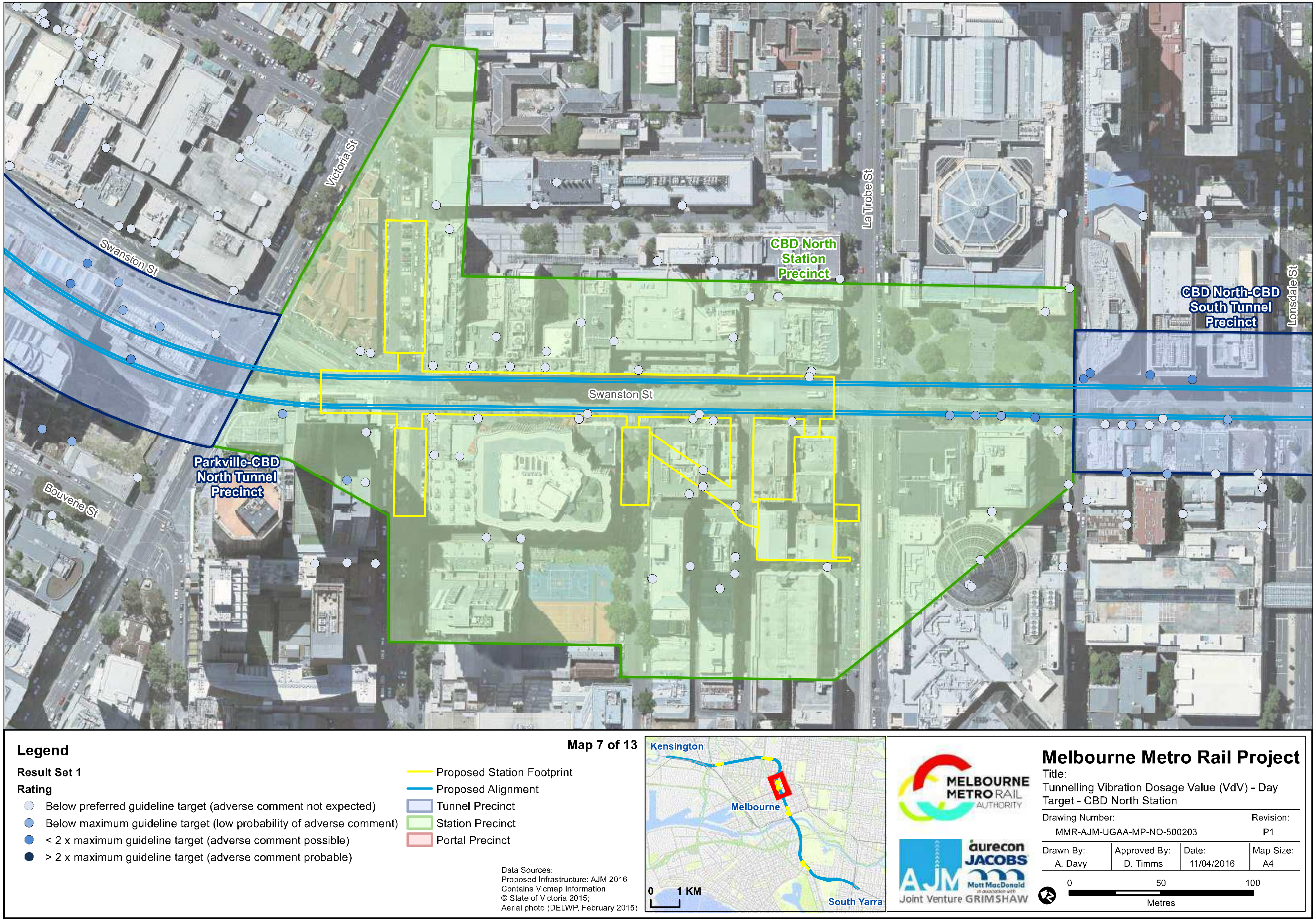
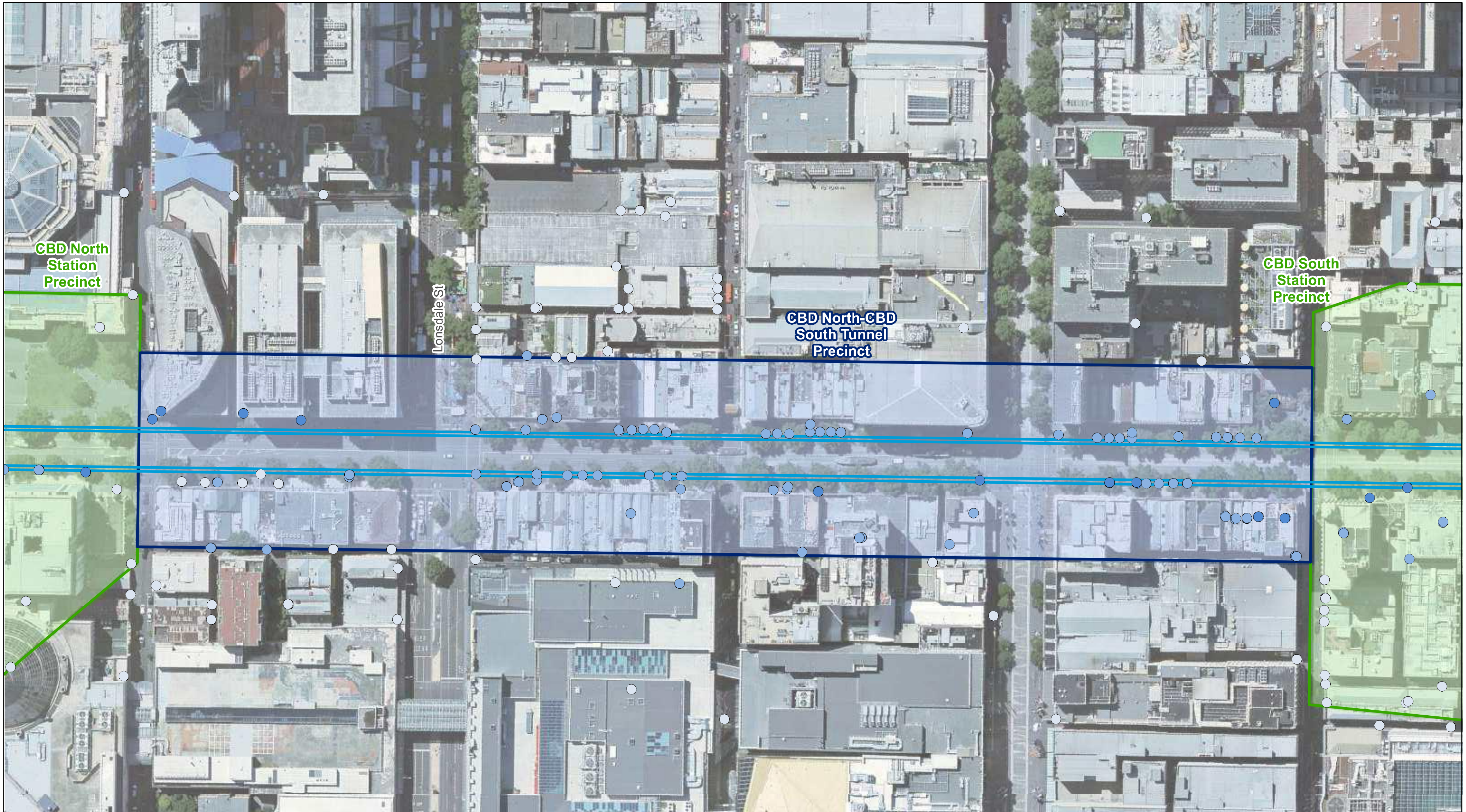


Figure B.23: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD North Station Precinct



Legend

Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 8 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
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Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - CBD North to CBD South

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.24: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD North and CBD South Tunnel Precinct

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Legend

Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

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

Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - CBD South Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_1.mxd

Figure B.25: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD South Station Precinct

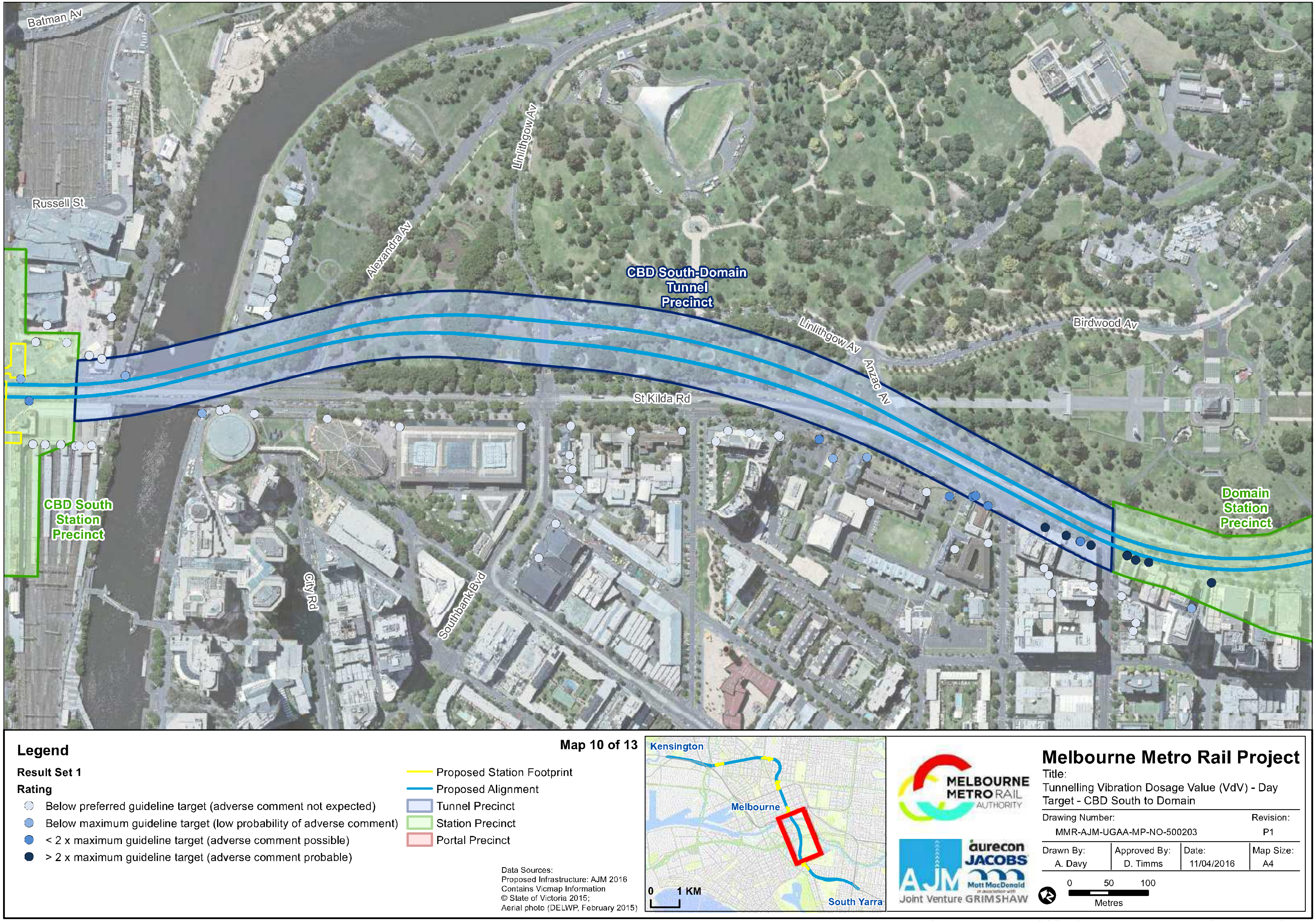
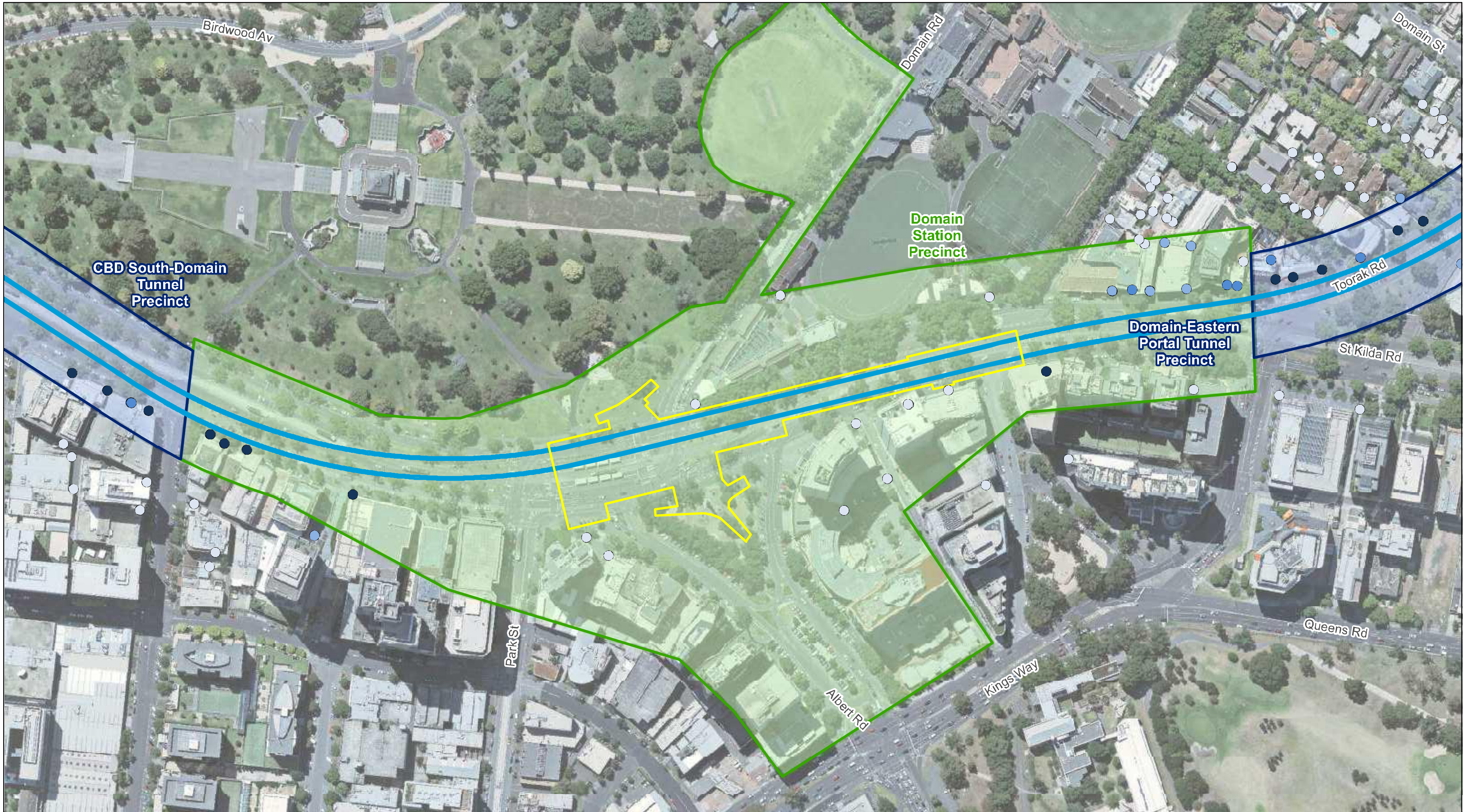


Figure B.26: Colour coded tunnelling VDV (day) levels for Human Comfort for CBD South to Domain Tunnel Precinct



Legend

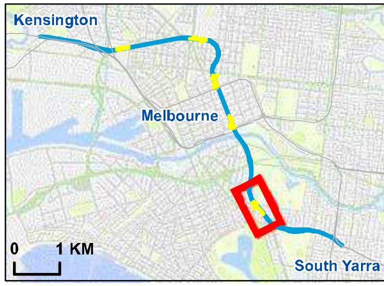
Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 11 of 13



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

aurecon JACOBS Mott MacDonald
AJM Joint Venture GRIMSHAW

Melbourne Metro Rail Project

Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Domain Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_1.mxd

Figure B.27: Colour coded tunnelling VDV (day) levels for Human Comfort for Domain Station Precinct

Legend

Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 12 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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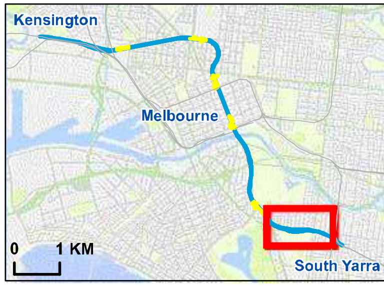


MELBOURNE METRO RAIL AUTHORITY

aurecon JACOBS Mott MacDonald AJM Joint Venture GRIMSHAW

Melbourne Metro Rail Project

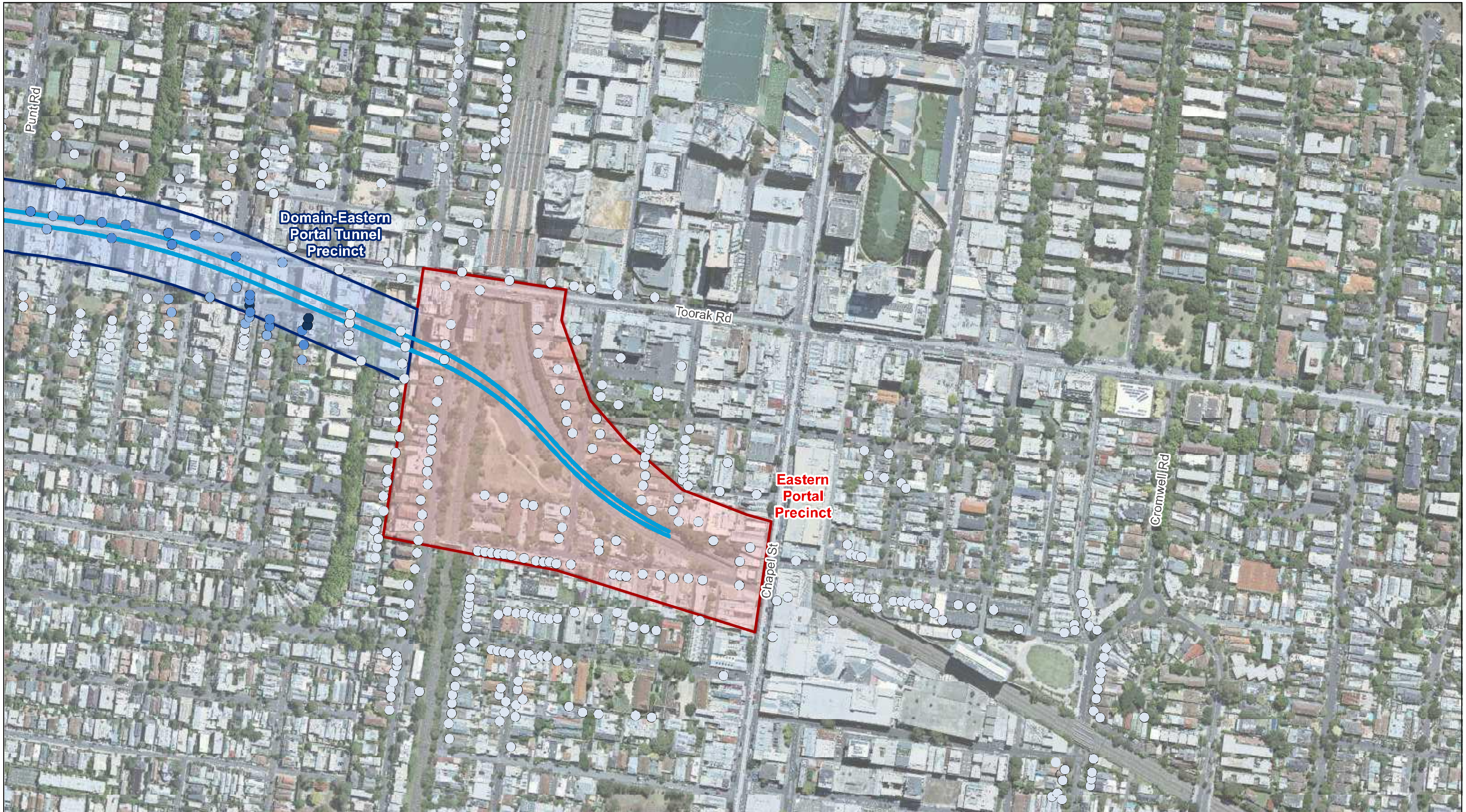
Title:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Domain to Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.28: Colour coded tunnelling VDV (day) levels for Human Comfort for Domain to Eastern Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_1.mxd



Legend

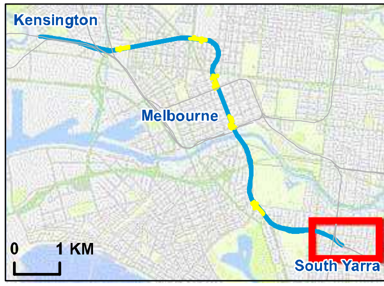
Result Set 1

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 13 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:
Tunnelling Vibration Dosage Value (VdV) - Day Target - Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500203			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Joint Venture

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_1.mxd

Figure B.29: Colour coded tunnelling VDV (day) levels for Human Comfort for Eastern Portal Precinct

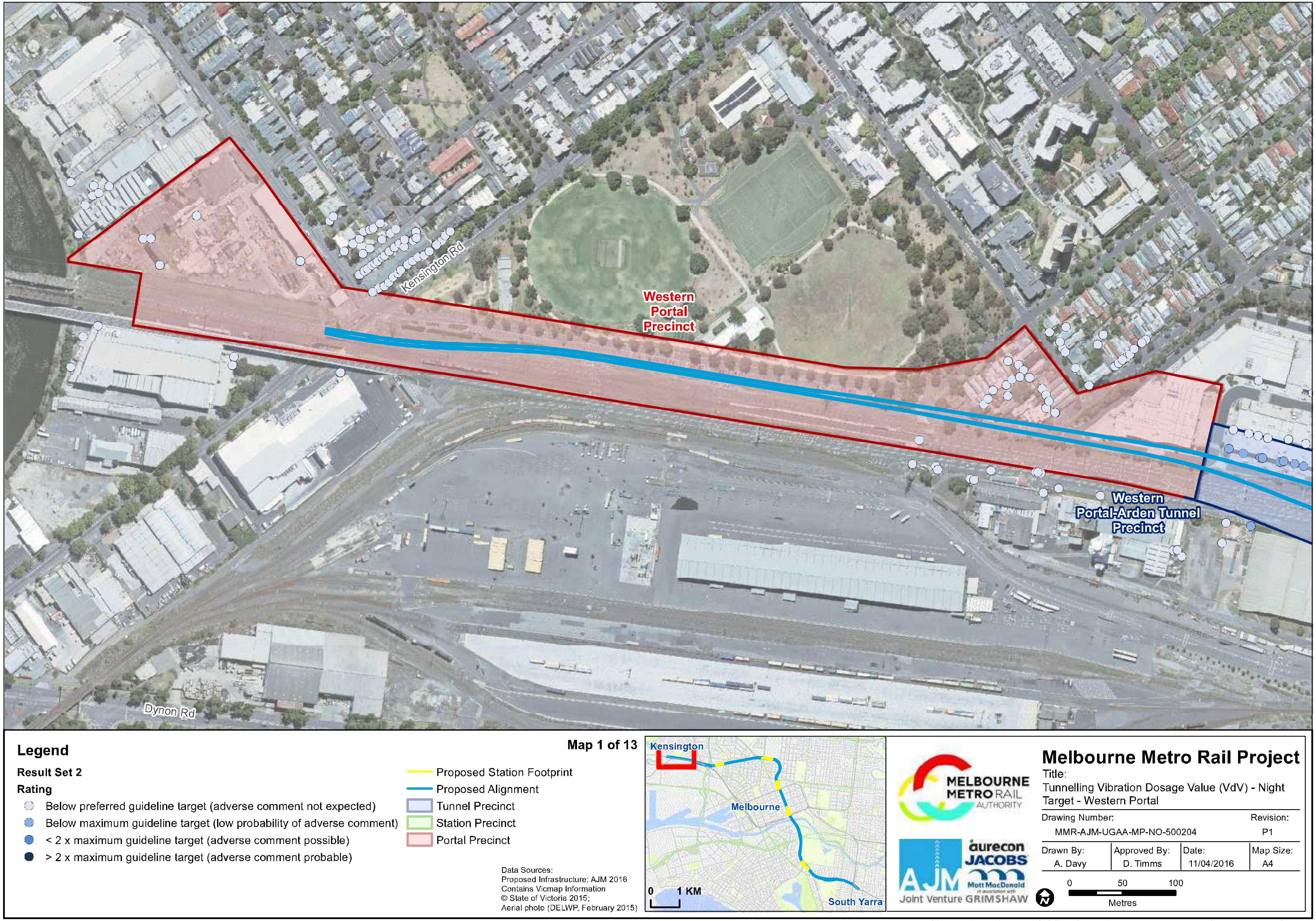
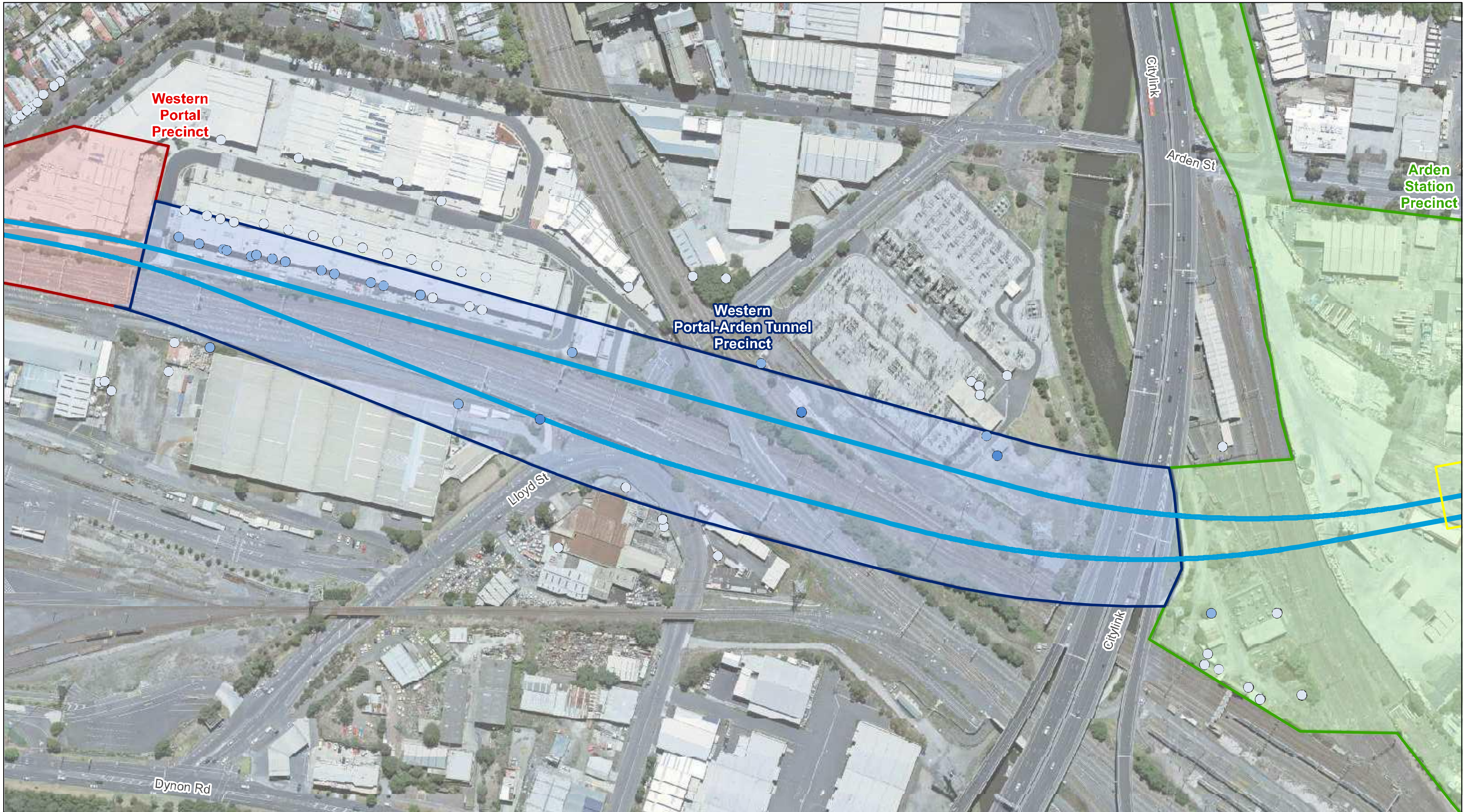


Figure B.30: Colour coded tunnelling VDV (night) levels for Human Comfort for Western Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd



Legend

Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 2 of 13

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

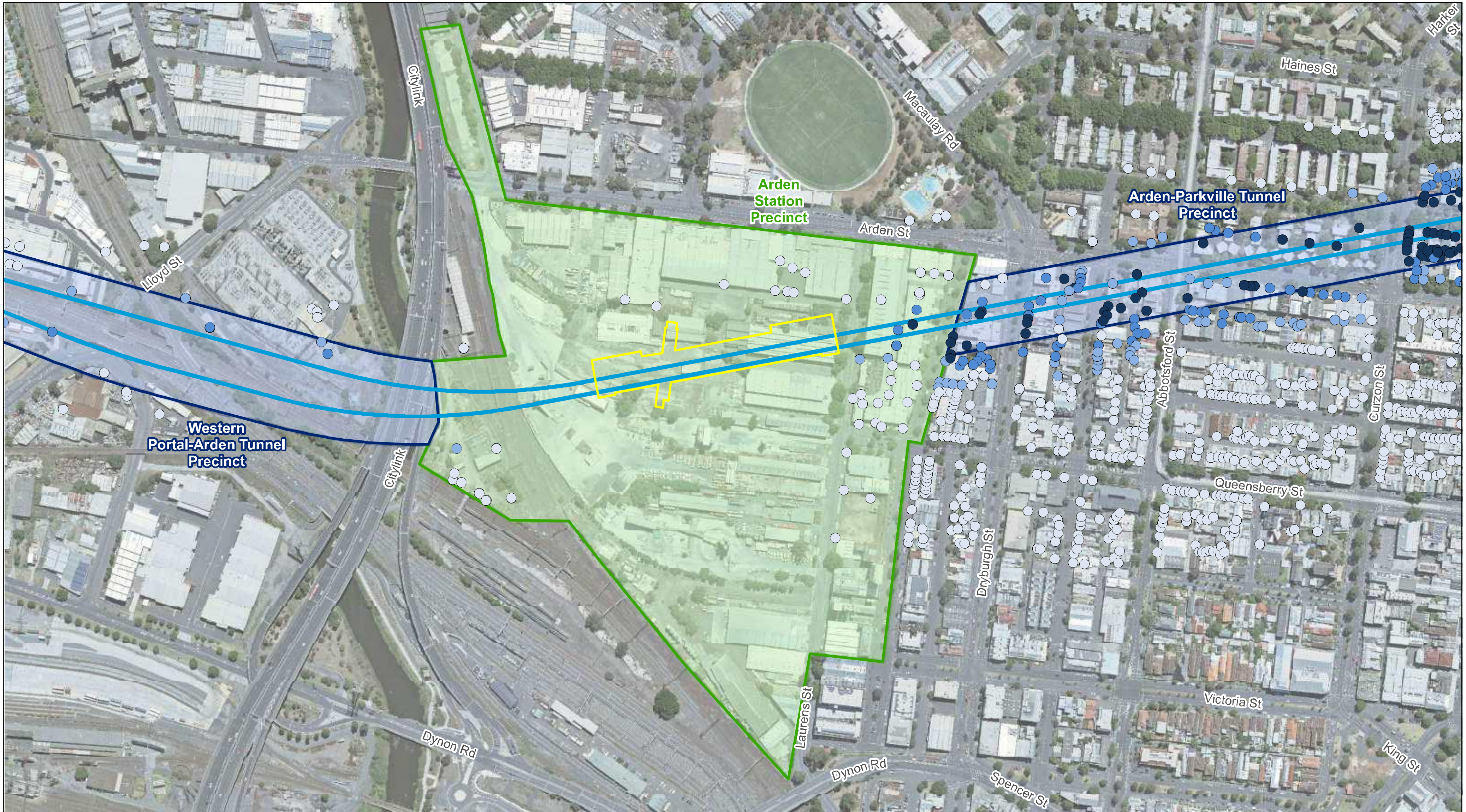
Title: Tunnelling Vibration Dosage Value (VdV) - Night Target - Western Portal to Arden

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.31: Colour coded tunnelling VDV (night) levels for Human Comfort for Western Portal to Arden Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd



Legend

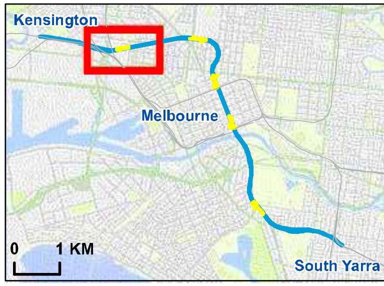
Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 3 of 13



Data Sources:
Proposed Infrastructure: AJM 2016
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Joint Venture GRIMSHAW

Melbourne Metro Rail Project

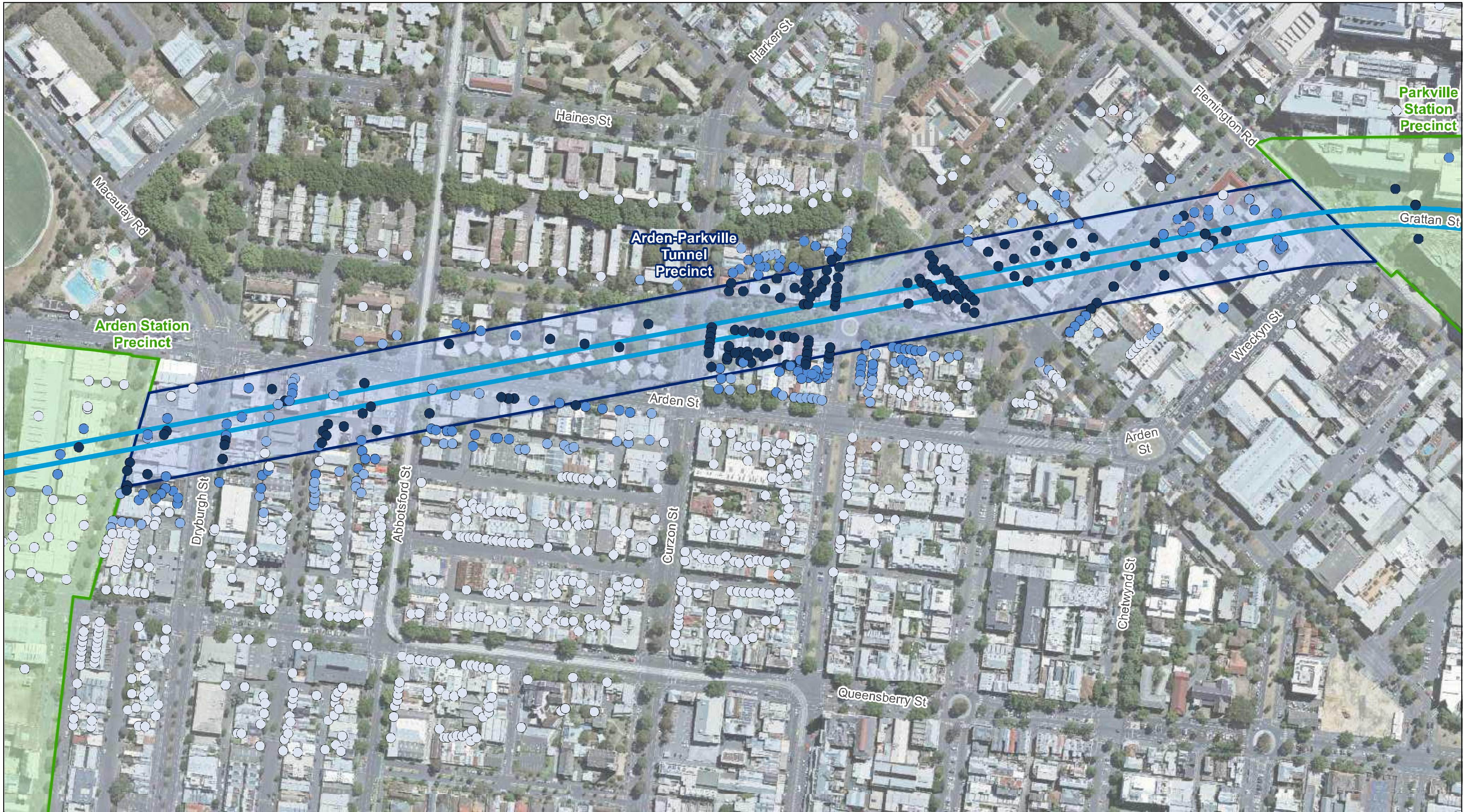
Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - Arden Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.32: Colour coded tunnelling VDV (night) levels for Human Comfort for Arden Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd



Legend

Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 4 of 13

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

Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - Arden to Parkville

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd

Figure B.33: Colour coded tunnelling VDV (night) levels for Human Comfort for Arden to Parkville Tunnel Precinct

Legend

Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 5 of 13

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

Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - Parkville Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd

Figure B.34: Colour coded tunnelling VDV (night) levels for Human Comfort for Parkville Station Precinct

Legend

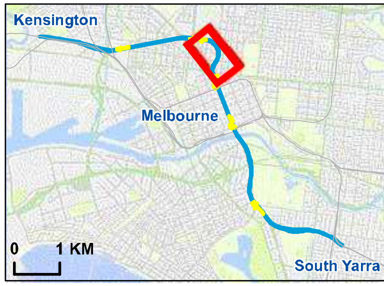
Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 6 of 13



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

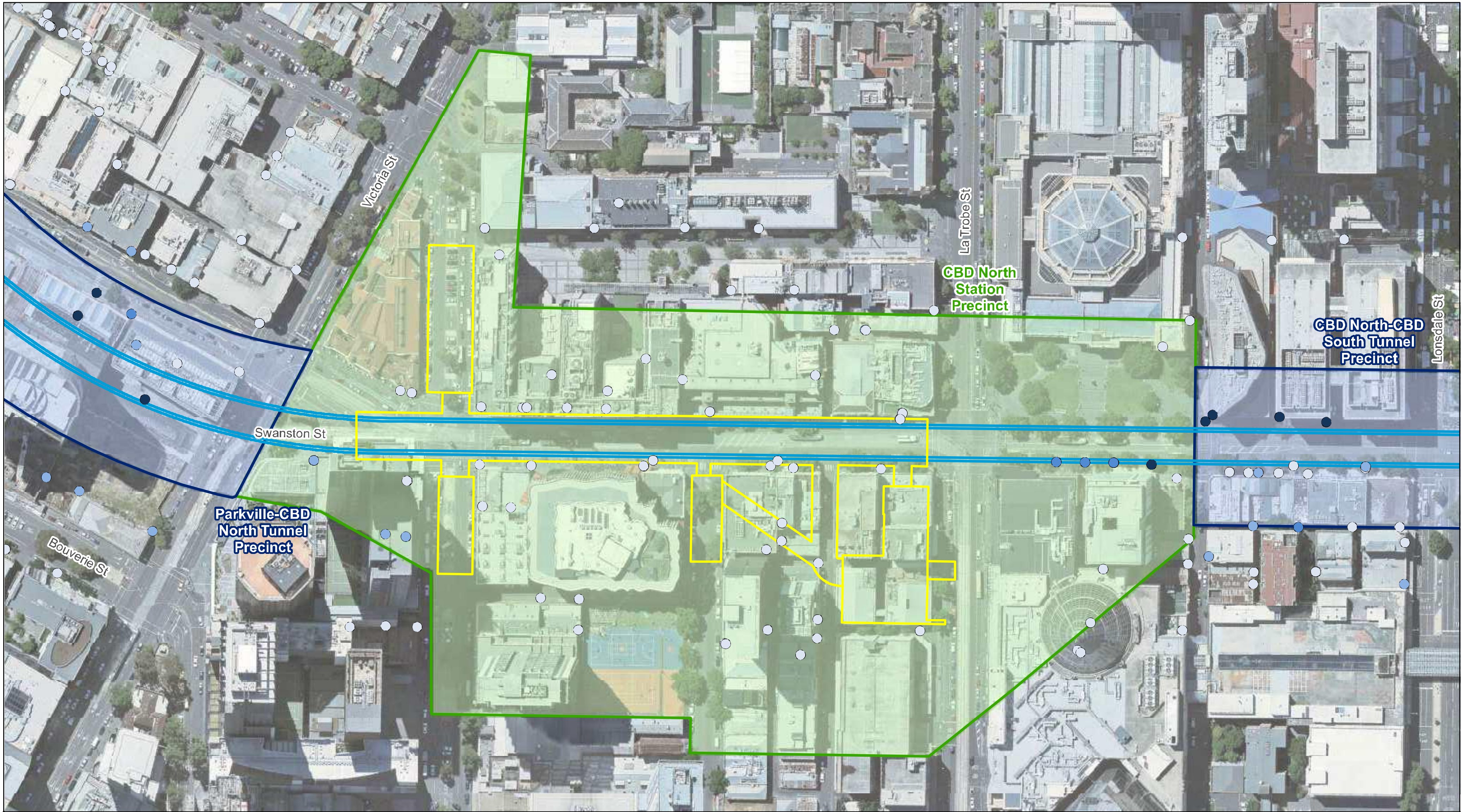
Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - Parkville to CBD North

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By: A. Davy	Approved By: D. Timms	Date: 11/04/2016	Map Size: A4

0 50 100
Metres

Figure B.35: Colour coded tunnelling VDV (night) levels for Human Comfort for Parkville to CBD North Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd



Legend

Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 7 of 13

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

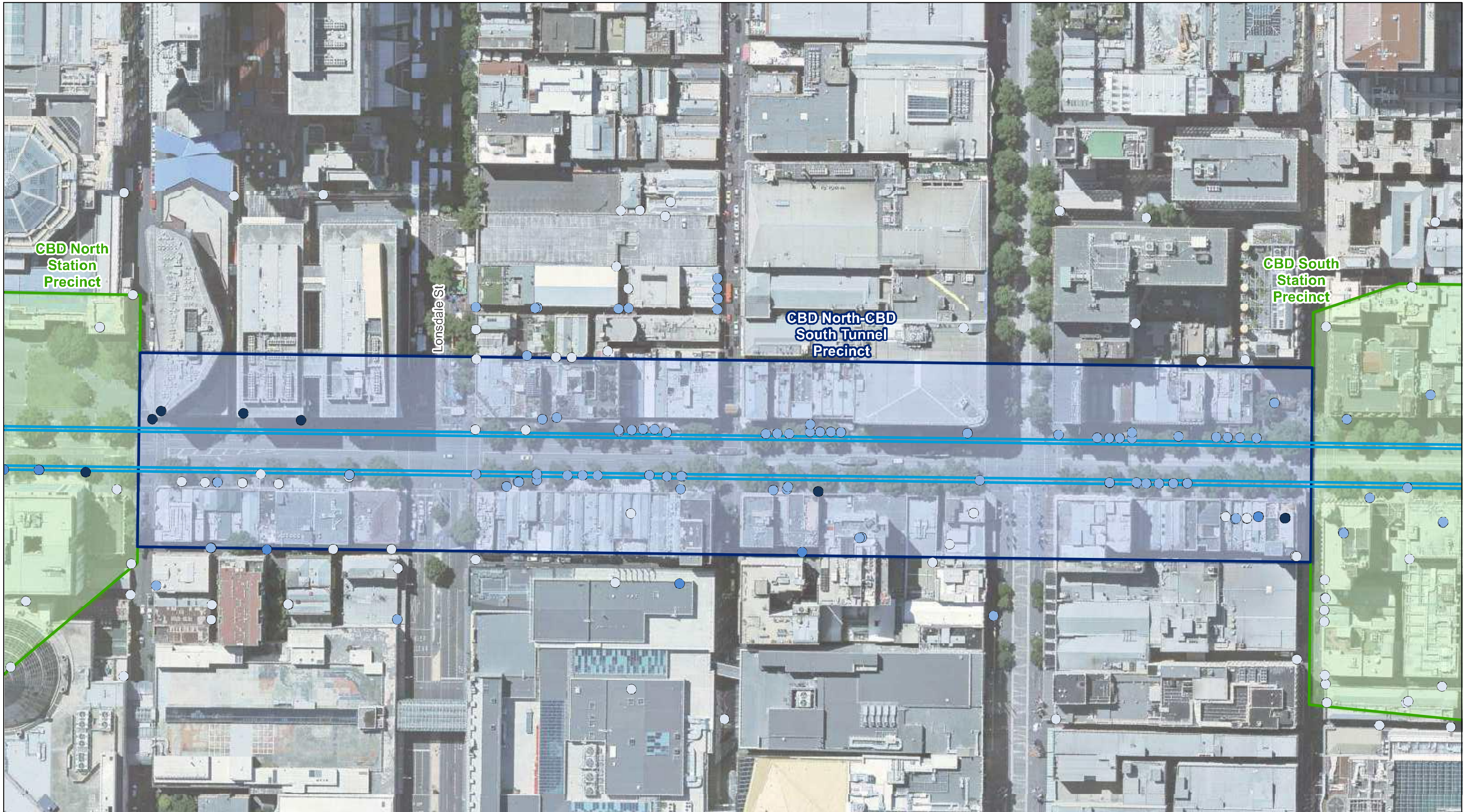
Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - CBD North Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.36: Colour coded tunnelling VDV (night) levels for Human Comfort for CBD North Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd



Legend

Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 8 of 13

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

Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - CBD North to CBD South

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.37: Colour coded tunnelling VDV (night) levels for Human Comfort CBD North and CBD South Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd

Legend

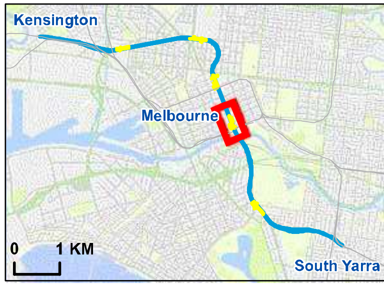
Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 9 of 13



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

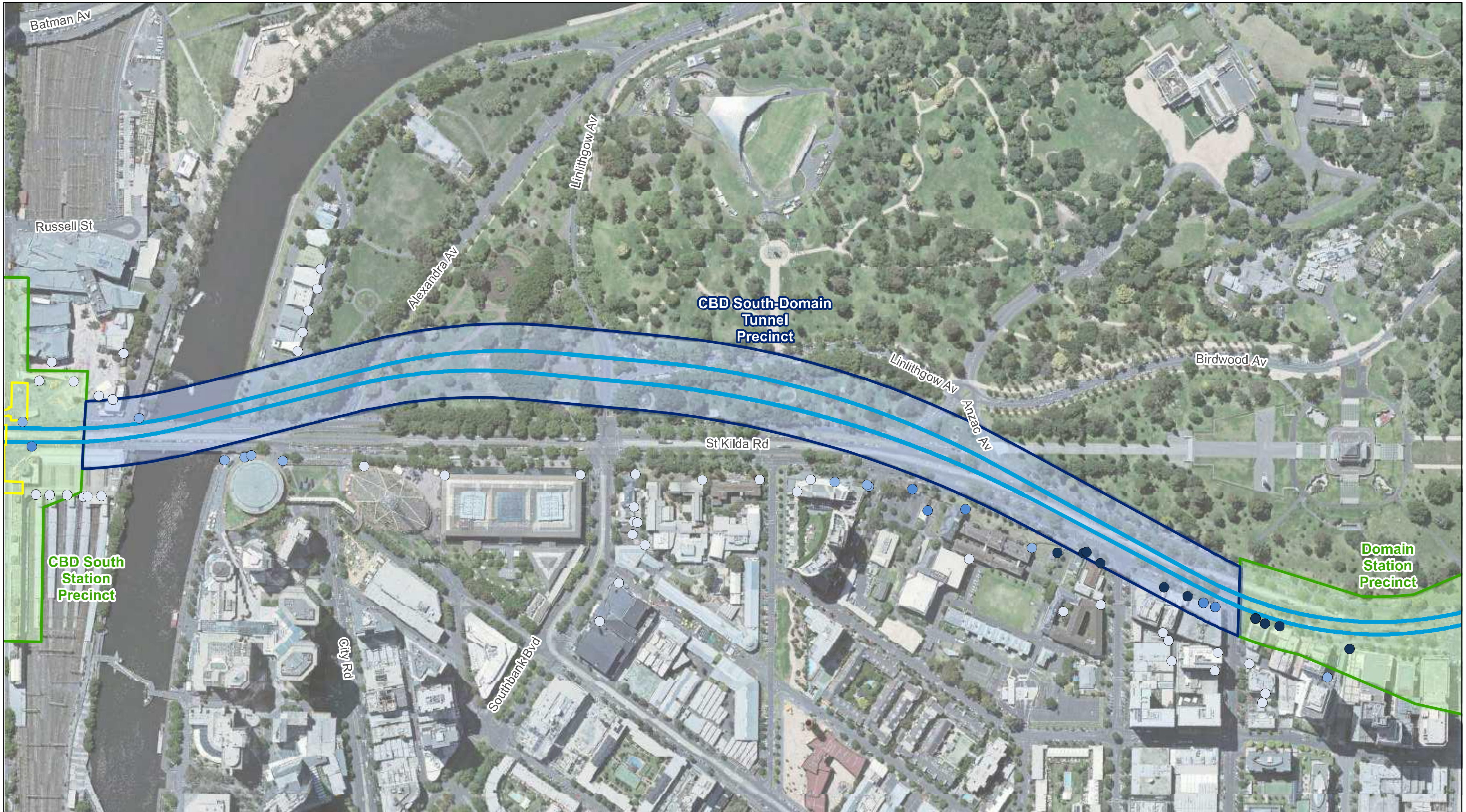
Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - CBD South Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.38: Colour coded tunnelling VDV (night) levels for Human Comfort for CBD South Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd



Legend

Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 10 of 13

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

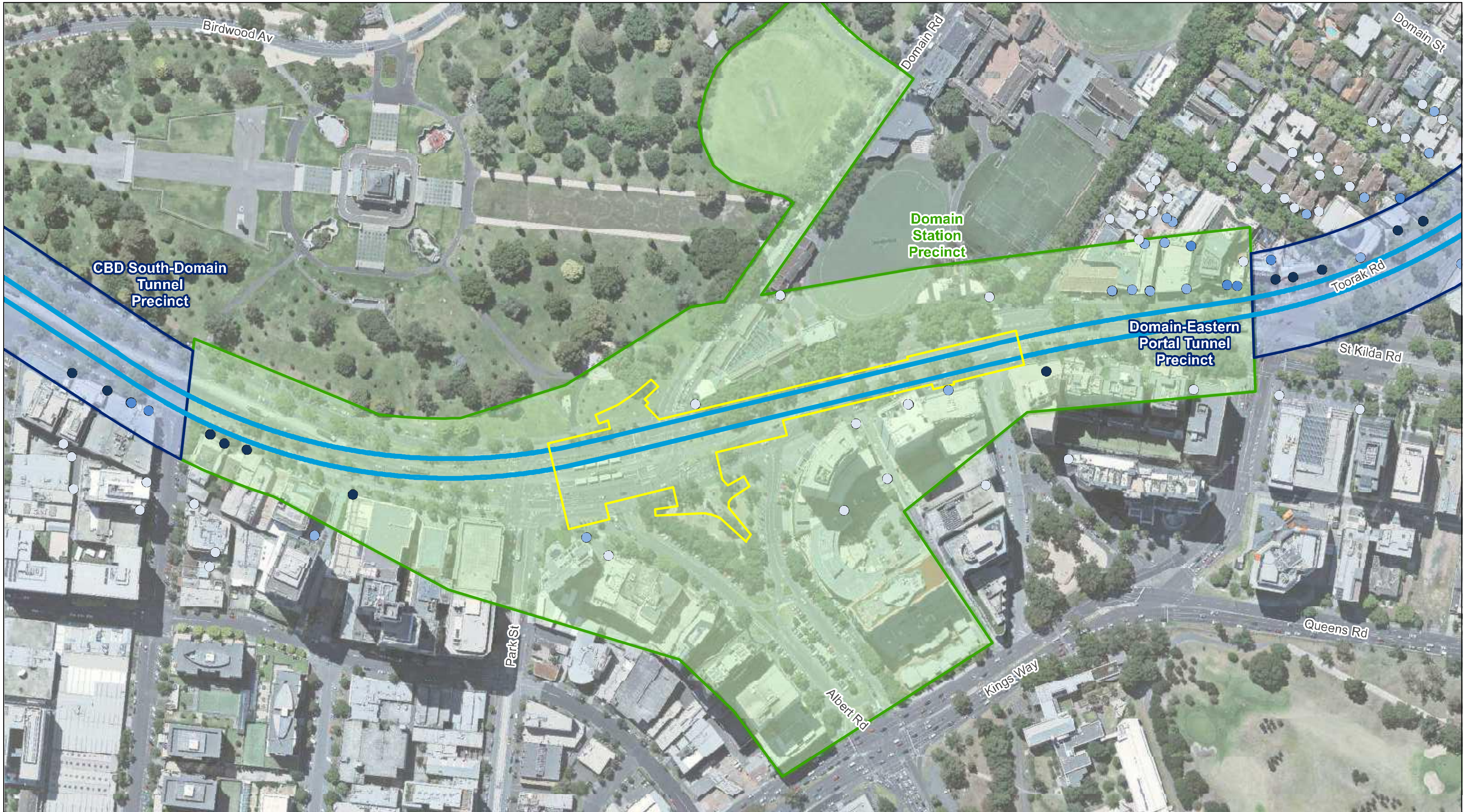
Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - CBD South to Domain

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.39: Colour coded tunnelling VDV (night) levels for Human Comfort for CBD South to Domain Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd



Legend

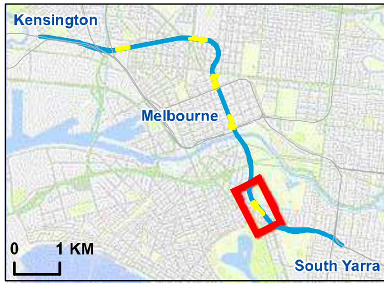
Result Set 2

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 11 of 13



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald GRIMSHAW

Melbourne Metro Rail Project

Title:
Tunnelling Vibration Dosage Value (VdV) - Night Target - Domain Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500204			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_2.mxd

Figure B.40: Colour coded tunnelling VDV (night) levels for Human Comfort for Domain Station Precinct

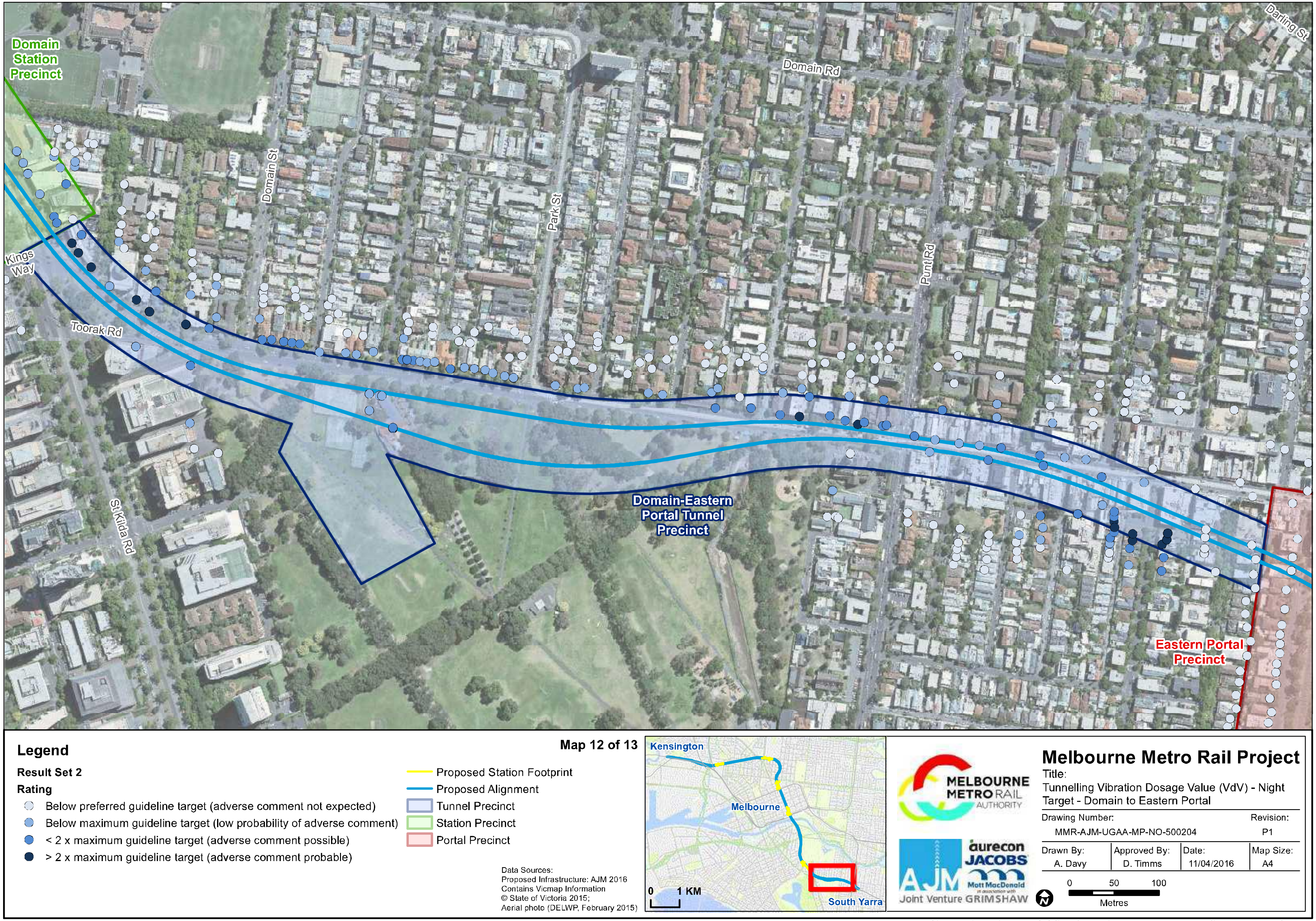


Figure B.41: Colour coded tunnelling VDV (night) levels for Human Comfort for Domain to Eastern Tunnel Precinct

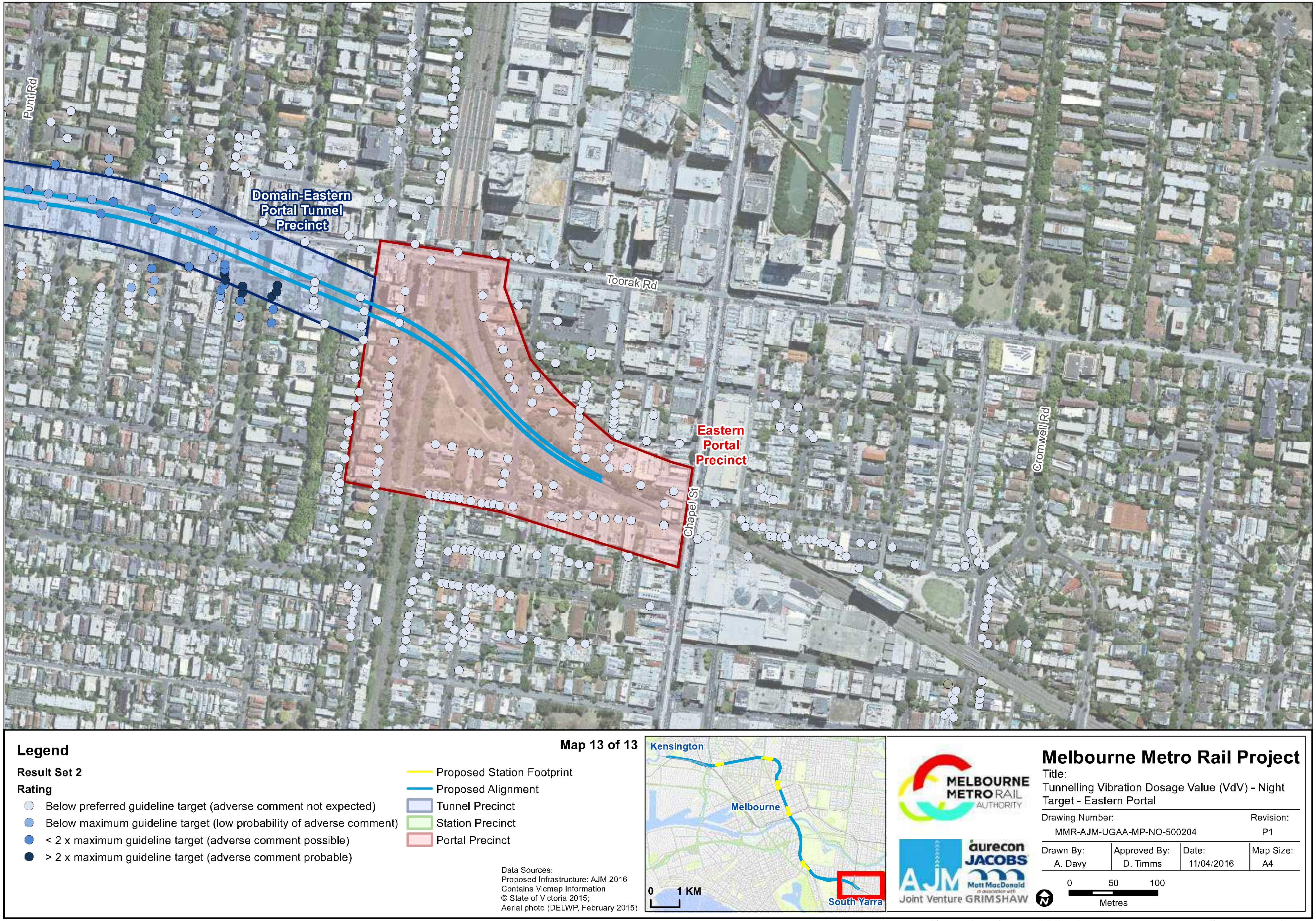
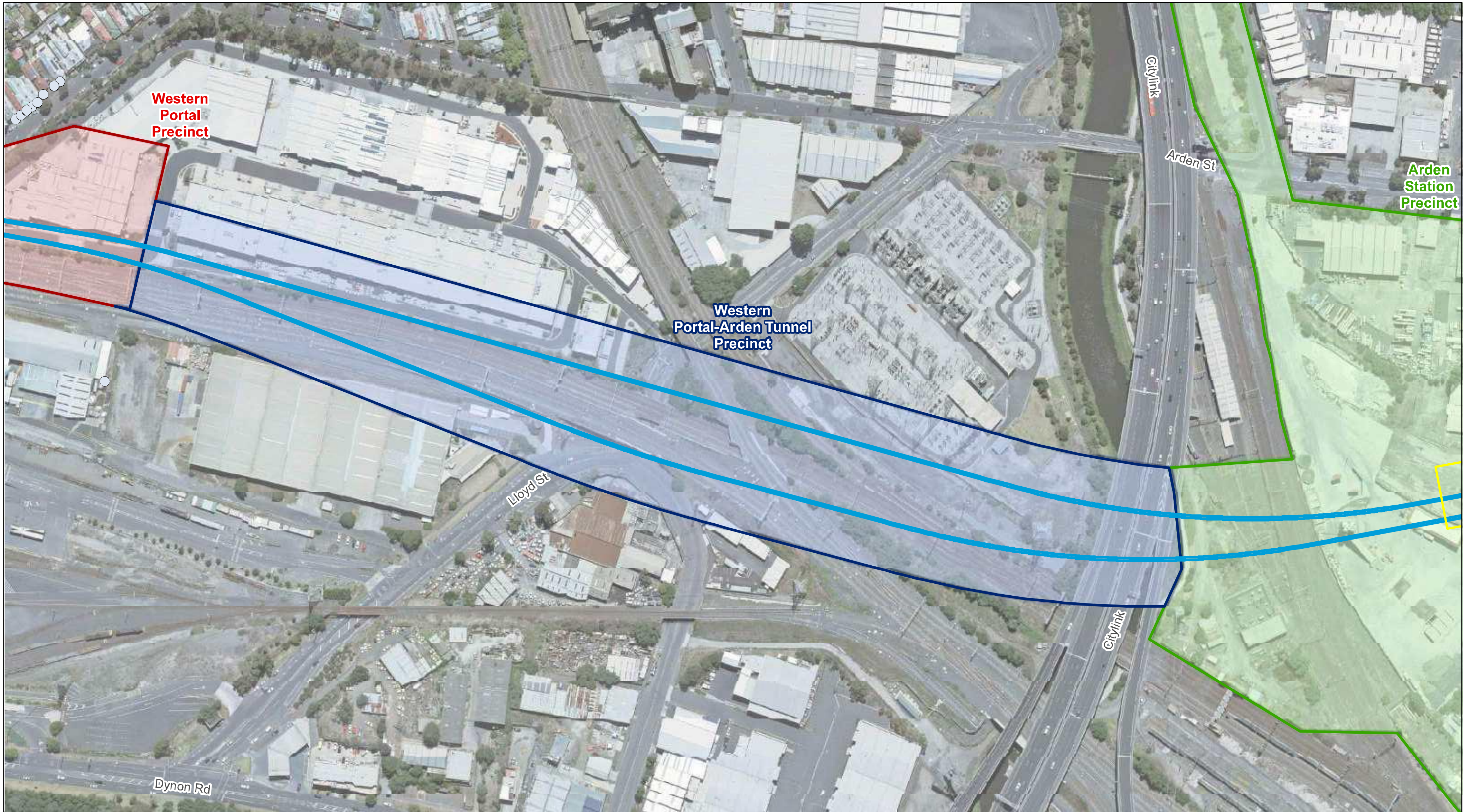


Figure B.42: Colour coded tunnelling VDV (night) levels for Human Comfort for Eastern Portal Precinct

Figure B.43: Colour coded tunnelling ground-borne noise levels for Western Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd



Legend

Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

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

Map 2 of 13

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

AJM Joint Venture — aurecon JACOBS Mott MacDonald GRIMSHAW

Melbourne Metro Rail Project

Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - Western Portal to Arden

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.44: Colour coded tunnelling ground-borne noise levels for Western Portal to Arden Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd

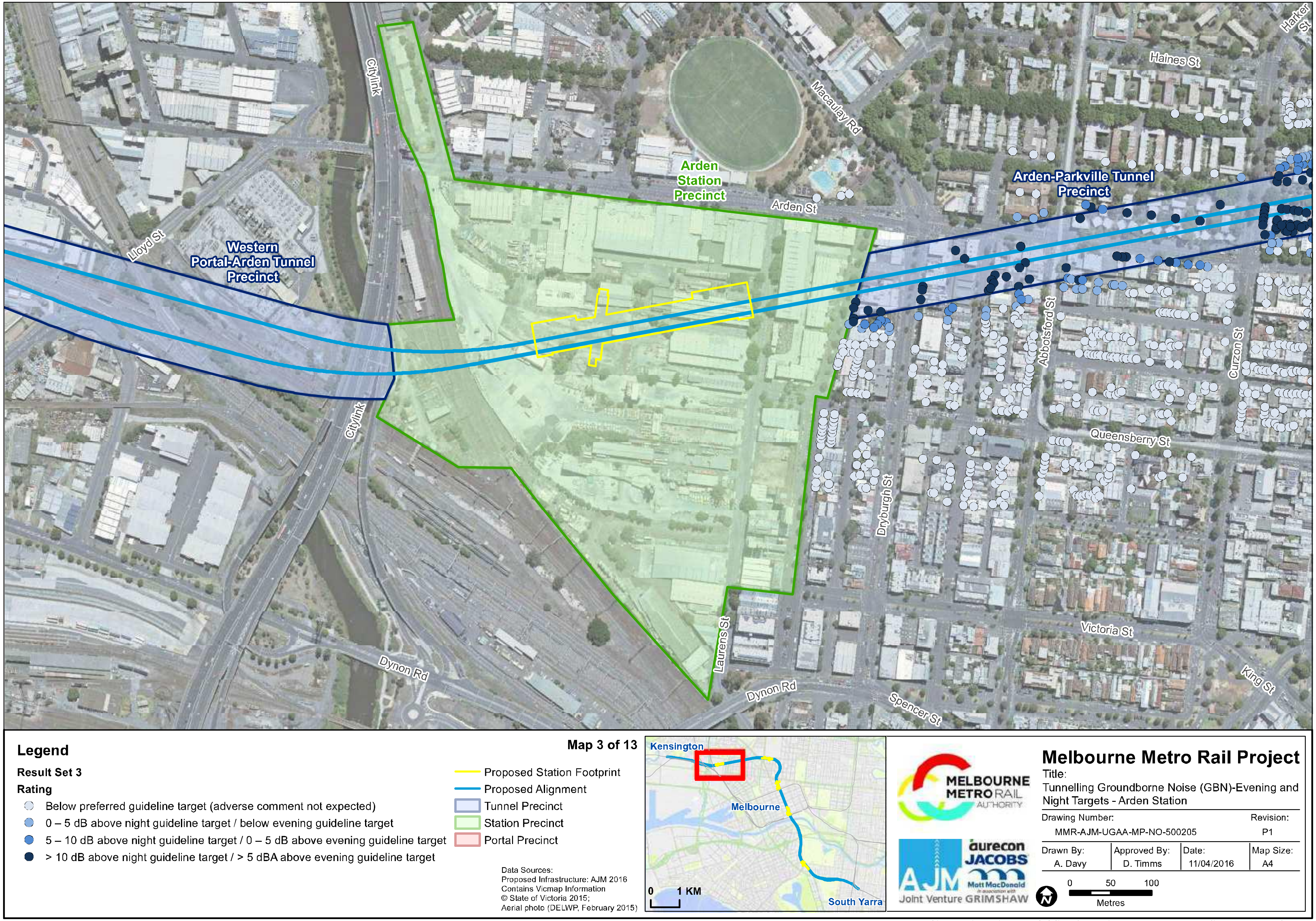
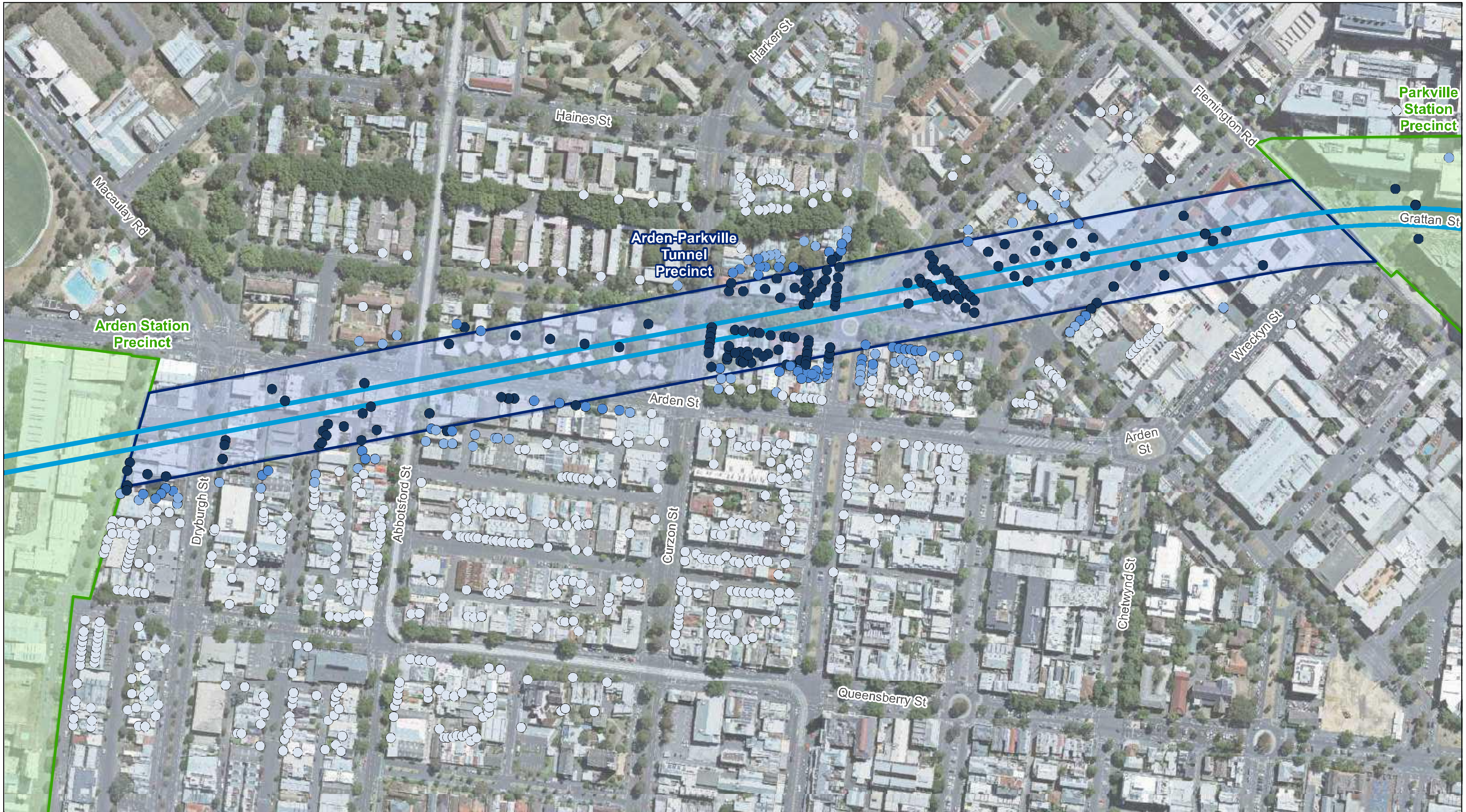


Figure B.45: Colour coded tunnelling ground-borne noise levels for Arden Station Precinct



Legend

Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

Map 4 of 13

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

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

AJM Joint Venture aurecon JACOBS Mott MacDonald GRIMSHAW

Melbourne Metro Rail Project

Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - Arden to Parkville

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd

Figure B.46: Colour coded tunnelling ground-borne noise levels for Western Portal to Parkville Tunnel Precinct

Legend

Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

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

Map 5 of 13

Kensington
Melbourne
South Yarra
0 1 KM

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - Parkville Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.47: Colour coded tunnelling ground-borne noise levels for Parkville Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd

Legend

Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

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

Map 6 of 13

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

aurecon JACOBS Mott MacDonald AJM Joint Venture GRIMSHAW

Melbourne Metro Rail Project

Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - Parkville to CBD North

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By: A. Davy	Approved By: D. Timms	Date: 11/04/2016	Map Size: A4

0 50 100
Metres

Figure B.48: Colour coded tunnelling ground-borne noise levels for Parkville to CBD North Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd

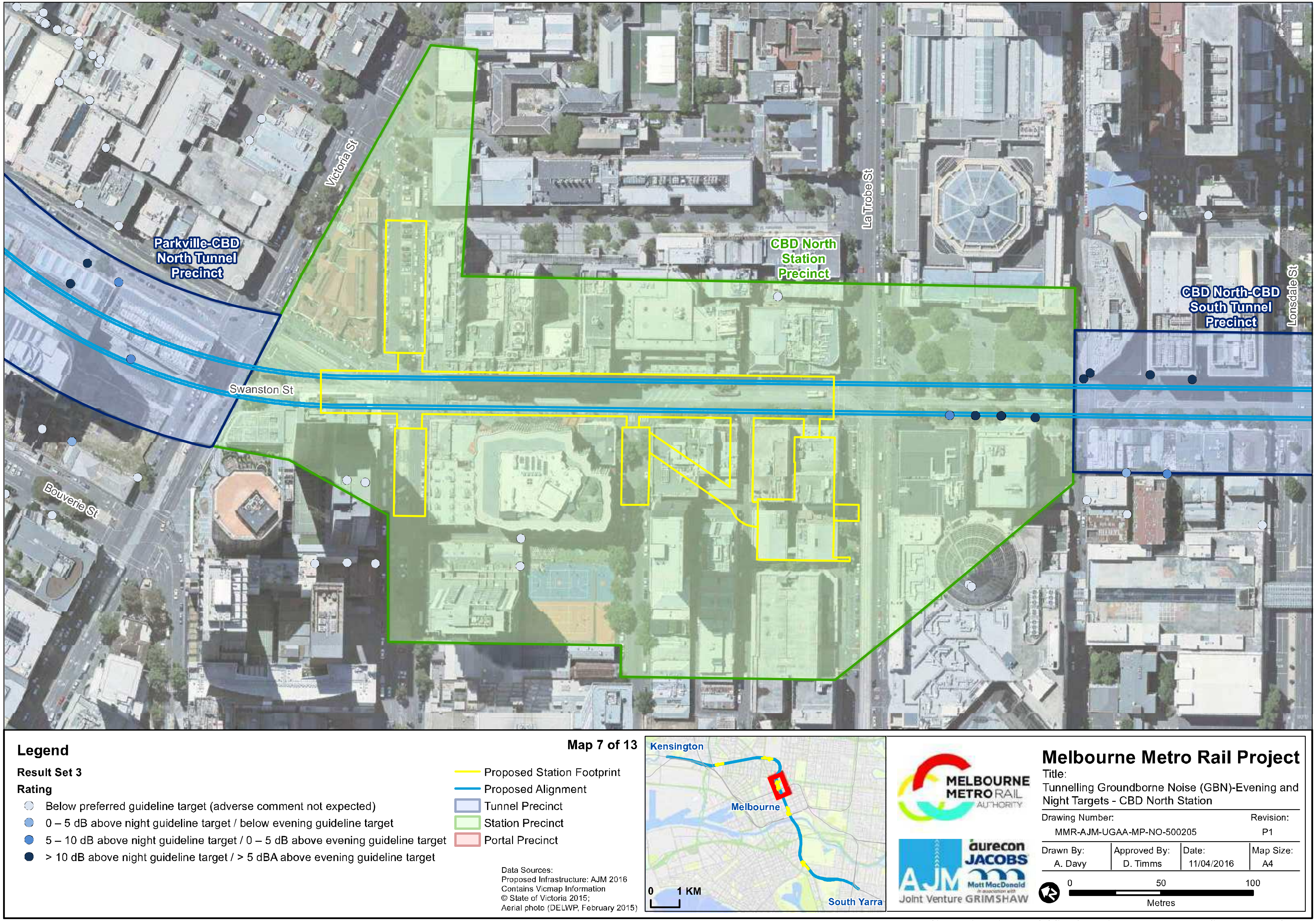

Figure B.49: Colour coded tunnelling ground-borne noise levels for CBD North Station Precinct

Figure B.50: Colour coded tunnelling ground-borne noise levels for CBD North and CBD South Tunnel Precinct

Legend

Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

Map 9 of 13

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

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

Melbourne Metro Rail Project

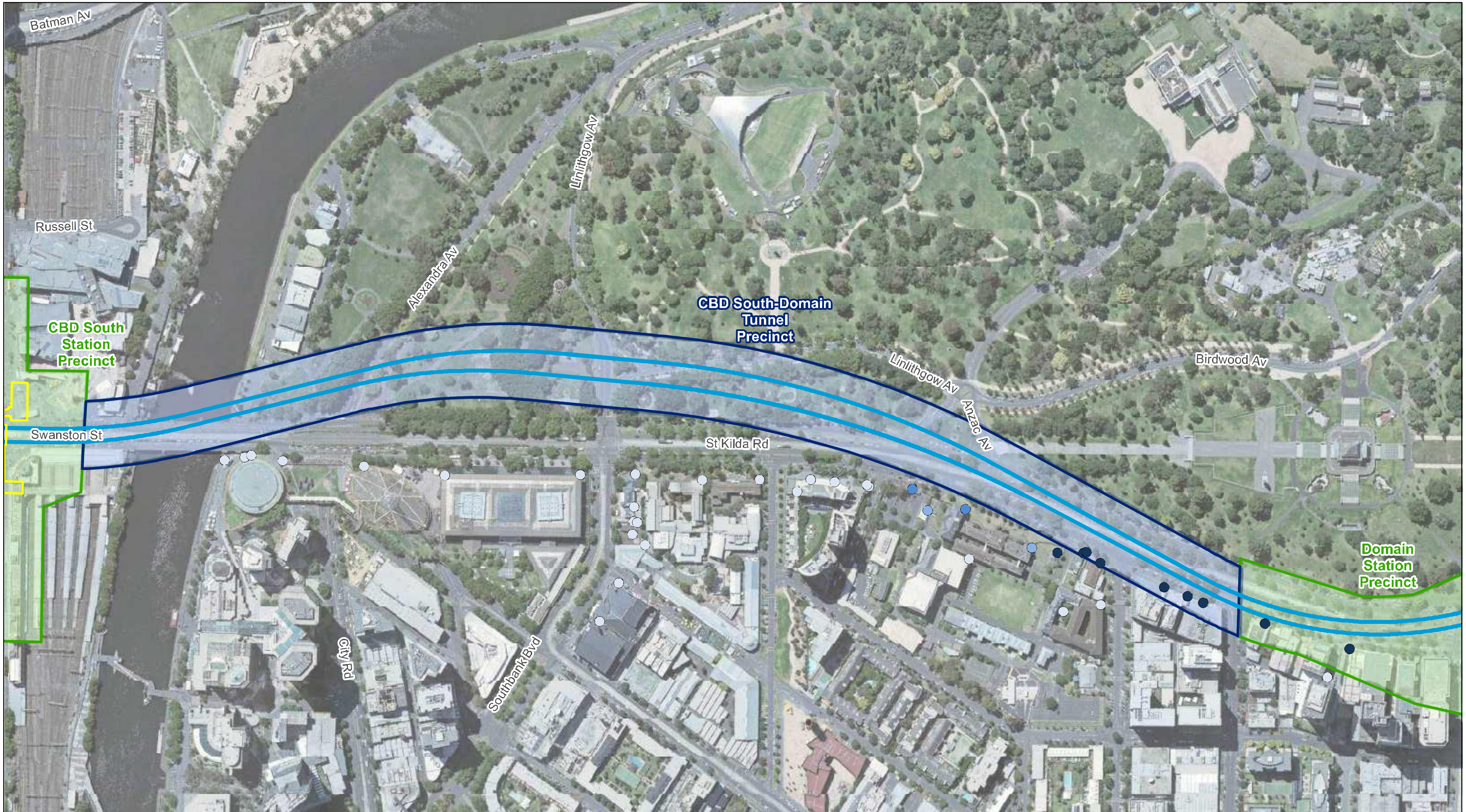
Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - CBD South Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.51: Colour coded tunnelling ground-borne noise levels for CBD South Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd



Legend

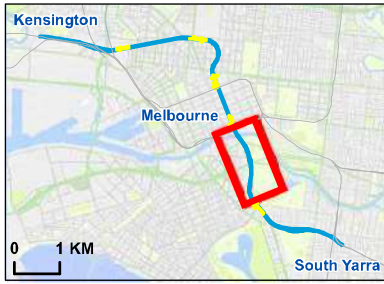
Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

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

Map 10 of 13



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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AJM Joint Venture GRIMSHAW

Melbourne Metro Rail Project

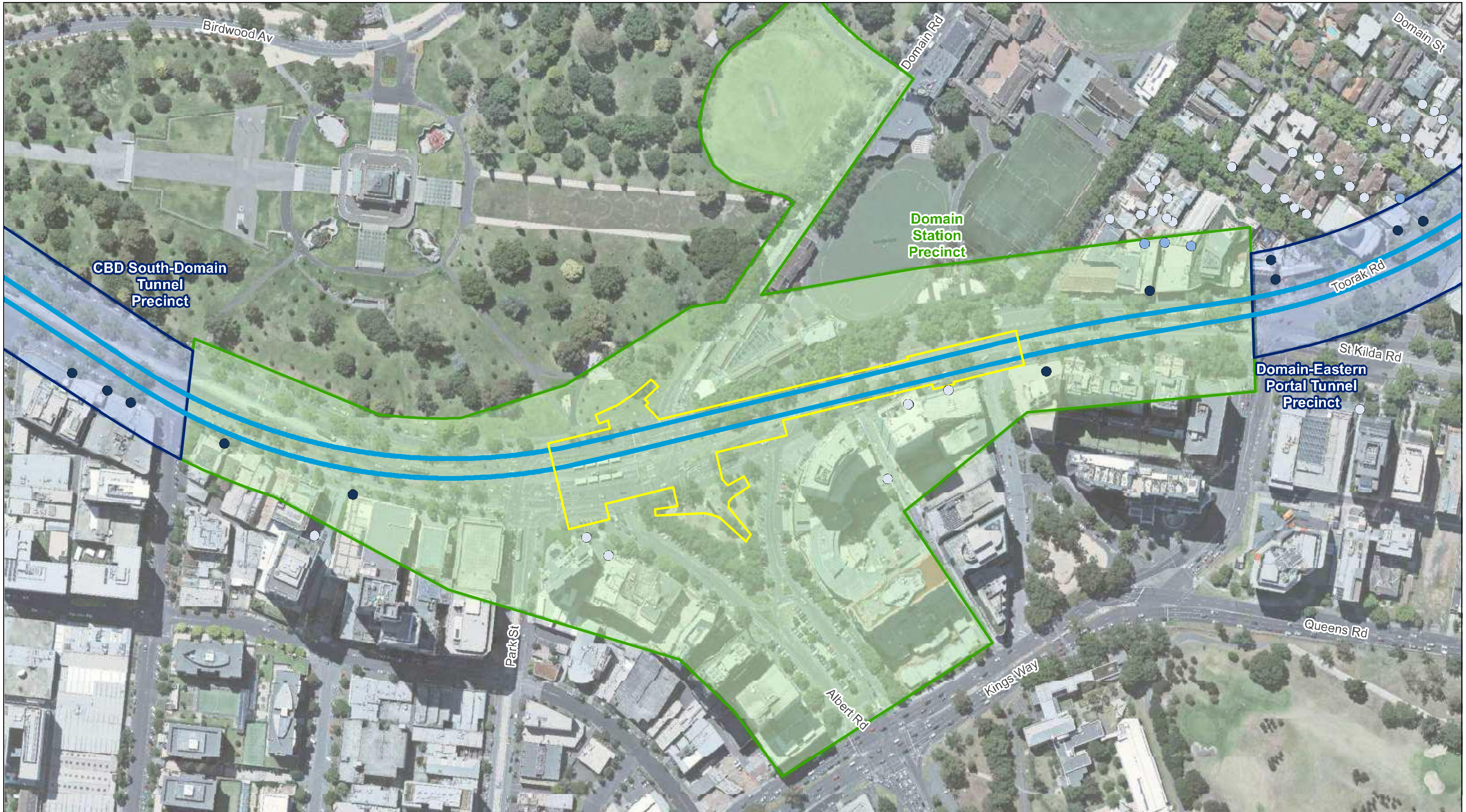
Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - CBD South to Domain

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.52: Colour coded tunnelling ground-borne noise levels for CBD South to Domain Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd



Legend

Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

Map 11 of 13

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

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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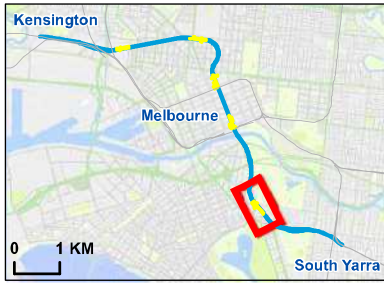


MELBOURNE METRO RAIL AUTHORITY

aurecon JACOBS Mott MacDonald AJM Joint Venture GRIMSHAW

Melbourne Metro Rail Project

Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - Domain Station

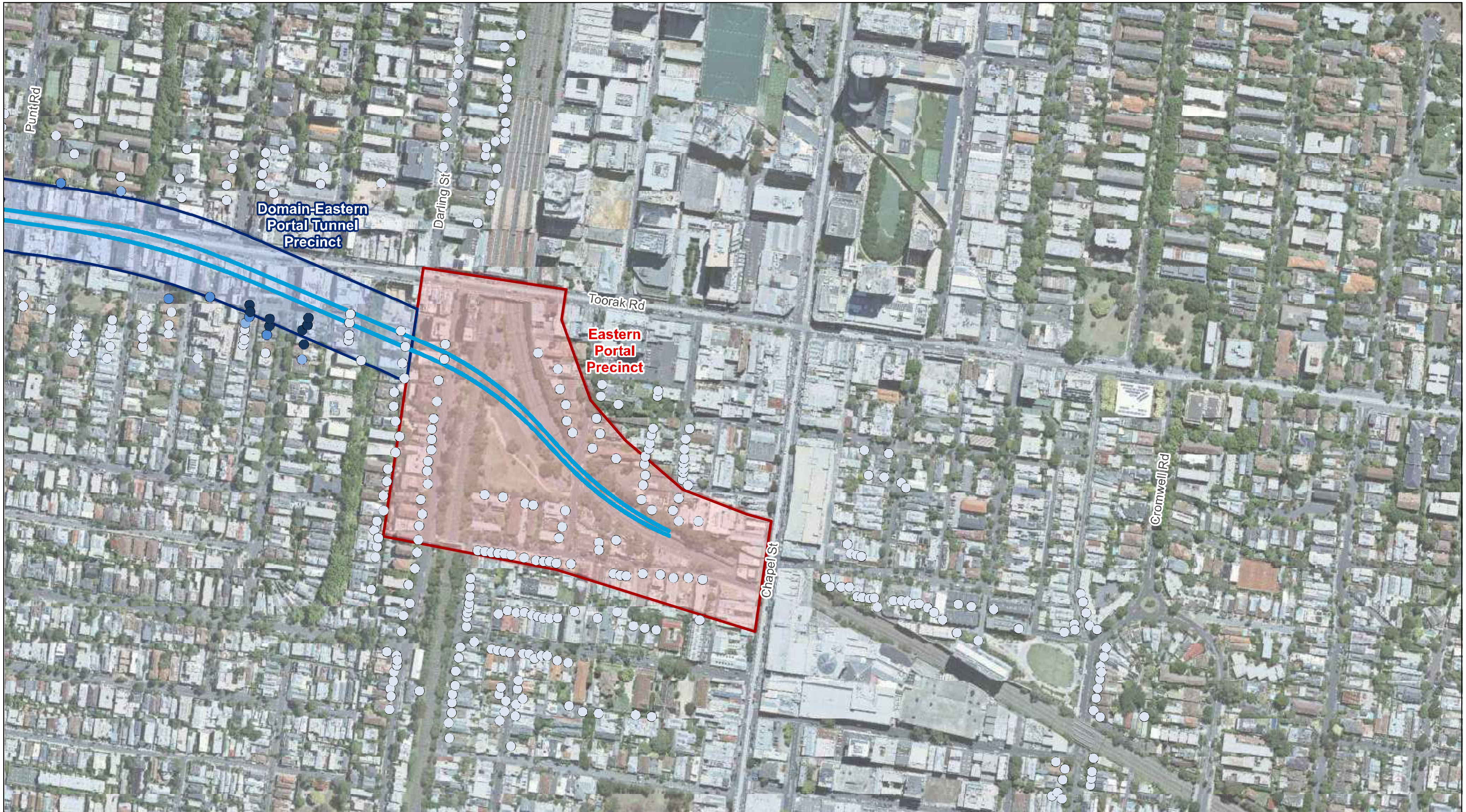
Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd

Figure B.53: Colour coded tunnelling ground-borne noise levels for Domain Station Precinct

Figure B.54: Colour coded tunnelling ground-borne noise levels for Domain to Eastern Tunnel Precinct



Legend

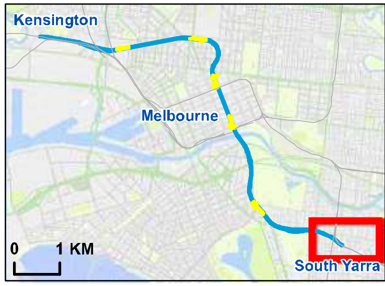
Result Set 3

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dB above night guideline target / below evening guideline target
- 5 – 10 dB above night guideline target / 0 – 5 dB above evening guideline target
- > 10 dB above night guideline target / > 5 dBA above evening guideline target

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

Map 13 of 13



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

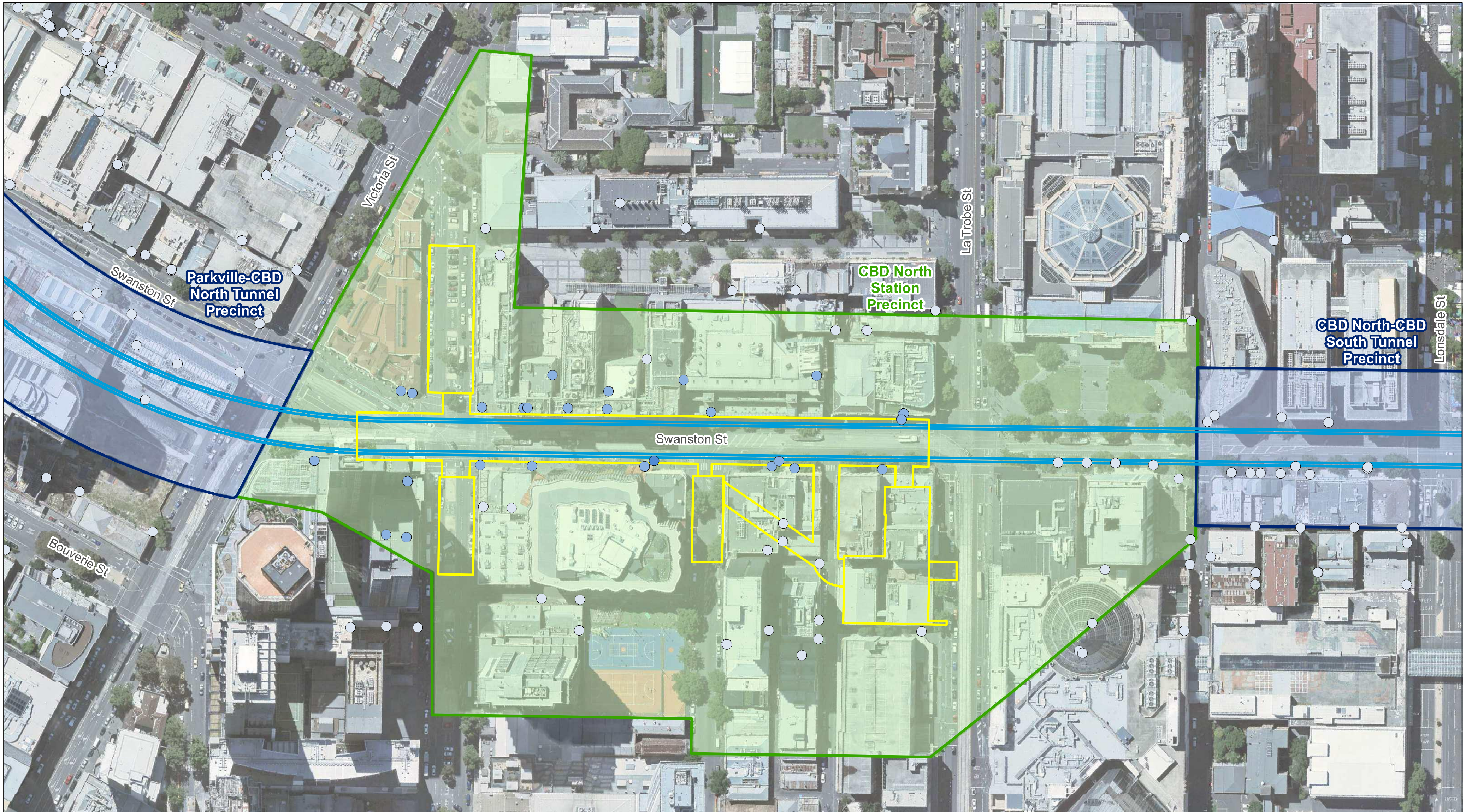
Title:
Tunnelling Groundborne Noise (GBN)-Evening and Night Targets - Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500205			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.55: Colour coded tunnelling ground-borne noise levels for Eastern Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_3.mxd



Legend

VdV Day Target Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

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

Melbourne Metro Rail Project

Title:
Station Cavern Mining Vibration Dosage Value (VdV) - Guideline Day Target - CBD North Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500446			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Station_Cavern_Mining_VdV_Day.mxd

Figure B.56: Colour coded station cavern mining VDV (day) levels for Human Comfort for CBD North Station Precinct

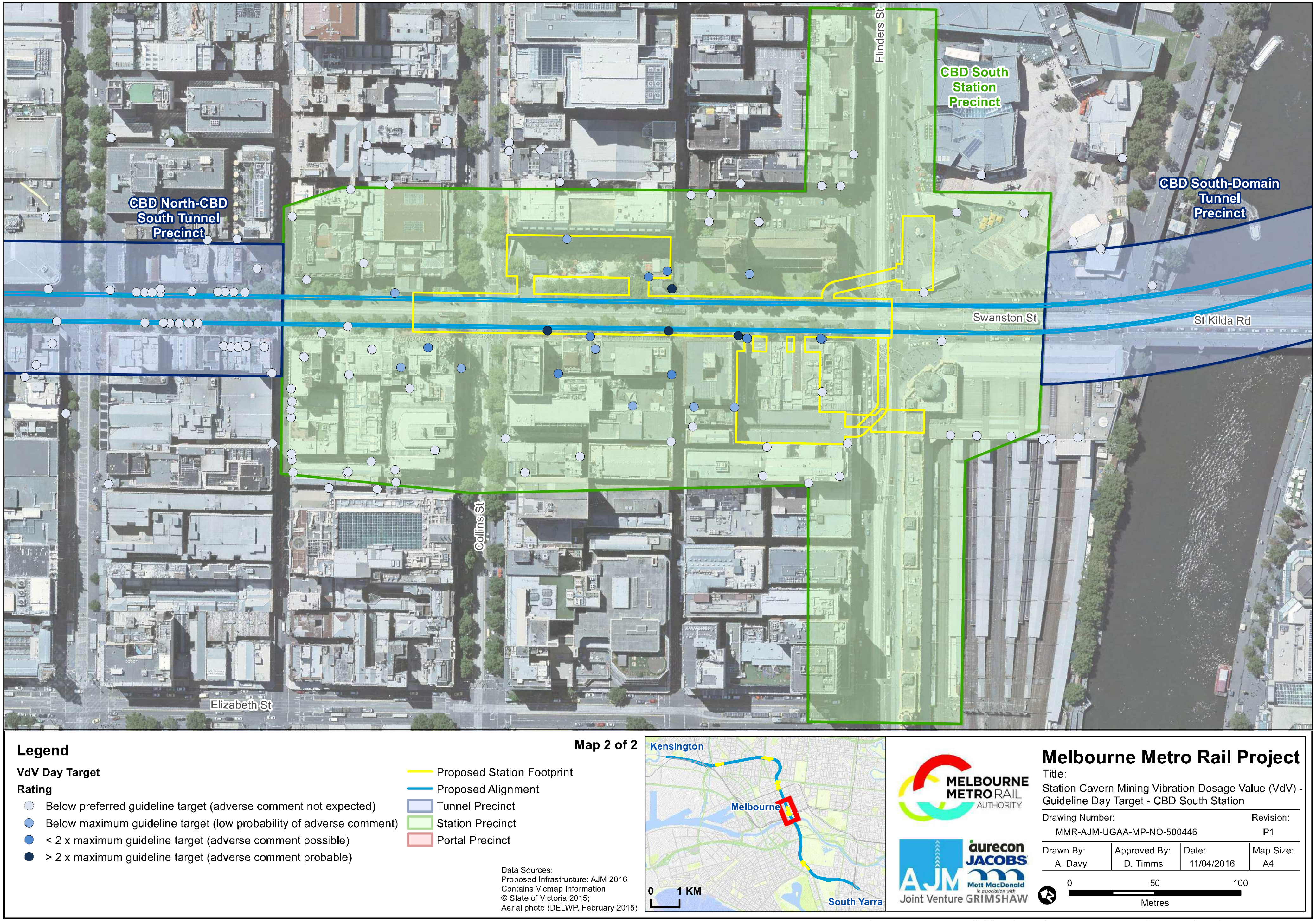
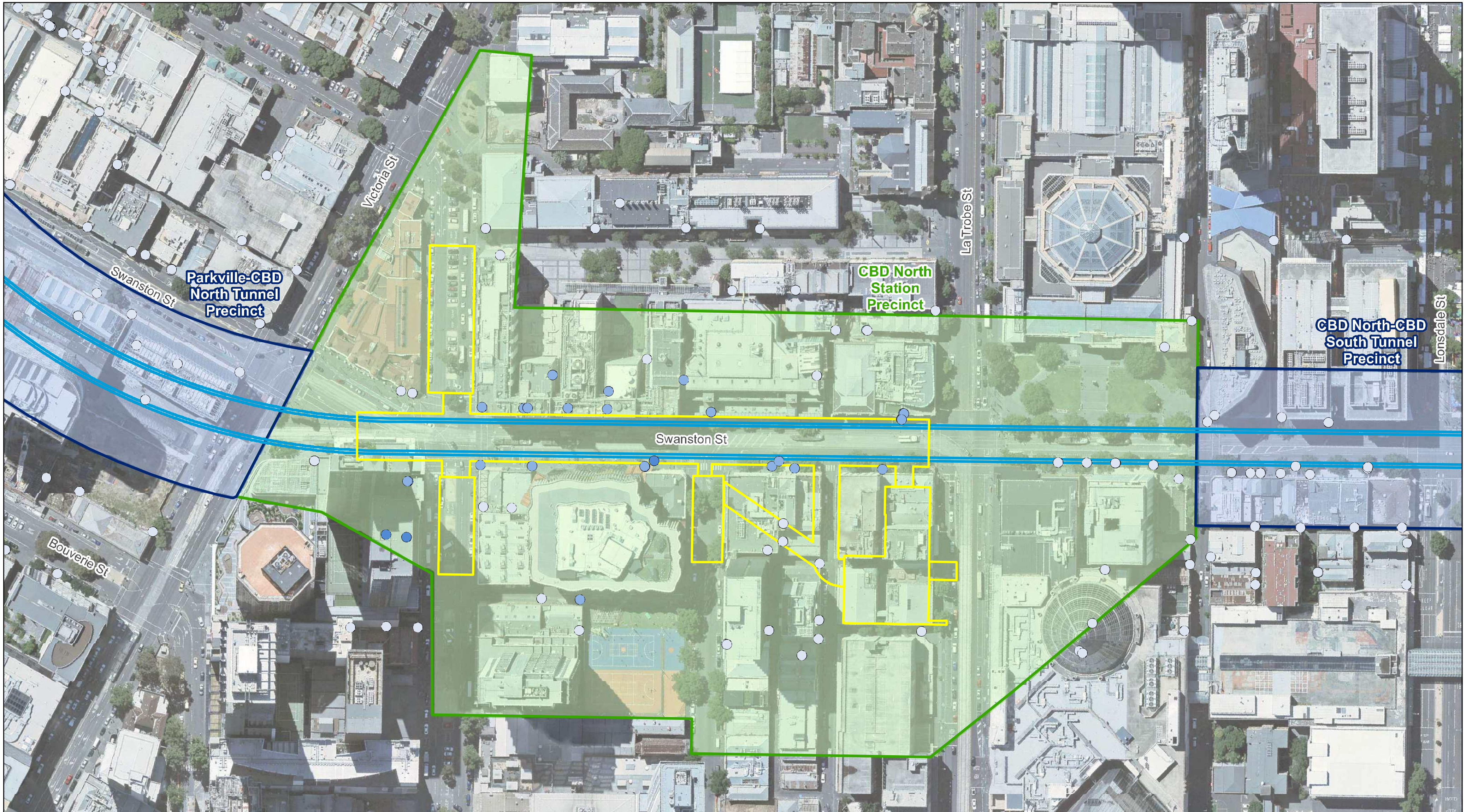


Figure B.57: Colour coded station cavern mining VDV (day) levels for Human Comfort for CBD South Station Precinct



Legend

VdV Night Target Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 1 of 2

Data Sources:
Proposed Infrastructure: AJM 2016
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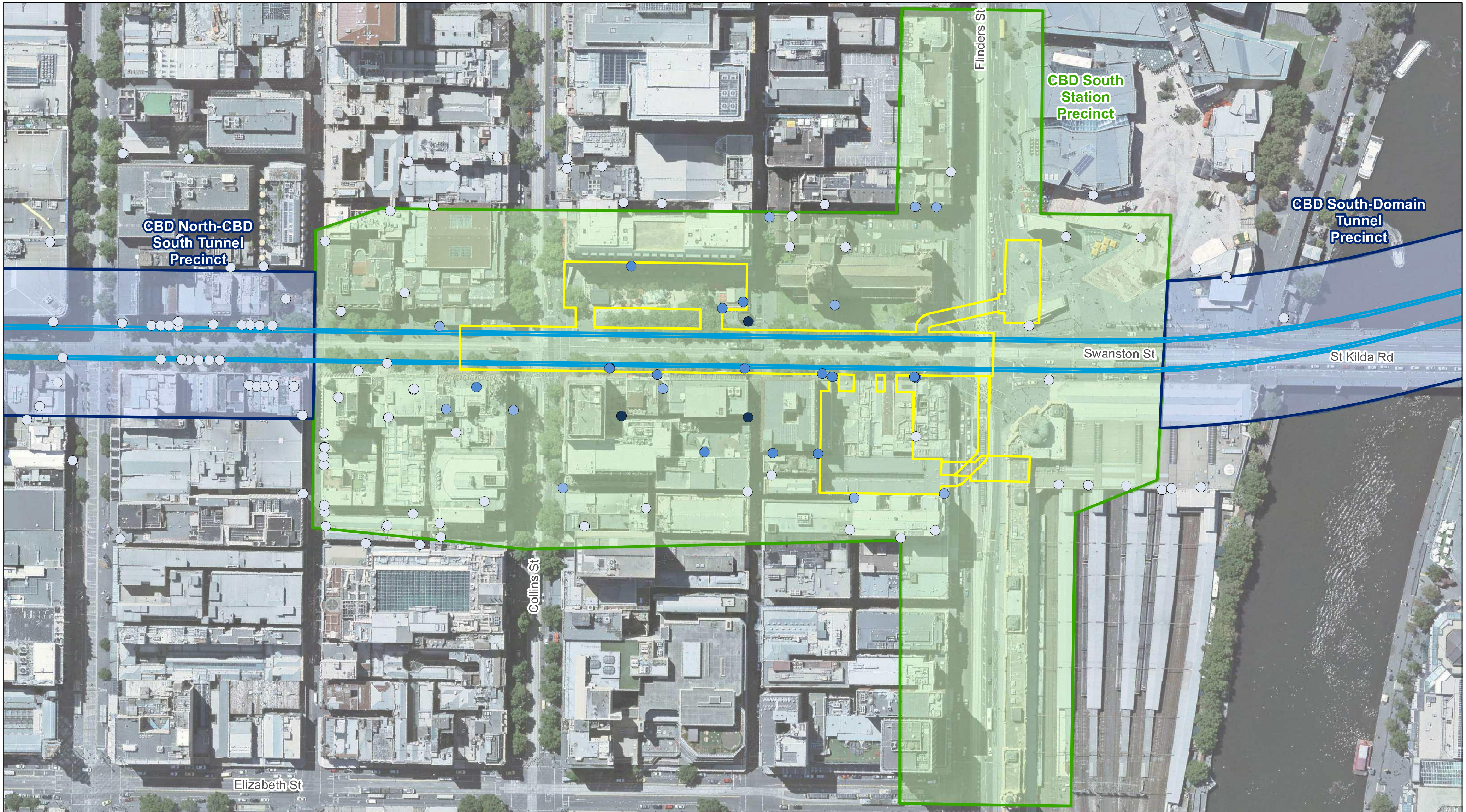
Title:
Station Cavern Mining Vibration Dosage Value (VdV) - Guideline Night Target - CBD North Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500447			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.58: Colour coded station cavern mining VDV (night) levels for Human Comfort for CBD North Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Station_Cavern_Mining_VdV_Night.mxd



Legend

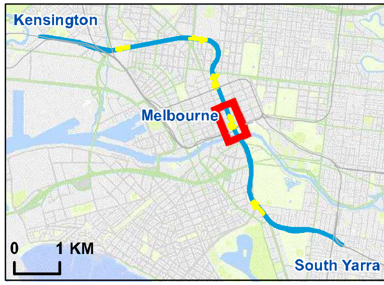
VdV Night Target

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 2 of 2



Data Sources:
Proposed Infrastructure: AJM 2016
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Title:
Station Cavern Mining Vibration Dosage Value (VdV) - Guideline Night Target - CBD South Station

Drawing Number:		Revision:
MMR-AJM-UGAA-MP-NO-500447		P1

Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Station_Cavern_Mining_VdV_Night.mxd

Figure B.59: Colour coded station cavern mining VDV (night) levels for Human Comfort for CBD South Station Precinct

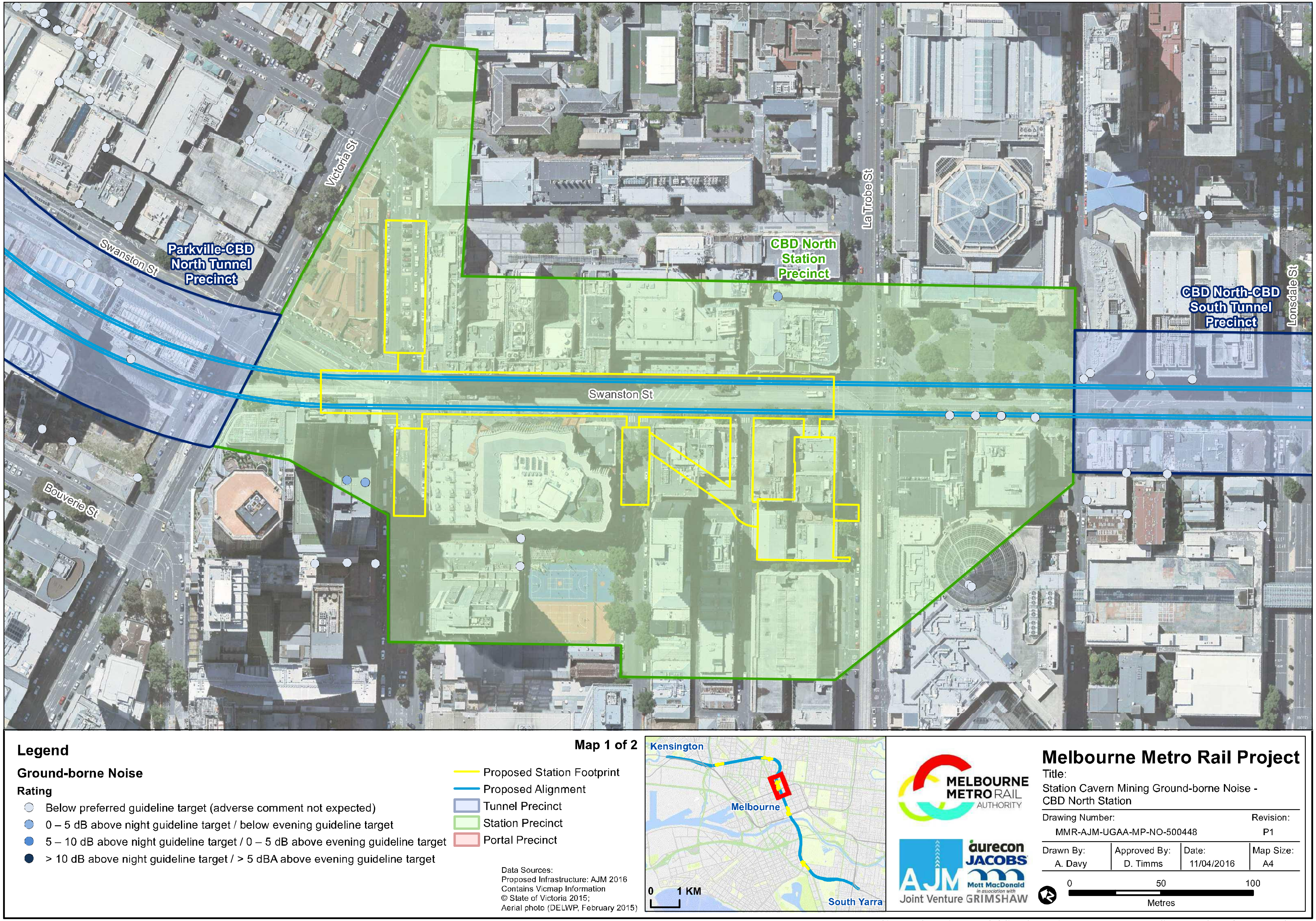


Figure B.60: Colour coded station cavern mining ground-borne noise levels for CBD North Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Station_Cavern_Mining_GBN.mxd

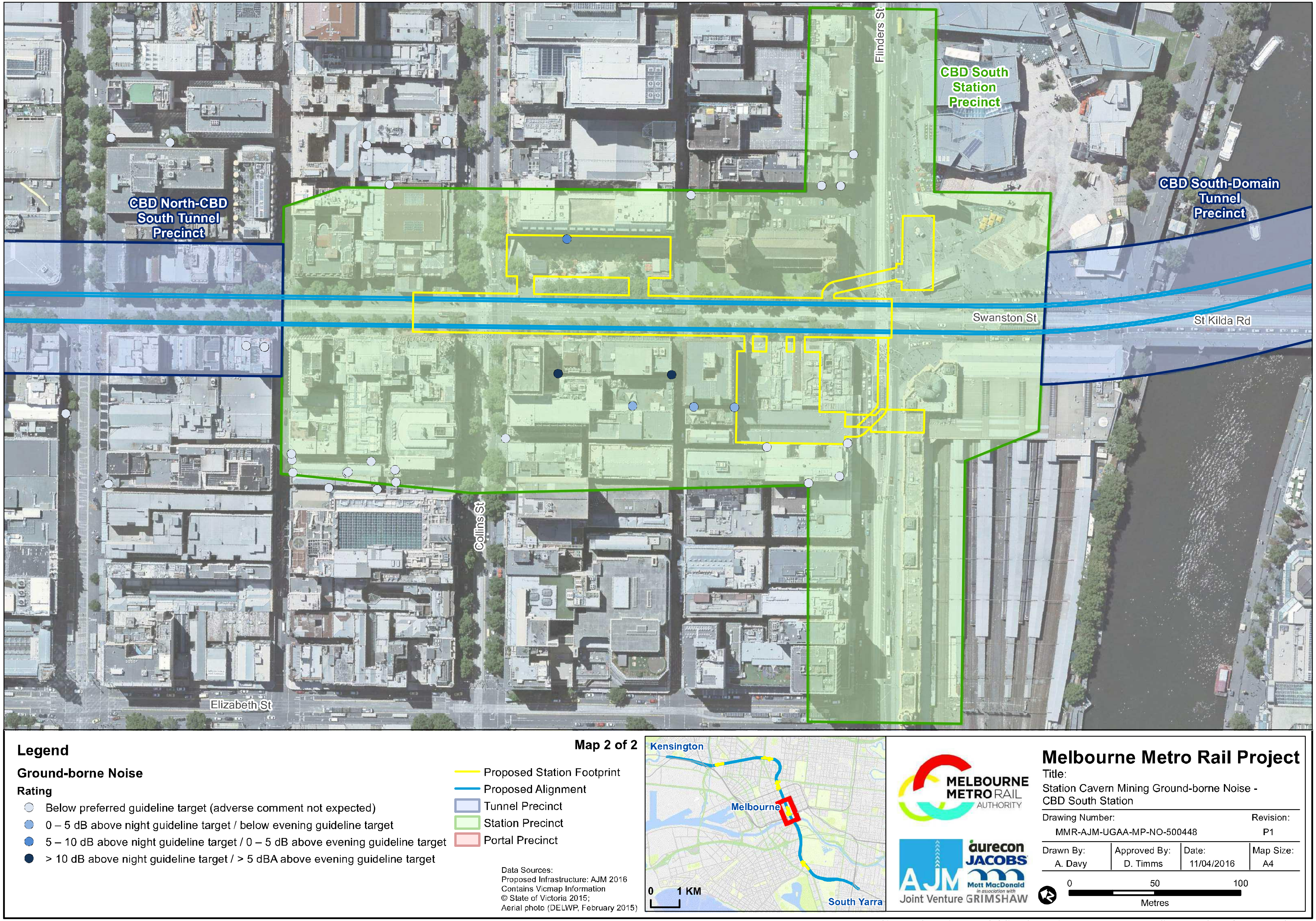


Figure B.61: Colour coded station cavern mining ground-borne noise levels for CBD South Station Precinct

B.5 Results of Initial Vibration and Ground-borne Noise Assessment for Additional Construction Works

Vibration and ground-borne noise has been predicted at each of the Melbourne Metro construction sites. The predictions relate to the highest vibration levels that are predicted to occur at any point in time during the construction. For multiple story buildings, the predictions relate to the vibration levels on the ground floor where vibration levels are expected to be highest. Vibration levels would be lower on higher floors of the multi-story buildings.

Vibration levels have been predicted and compared against the guideline target PPV for building damage (from DIN 4150) and are presented as follows:

- Figure B.62: Colour coded building damage assessment due to Additional Construction Works – Western Portal Precinct
- Figure B.63: Colour coded building damage assessment due to Additional Construction Works – Arden Station Precinct
- Figure B.64: Colour coded building damage assessment due to Additional Construction Works – Parkville Station Precinct
- Figure B.65: Colour coded building damage assessment due to Additional Construction Works – CBD North Station Precinct
- Figure B.66: Colour coded building damage assessment due to Additional Construction Works – CBD South Station Precinct
- Figure B.67: Colour coded building damage assessment due to Additional Construction Works – CBD South to Domain Tunnel Precinct
- Figure B.68: Colour coded building damage assessment due to Additional Construction Works – Domain Station Precinct
- Figure B.69: Colour coded building damage assessment due to Additional Construction Works – Domain to Eastern Tunnel Precinct
- Figure B.70: Colour coded building damage assessment due to Additional Construction Works – Eastern Portal Precinct

VDV day levels have been predicted and compared with the guideline targets and are presented as follows:

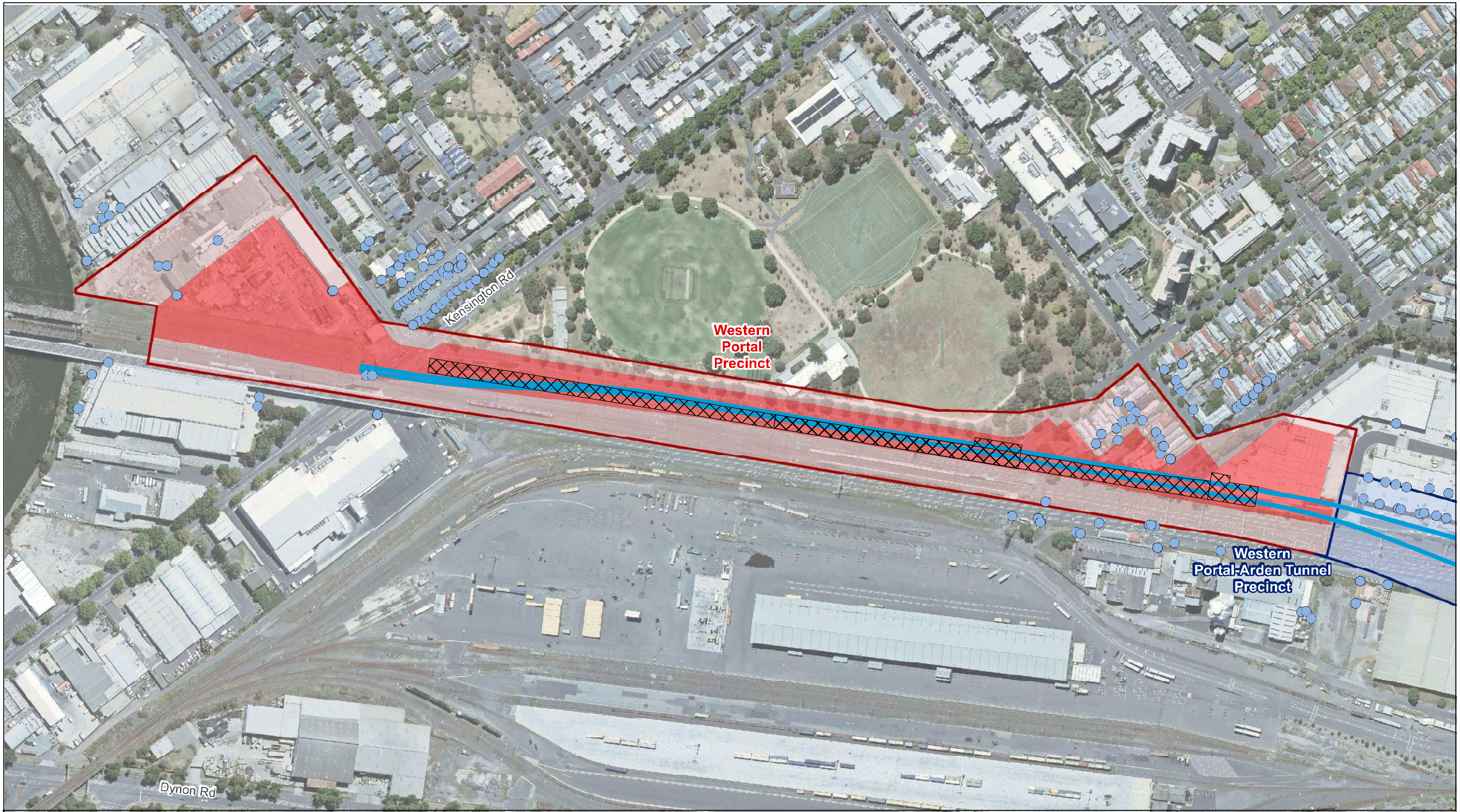
- Figure B.71: Colour coded VDV day assessment for Additional Construction Works – Western Portal Precinct
- Figure B.72: Colour coded VDV day assessment for Additional Construction Works – Arden Station Precinct
- Figure B.73: Colour coded VDV day assessment for Additional Construction Works – Parkville Station Precinct
- Figure B.74: Colour coded VDV day assessment for Additional Construction Works – CBD North Station Precinct
- Figure B.75: Colour coded VDV day assessment for Additional Construction Works – CBD South Station Precinct
- Figure B.76: Colour coded VDV day assessment for Additional Construction Works – Domain Station Precinct
- Figure B.77: Colour coded VDV day assessment for Additional Construction Works – Domain to Eastern Portal Tunnels Precinct
- Figure B.78: Colour coded VDV day assessment for Additional Construction Works – Eastern Portal Precinct

VDV night levels have been predicted and compared with the guideline targets and are presented as follows:

- Figure B.79: Colour coded VDV night assessment for Additional Construction Works – Western Portal Precinct
- Figure B.80: Colour coded VDV night assessment for Additional Construction Works – Arden Station Precinct
- Figure B.81: Colour coded VDV night assessment for Additional Construction Works – Parkville Station Precinct
- Figure B.82: Colour coded VDV night assessment for Additional Construction Works – CBD North Station Precinct
- Figure B.83: Colour coded VDV night assessment for Additional Construction Works – CBD South Station Precinct
- Figure B.84: Colour coded VDV night assessment for Additional Construction Works – Domain Station Precinct
- Figure B.85: Colour coded VDV night assessment for Additional Construction Works – Domain to Eastern Portal Tunnels Precinct
- Figure B.86: Colour coded VDV night assessment for Additional Construction Works – Eastern Portal Precinct

Ground-borne noise levels have been predicted and compared against the guideline ground-borne noise targets and are presented as follows:

- Figure B.87: Colour coded ground-borne noise assessment for Additional Construction Works – Western Portal Precinct
- Figure B.88: Colour coded ground-borne noise assessment for Additional Construction Works – Arden Station Precinct
- Figure B.89: Colour coded ground-borne noise assessment for Additional Construction Works – Parkville Station Precinct
- Figure B.90: Colour coded ground-borne noise assessment for Additional Construction Works – CBD North Station Precinct
- Figure B.91: Colour coded ground-borne noise assessment for Additional Construction Works – CBD South Station Precinct
- Figure B.92: Colour coded ground-borne noise assessment for Additional Construction Works – CBD South to Domain Tunnel Precinct
- Figure B.93: Colour coded ground-borne noise assessment for Additional Construction Works – Domain Station Precinct
- Figure B.94: Colour coded ground-borne noise assessment for Additional Construction Works – Domain to Eastern Tunnel Precinct
- Figure B.95: Colour coded ground-borne noise assessment for Additional Construction Works – Eastern Portal Precinct



Legend

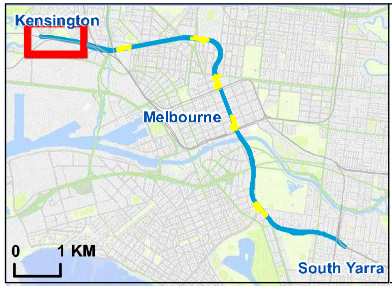
Result Set 4

Rating

- Below PPV guideline target (cosmetic damage is not expected)
- Above PPV guideline target (trigger level for further investigation)

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 1 of 9



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information

Aerial photo (DELWP, February 2015)

MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Building Damage (PPV) - Western Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.62: Colour coded building damage assessment due to Additional Construction Works – Western Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

Legend

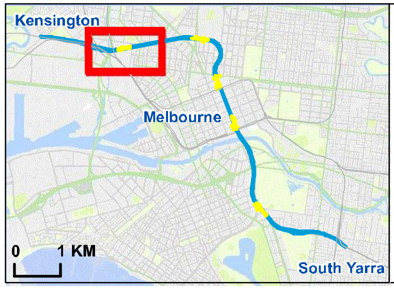
Result Set 4

Rating

- Below PPV guideline target (cosmetic damage is not expected)
- Above PPV guideline target (trigger level for further investigation)

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 2 of 9



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

Title:
Additional Construction Works Building Damage (PPV) - Arden Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.63: Colour coded building damage assessment due to Additional Construction Works – Arden Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

Legend

Result Set 4

Rating

- Below PPV guideline target (cosmetic damage is not expected)
- Above PPV guideline target (trigger level for further investigation)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 3 of 9

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture: aurecon, JACOBS, Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Building Damage (PPV) - Parkville Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.64: Colour coded building damage assessment due to Additional Construction Works – Parkville Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

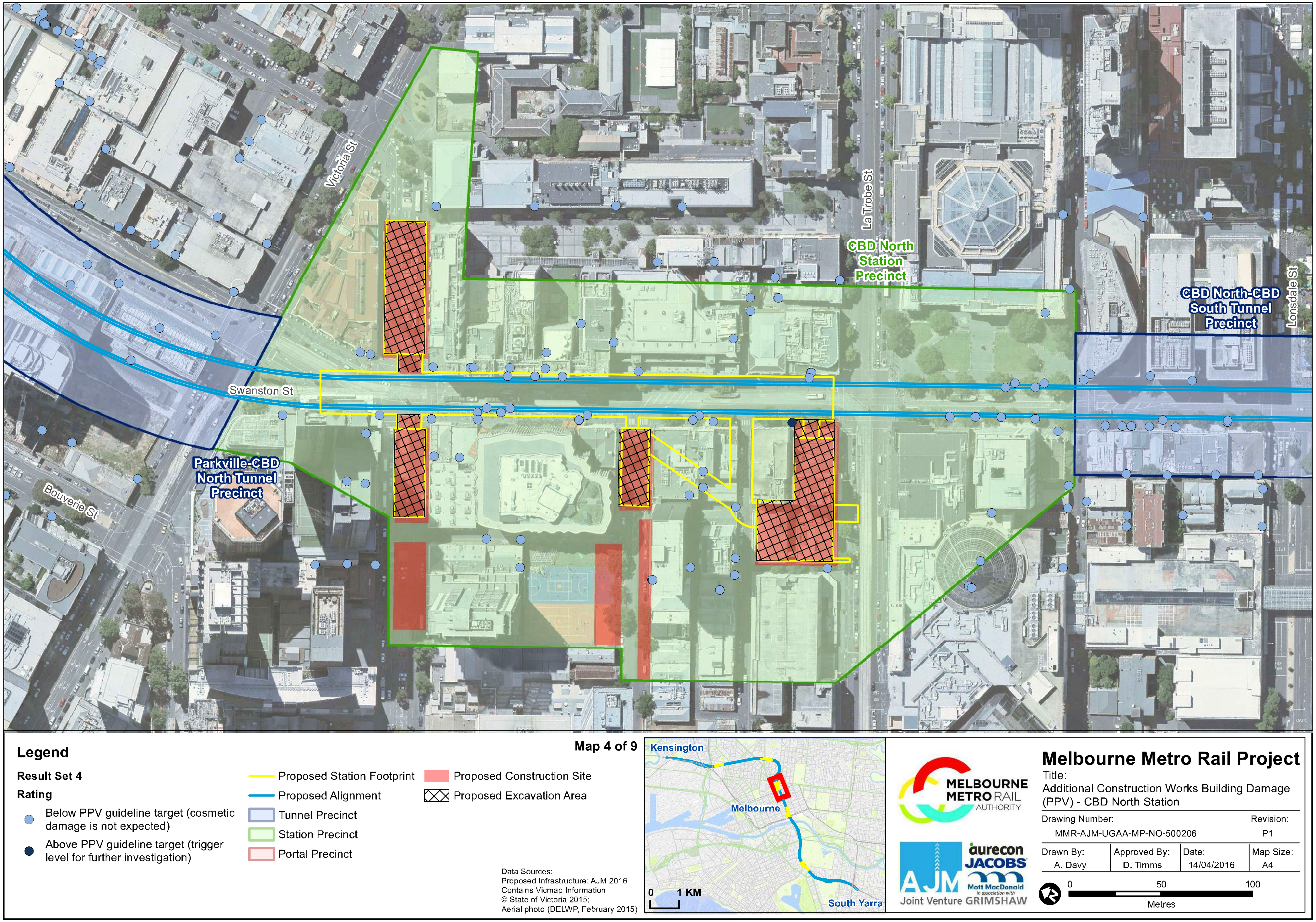
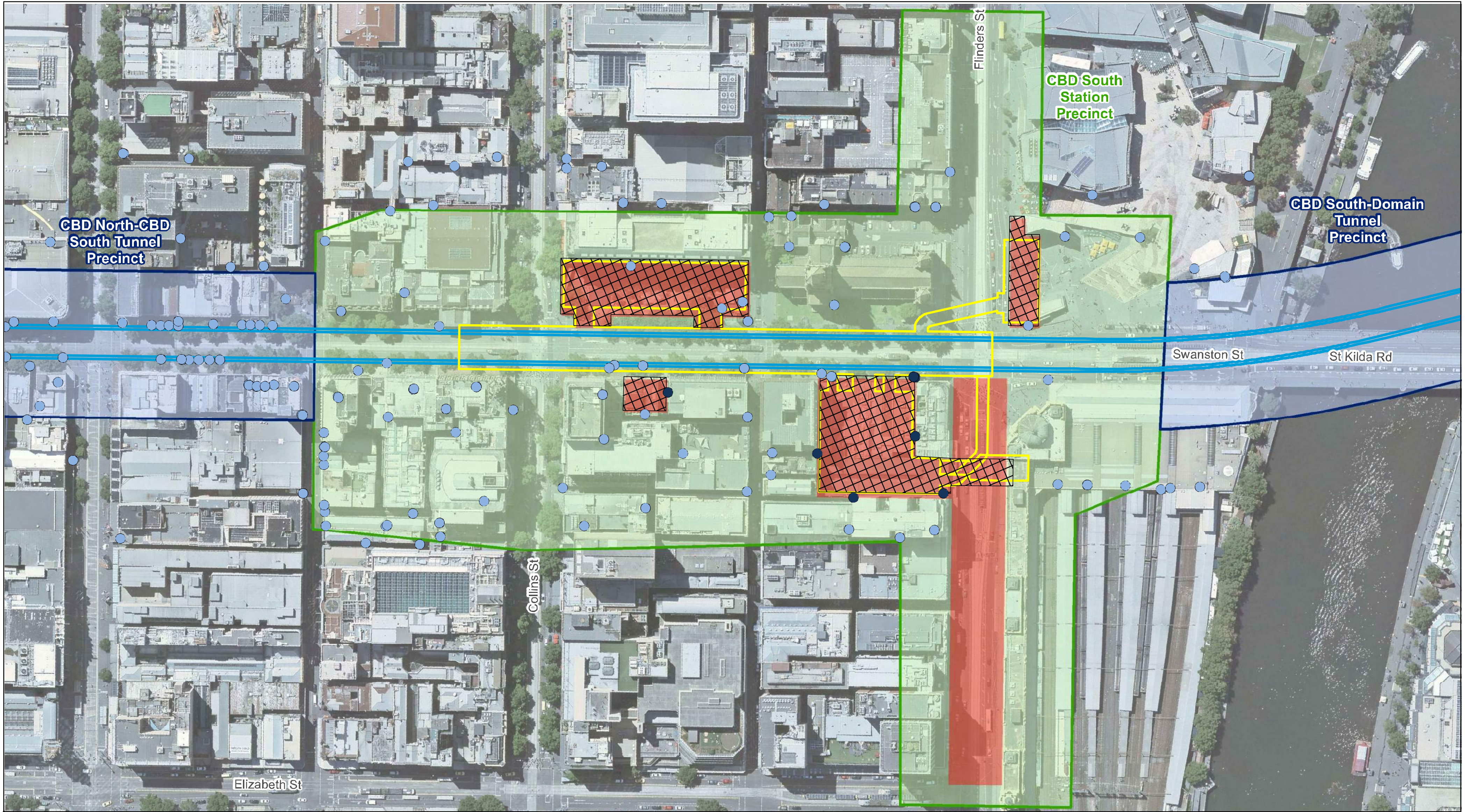


Figure B.65: Colour coded building damage assessment due to Additional Construction Works – CBD North Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd



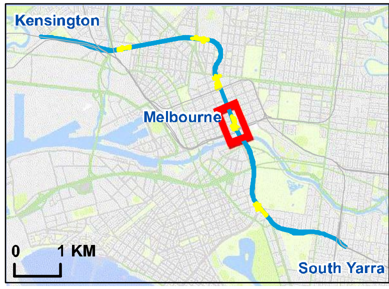
Legend

Result Set 4

Rating

- Below PPV guideline target (cosmetic damage is not expected)
- Above PPV guideline target (trigger level for further investigation)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 5 of 9



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information

Aerial photo (DELWP, February 2015)

MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

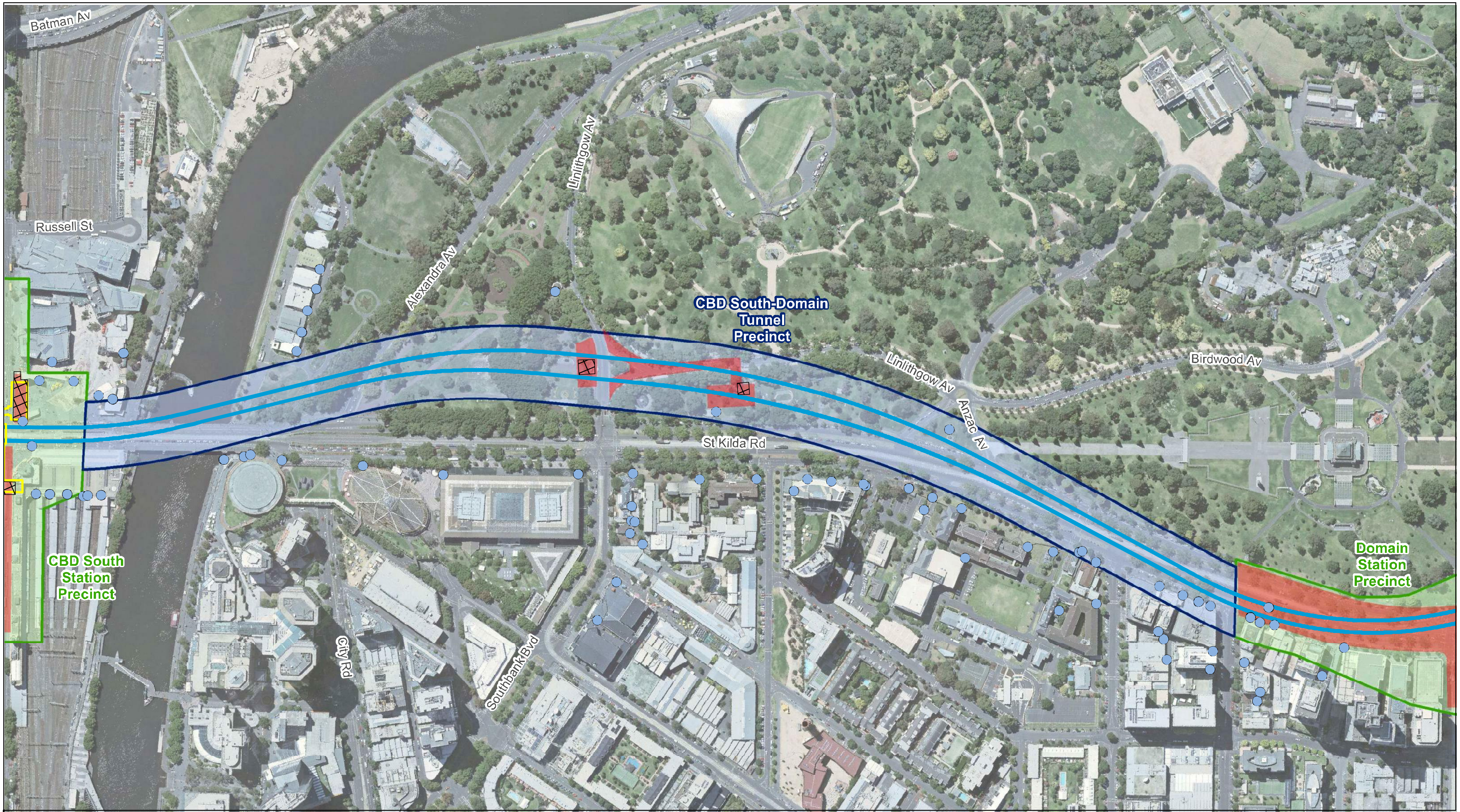
Title:
Additional Construction Works Building Damage (PPV) - CBD South Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

Figure B.66: Colour coded building damage assessment due to Additional Construction Works – CBD South Station Precinct



Legend

Result Set 4

Rating

- Below PPV guideline target (cosmetic damage is not expected)
- Above PPV guideline target (trigger level for further investigation)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

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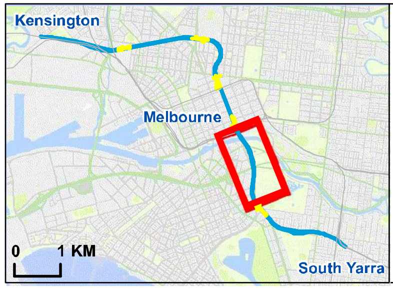
Aerial photo (DELWP, February 2015)

Map 6 of 9



MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Building Damage (PPV) - CBD South to Domain

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.67: Colour coded building damage assessment due to Additional Construction Works – CBD South to Domain Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

Legend

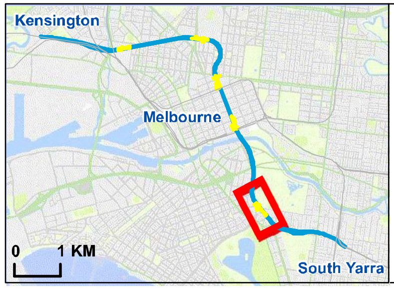
Result Set 4

Rating

- Below PPV guideline target (cosmetic damage is not expected)
- Above PPV guideline target (trigger level for further investigation)

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 7 of 9



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 in association with GRIMSHAW

Melbourne Metro Rail Project

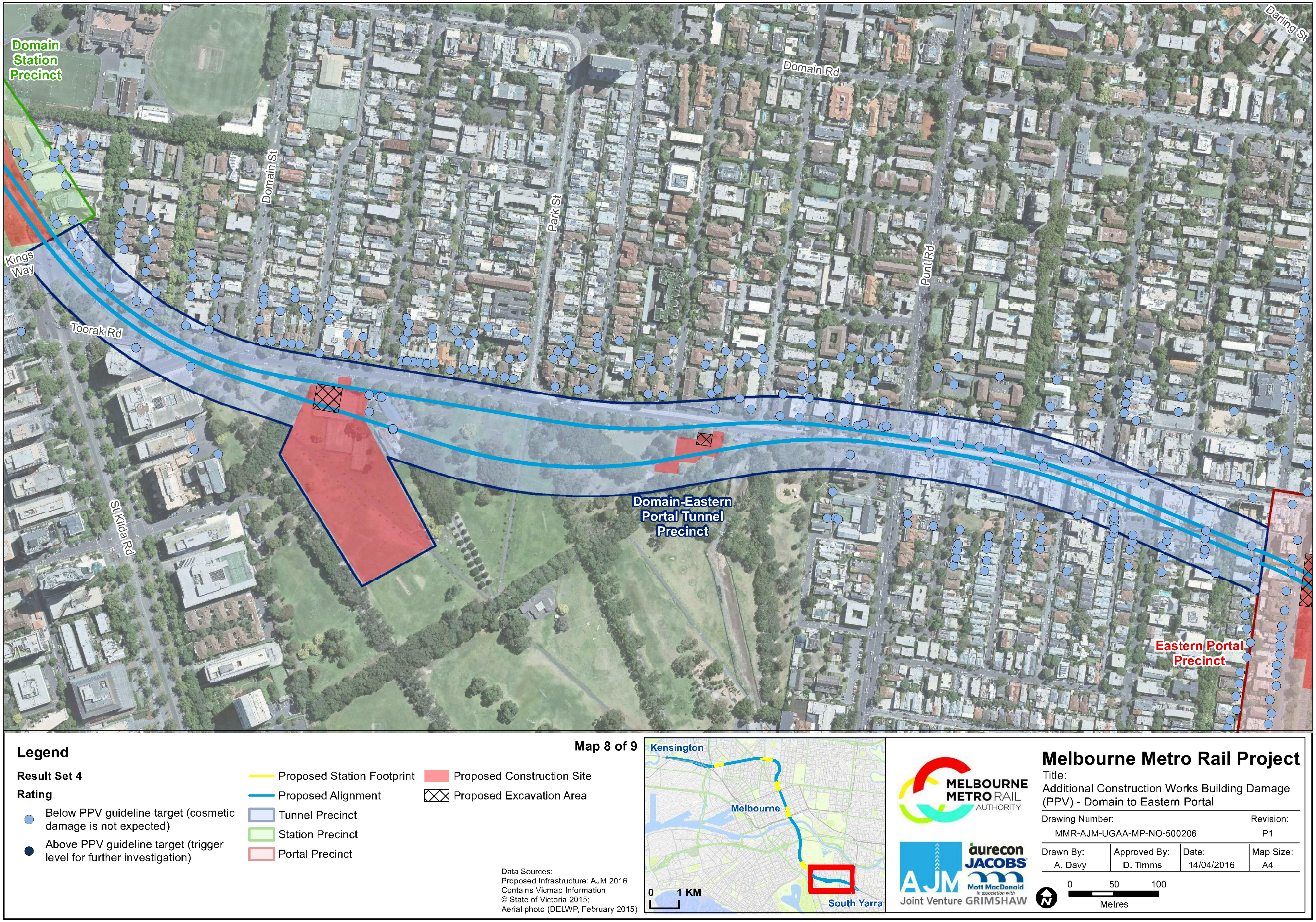
Title:
Additional Construction Works Building Damage (PPV) - Domain Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

Figure B.68: Colour coded building damage assessment due to Additional Construction Works – Domain Station Precinct



Melbourne Metro Rail Project

Title:
Additional Construction Works Building Damage (PPV) - Domain to Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

Figure B.69: Colour coded building damage assessment due to Additional Construction Works – Domain to Eastern Tunnel Precinct

Legend

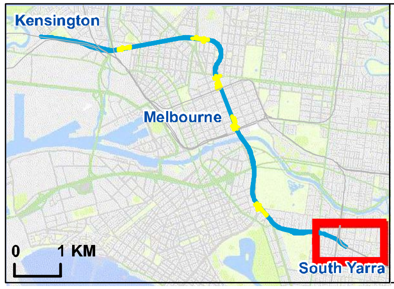
Result Set 4

Rating

- Below PPV guideline target (cosmetic damage is not expected)
- Above PPV guideline target (trigger level for further investigation)
- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 9 of 9

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



Melbourne Metro Rail Project

Title:
Additional Construction Works Building Damage (PPV) - Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500206			P1
Drawn By: A. Davy	Approved By: D. Timms	Date: 14/04/2016	Map Size: A4

0 50 100
Metres

Figure B.70: Colour coded building damage assessment due to Additional Construction Works – Eastern Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_4.mxd

Legend

Result Set 6

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

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

Map 1 of 13

MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture

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Melbourne Metro Rail Project

Title:

Additional Construction Works Vibration Dosage Value (VdV) - Guideline Day Target - Western Portal

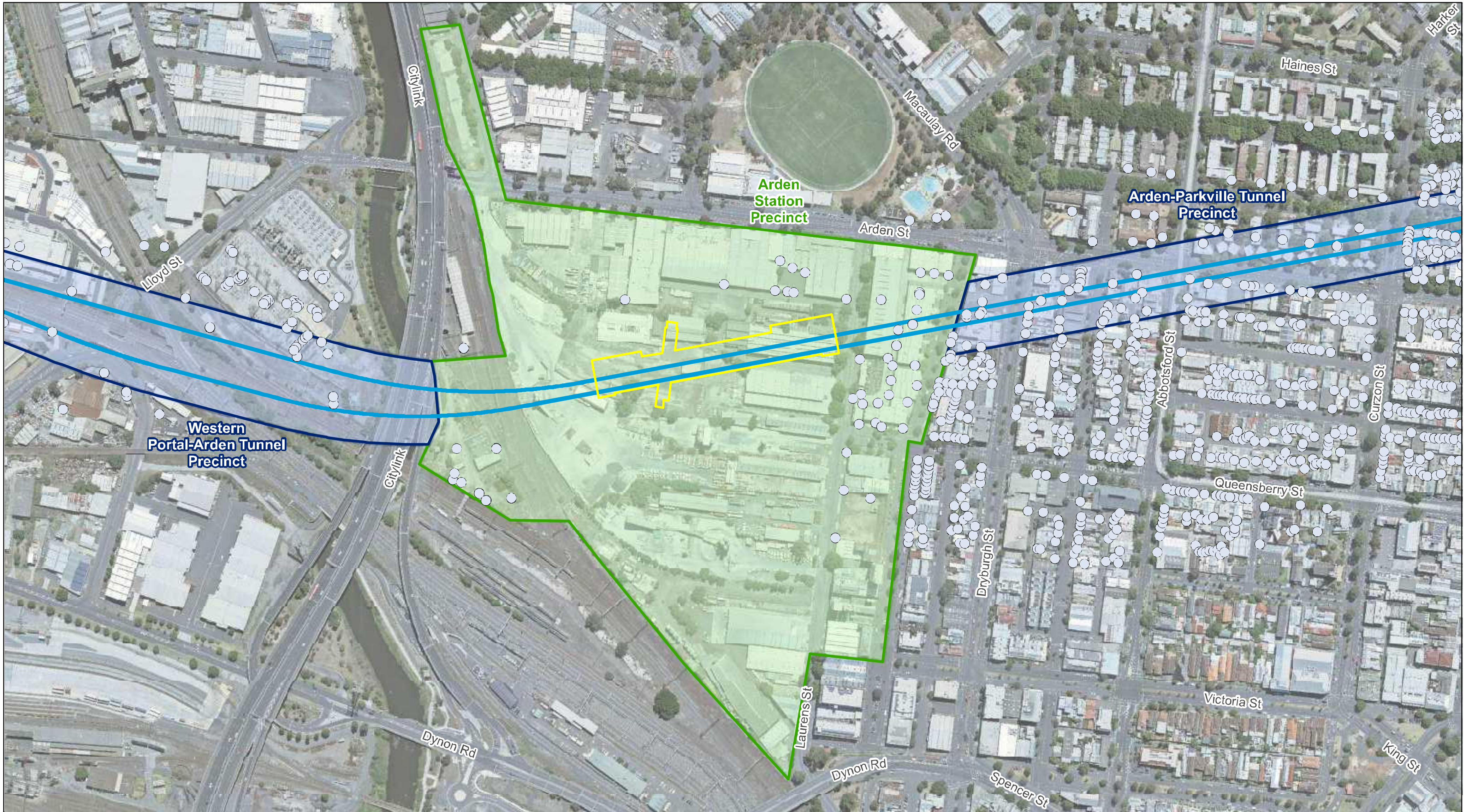
Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500293			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100

Metres

Figure B.71: Colour coded VDV day assessment for Additional Construction Works – Western Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_6.mxd



Legend

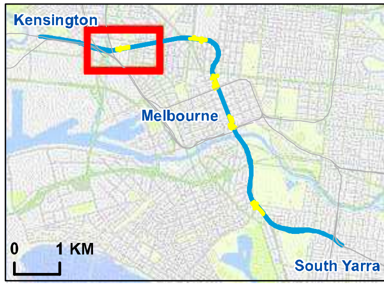
Result Set 6

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 3 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:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Day Target - Arden Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500293			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.72: Colour coded VDV day assessment for Additional Construction Works – Arden Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_6.mxd

Legend

Result Set 6

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 5 of 13

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

MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture — aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

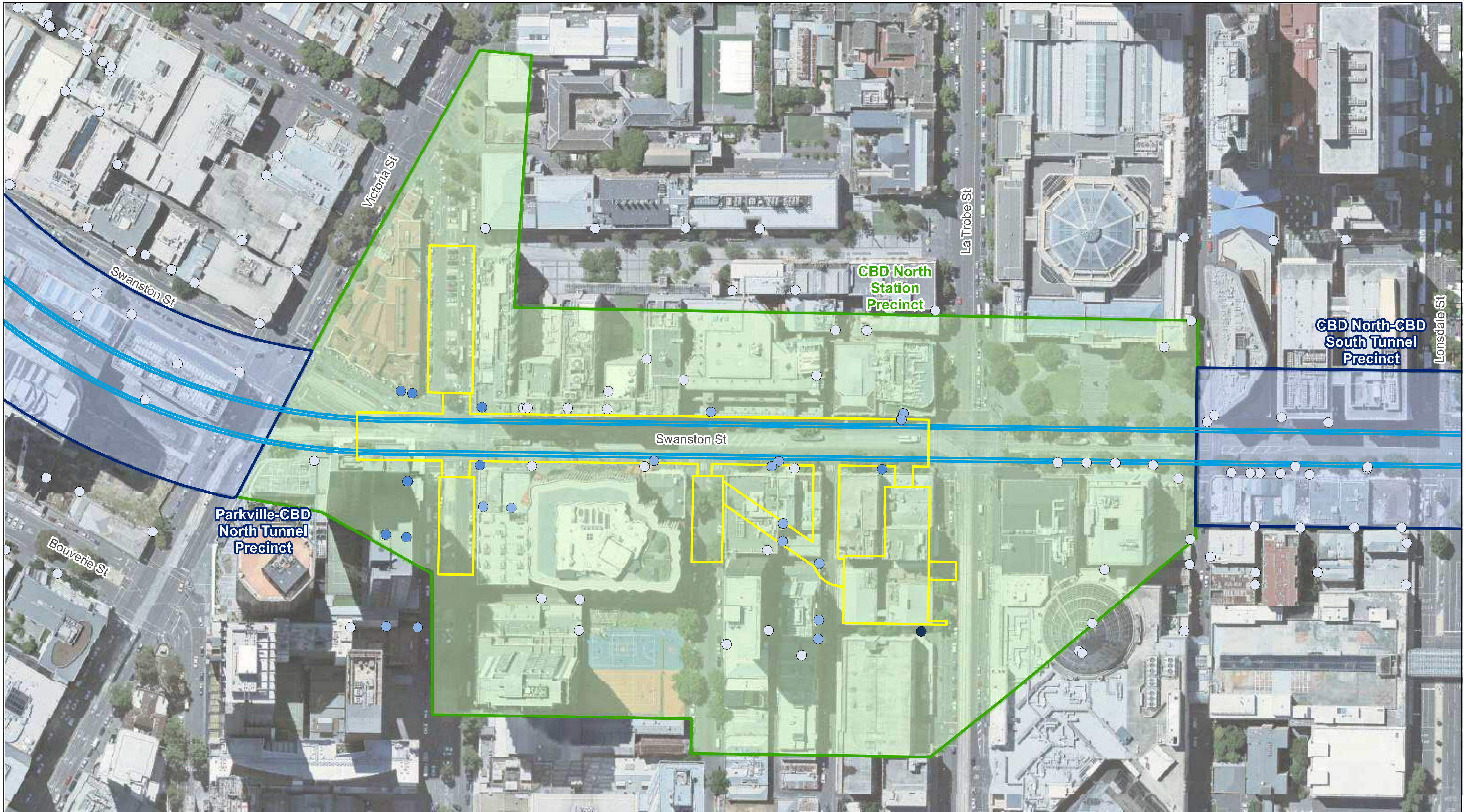
Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Day Target - Parkville Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500293			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.73: Colour coded VDV day assessment for Additional Construction Works – Parkville Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_6.mxd



Legend

Result Set 6

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 7 of 13

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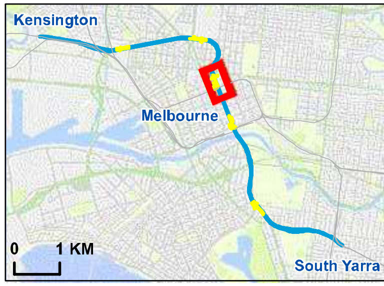
Aerial photo (DELWP, February 2015)



Melbourne Metro Rail Project

Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Day Target - CBD North Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500293			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_6.mxd

Figure B.74: Colour coded VDV day assessment for Additional Construction Works – CBD North Station Precinct

Legend

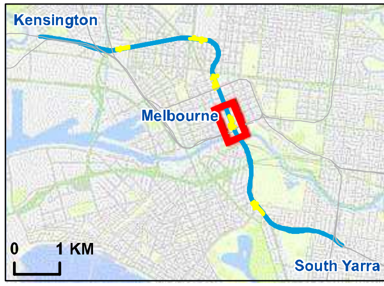
Result Set 6

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 9 of 13



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information

Aerial photo (DELWP, February 2015)

Melbourne Metro Rail Project

Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Day Target - CBD South Station

Drawing Number: MMR-AJM-UGAA-MP-NO-500293
Revision: P1

Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

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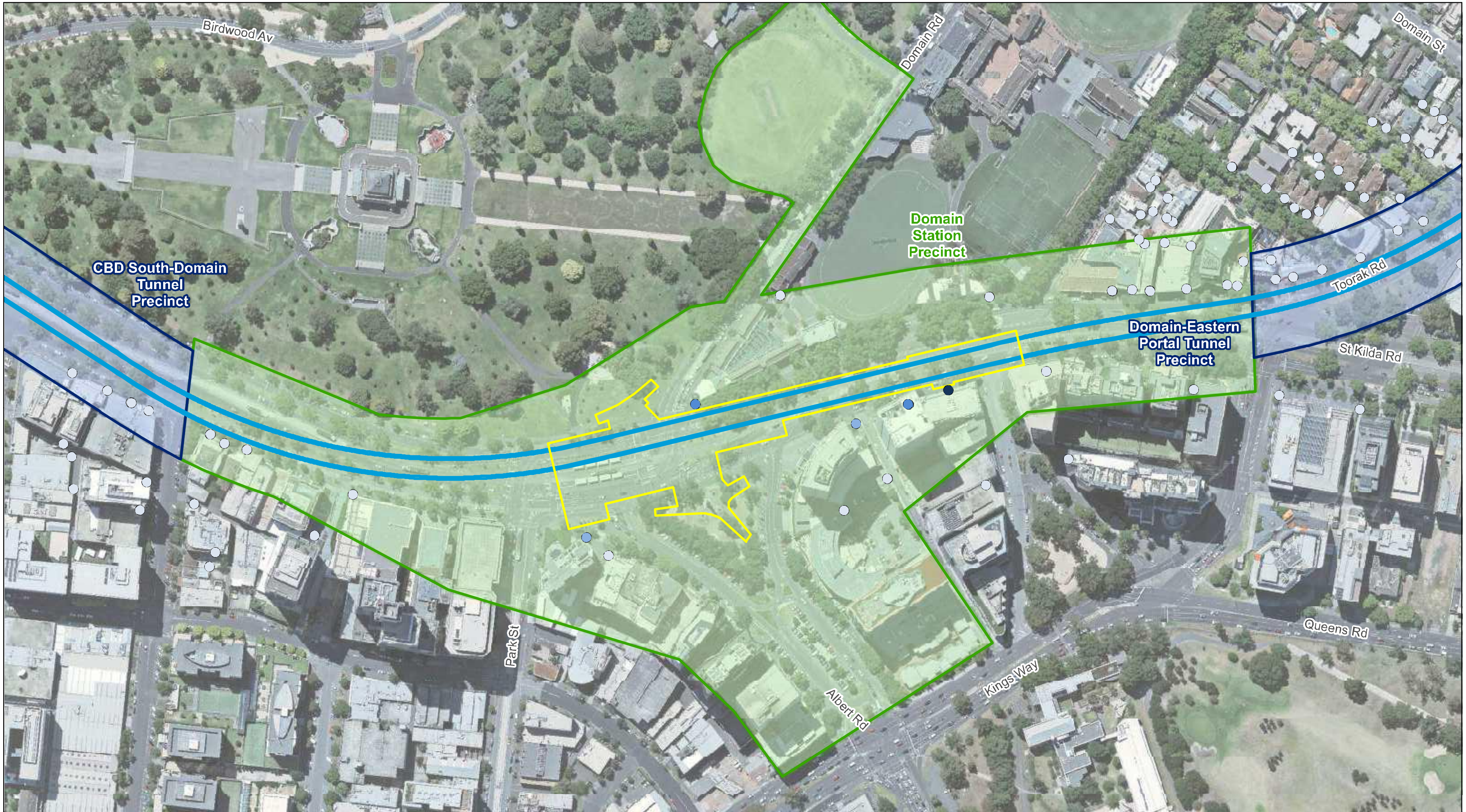
Figure B.75: Colour coded VDV day assessment for Additional Construction Works – CBD South Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_6.mxd



Legend

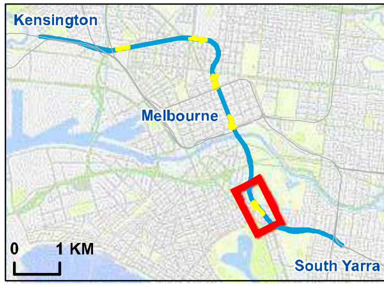
Result Set 6

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

- 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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Melbourne Metro Rail Project

Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Day Target - Domain Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500293			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.76: Colour coded VDV day assessment for Additional Construction Works – Domain Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_6.mxd

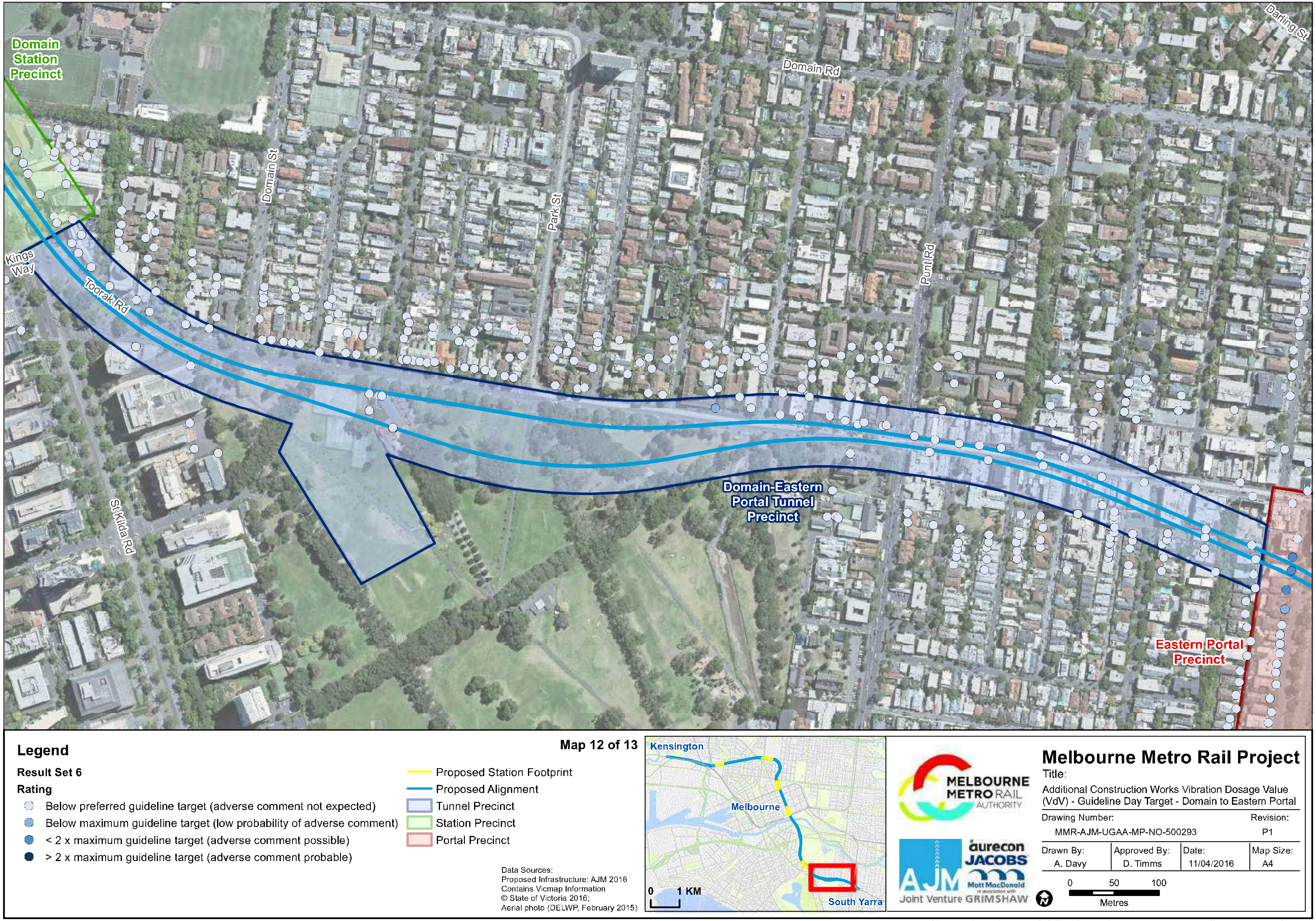
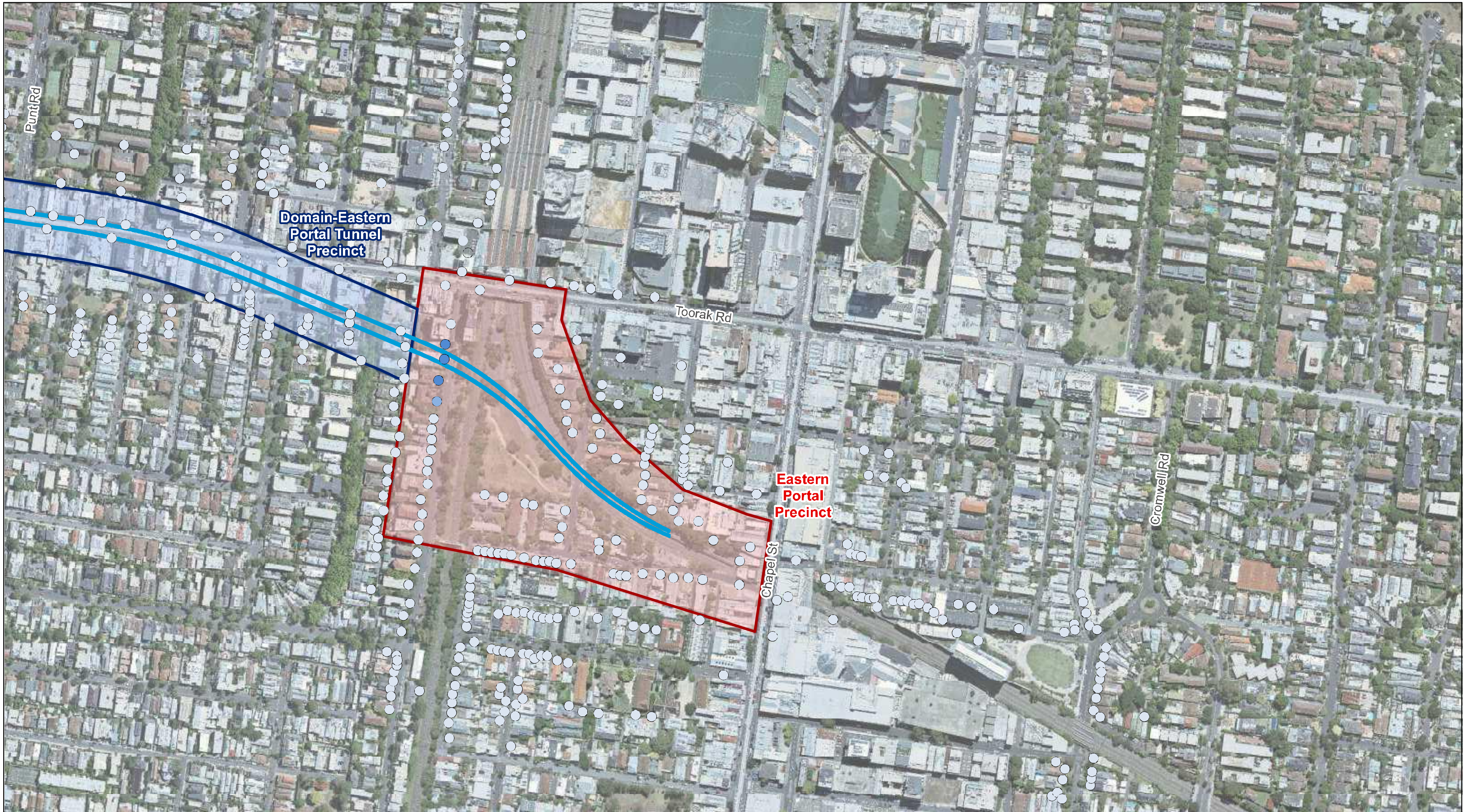


Figure B.77: Colour coded VDV day assessment for Additional Construction Works – Domain to Eastern Portal Tunnels Precinct



Legend

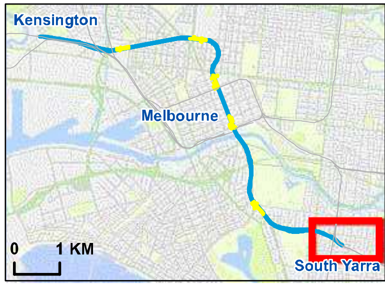
Result Set 6

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 13 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:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Day Target - Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500293			P1
Drawn By: A. Davy	Approved By: D. Timms	Date: 11/04/2016	Map Size: A4

0 50 100
Metres

Figure B.78: Colour coded VDV day assessment for Additional Construction Works – Eastern Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_6.mxd

Legend

Result Set 7

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

- Proposed Station Footprint
- Proposed Alignment
- Tunnel 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

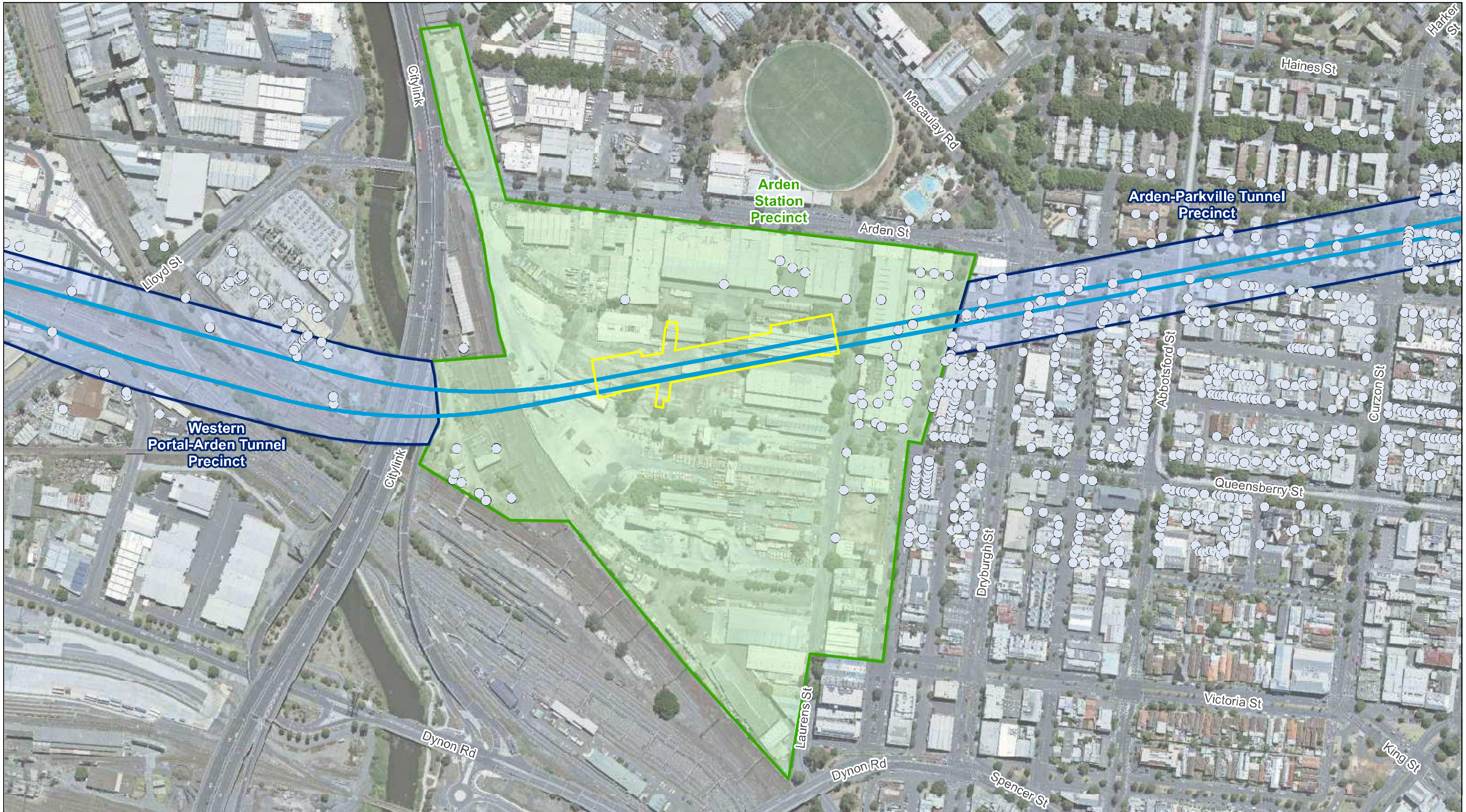
Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Night Target - Western Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500294			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.79: Colour coded VDV night assessment for Additional Construction Works – Western Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_7.mxd



Legend

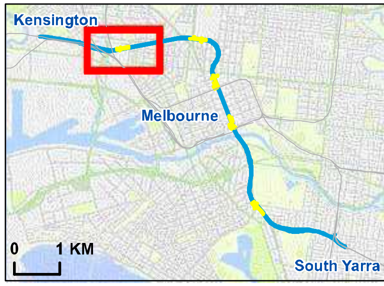
Result Set 7

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 3 of 13



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

MELBOURNE METRO RAIL AUTHORITY

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Melbourne Metro Rail Project

Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Night Target - Arden Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500294			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.80: Colour coded VDV night assessment for Additional Construction Works – Arden Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_7.mxd

Legend

Result Set 7

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 5 of 13

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

MELBOURNE METRO RAIL AUTHORITY

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Melbourne Metro Rail Project

Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Night Target - Parkville Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500294			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.81: Colour coded VDV night assessment for Additional Construction Works – Parkville Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_7.mxd

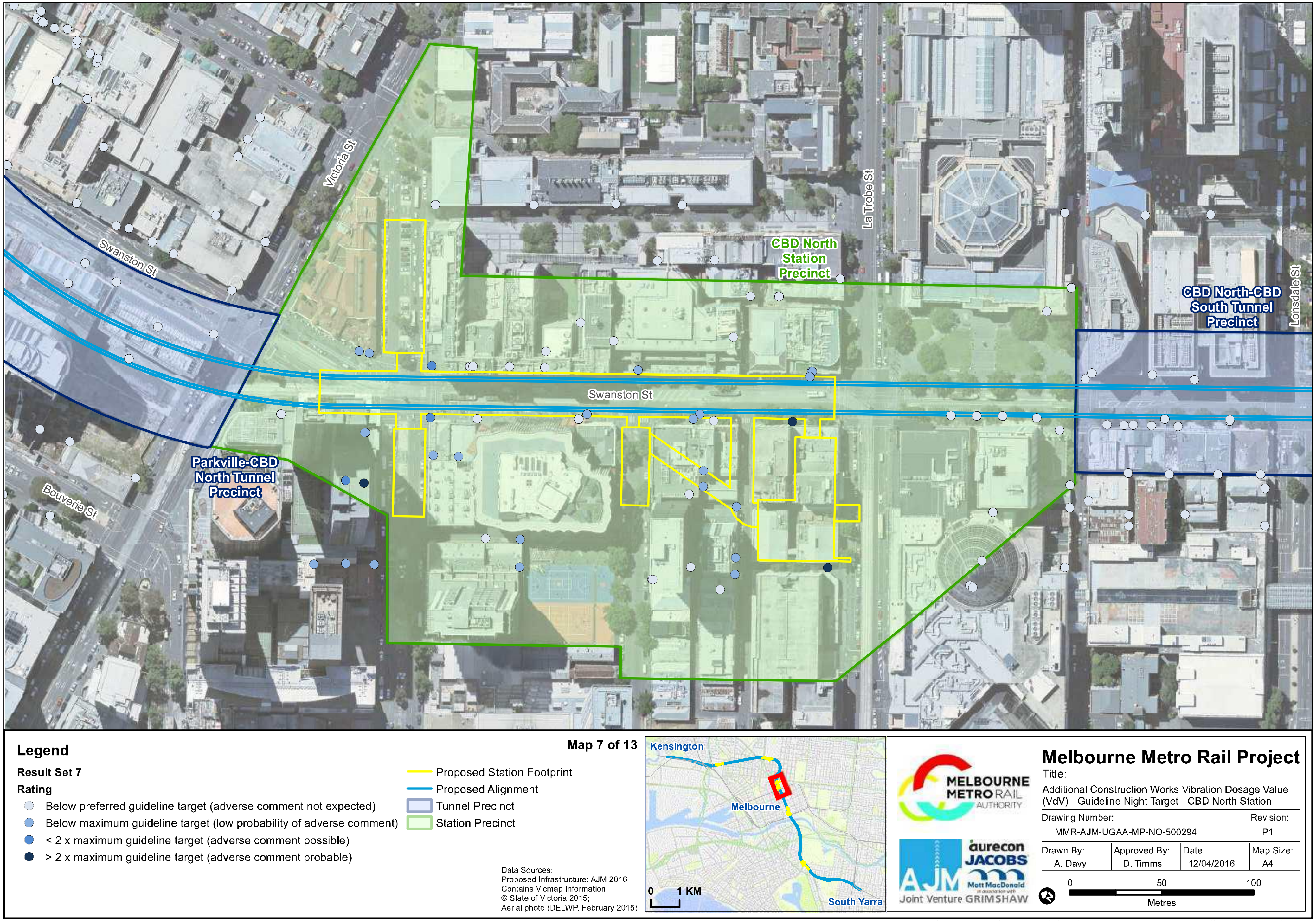


Figure B.82: Colour coded VDV night assessment for Additional Construction Works – CBD North Station Precinct

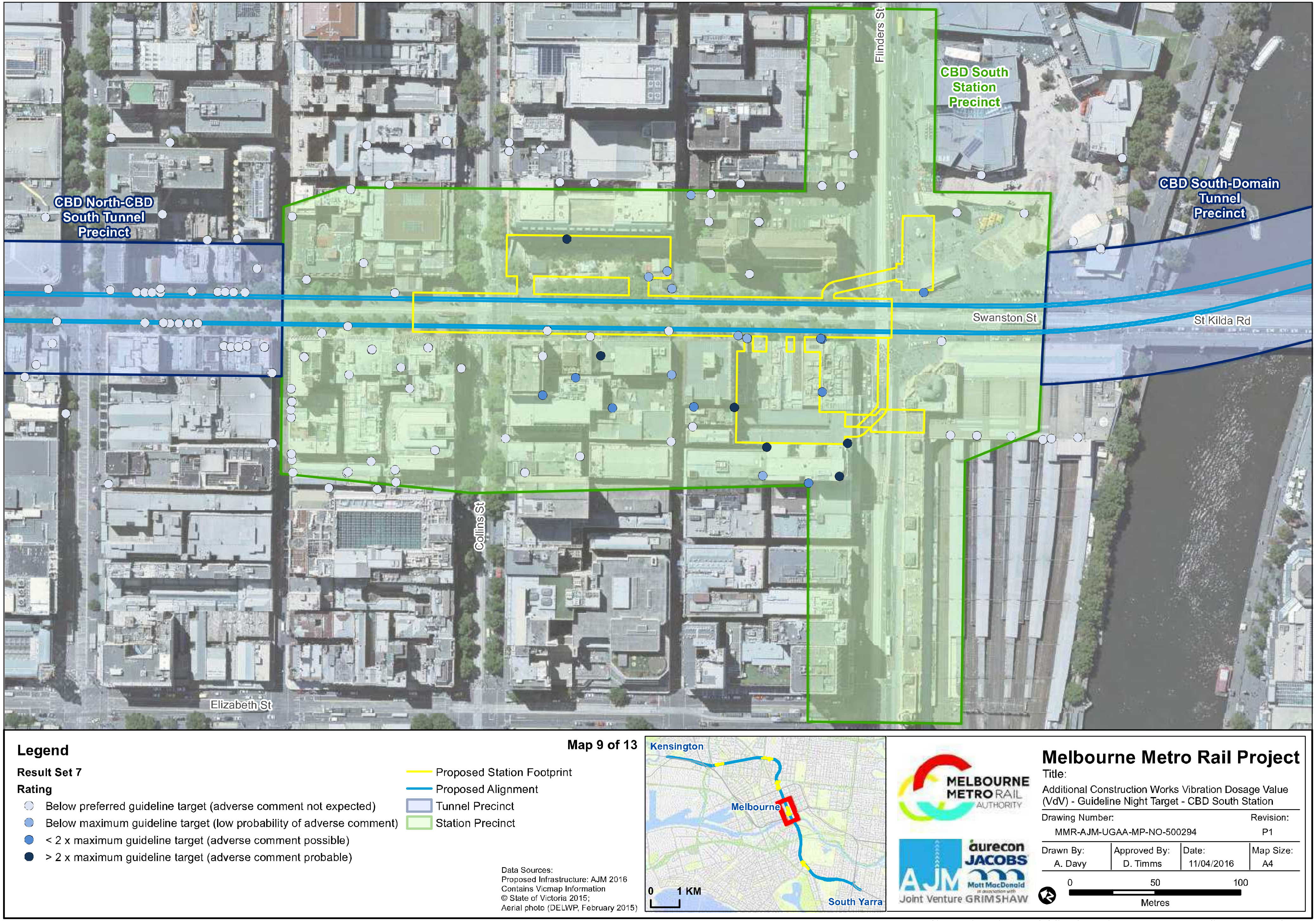


Figure B.83: Colour coded VDV night assessment for Additional Construction Works – CBD South Station Precinct

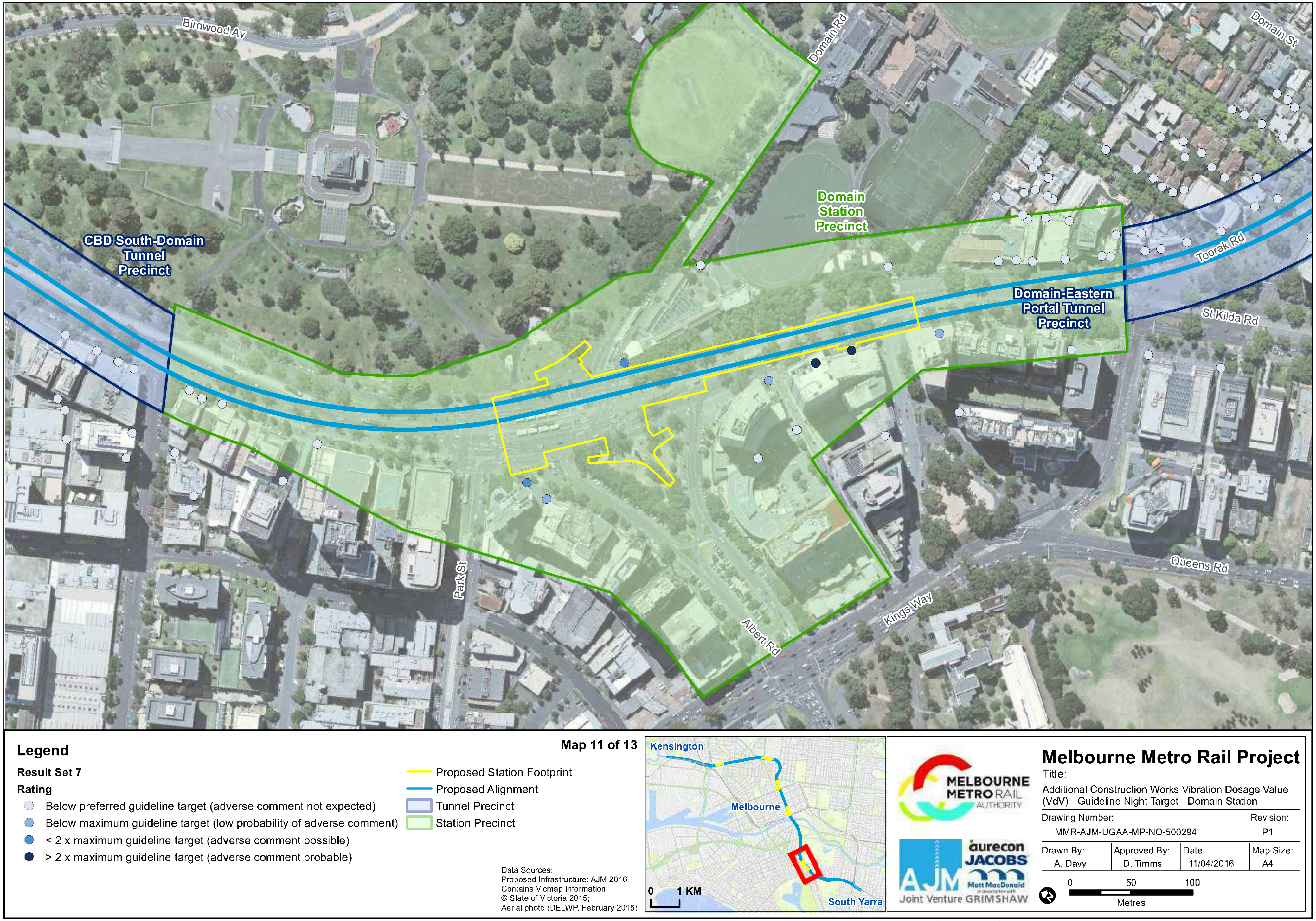


Figure B.84: Colour coded VDV night assessment for Additional Construction Works – Domain Station Precinct

Legend

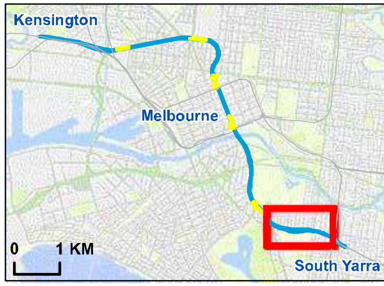
Result Set 7

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 12 of 13



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

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aurecon JACOBS AJM Mott MacDonald Joint Venture GRIMSHAW

Melbourne Metro Rail Project

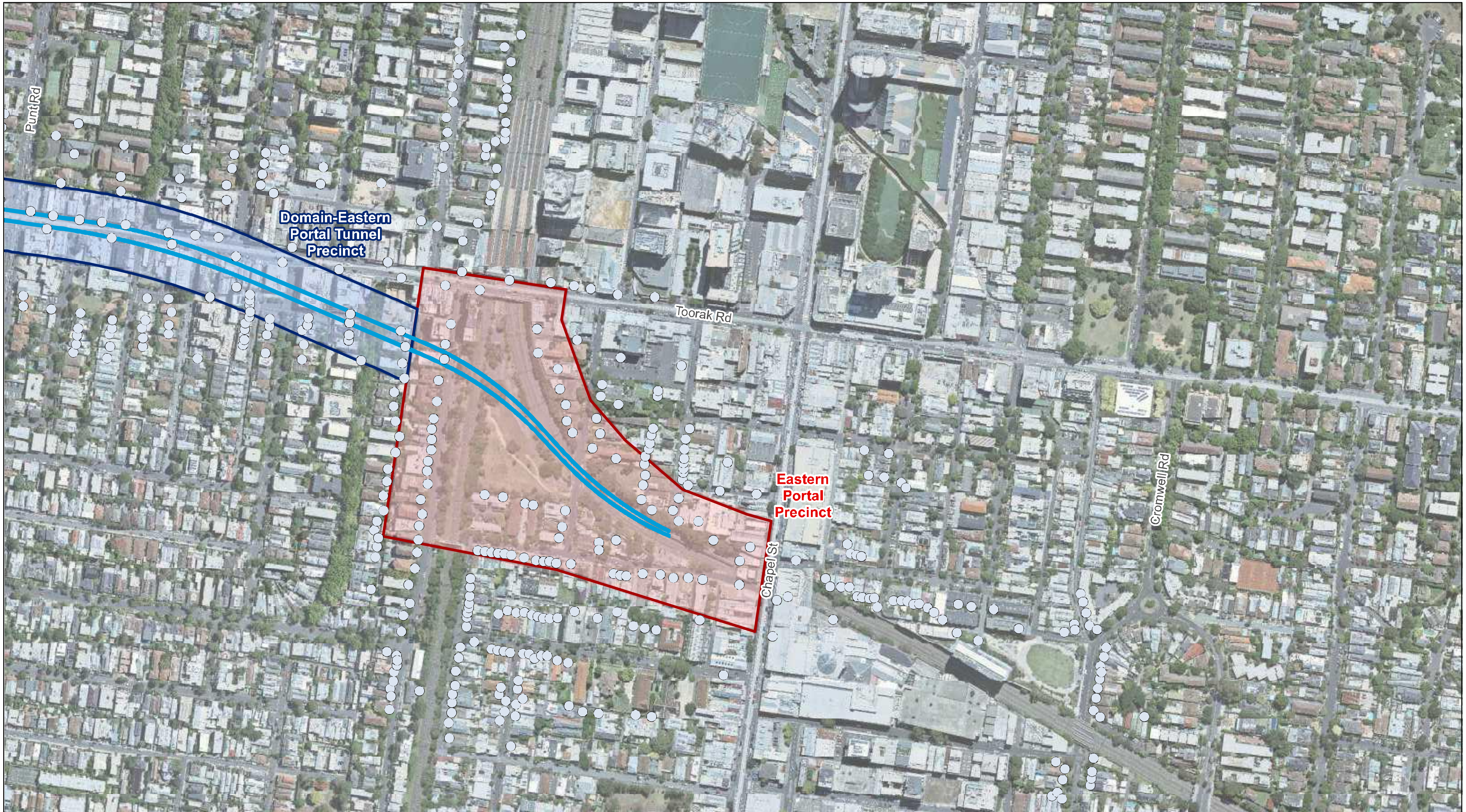
Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Night Target - Domain to Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500294			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_7.mxd

Figure B.85: Colour coded VDV night assessment for Additional Construction Works – Domain to Eastern Portal Tunnels Precinct



Legend

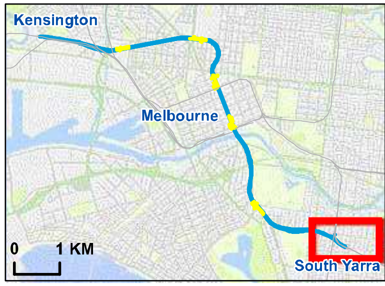
Result Set 7

Rating

- Below preferred guideline target (adverse comment not expected)
- Below maximum guideline target (low probability of adverse comment)
- < 2 x maximum guideline target (adverse comment possible)
- > 2 x maximum guideline target (adverse comment probable)

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

Map 13 of 13



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

MELBOURNE METRO RAIL AUTHORITY

aurecon JACOBS Mott MacDonald in association with AJM Joint Venture GRIMSHAW

Melbourne Metro Rail Project

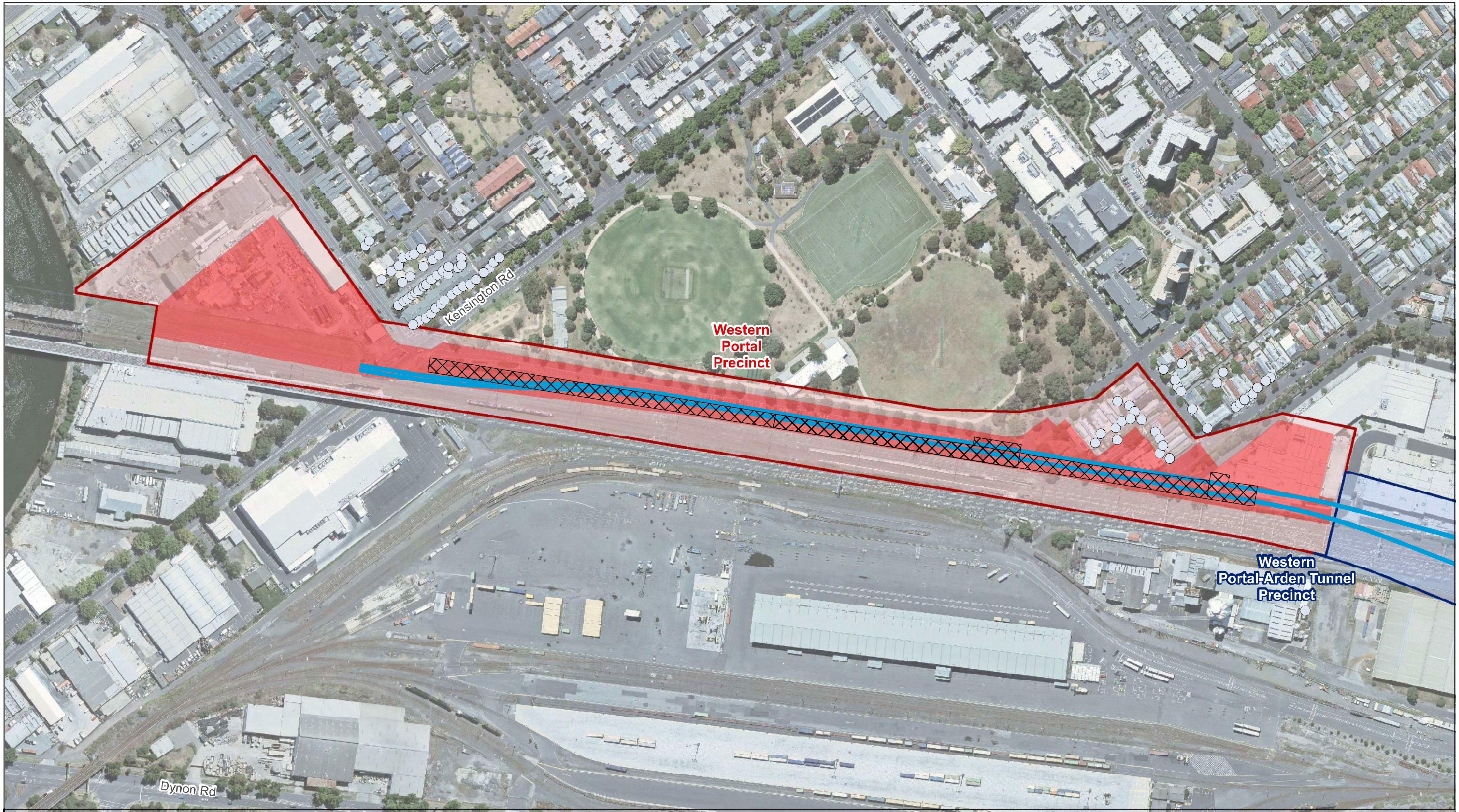
Title:
Additional Construction Works Vibration Dosage Value (VdV) - Guideline Night Target - Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500294			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	11/04/2016	A4

0 50 100
Metres

Figure B.86: Colour coded VDV night assessment for Additional Construction Works – Eastern Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_7.mxd



Legend

Result Set 5

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dBA above night guideline target / below evening guideline target
- 5 – 10 dBA above night guideline target / 0 – 5 dBA above evening guideline target
- > 10 dBA above night guideline target / > 5 dBA above evening guideline target

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 1 of 9

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

MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture — aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Ground-borne Noise - Western Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500207			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.87: Colour coded ground-borne noise assessment for Additional Construction Works – Western Portal Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\840_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_5.mxd

Legend

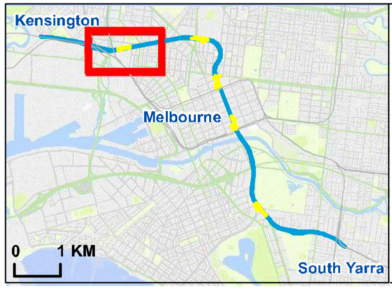
Result Set 5

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dBA above night guideline target / below evening guideline target
- 5 – 10 dBA above night guideline target / 0 – 5 dBA above evening guideline target
- > 10 dBA above night guideline target / > 5 dBA above evening guideline target

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 2 of 9



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

AJM Joint Venture — aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Ground-borne Noise - Arden Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500207			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.88: Colour coded ground-borne noise assessment for Additional Construction Works – Arden Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_5.mxd

Legend

Result Set 5

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dBA above night guideline target / below evening guideline target
- 5 – 10 dBA above night guideline target / 0 – 5 dBA above evening guideline target
- > 10 dBA above night guideline target / > 5 dBA above evening guideline target

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 3 of 9

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

Melbourne Metro Rail Project

Title:
Additional Construction Works Ground-borne Noise - Parkville Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500207			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

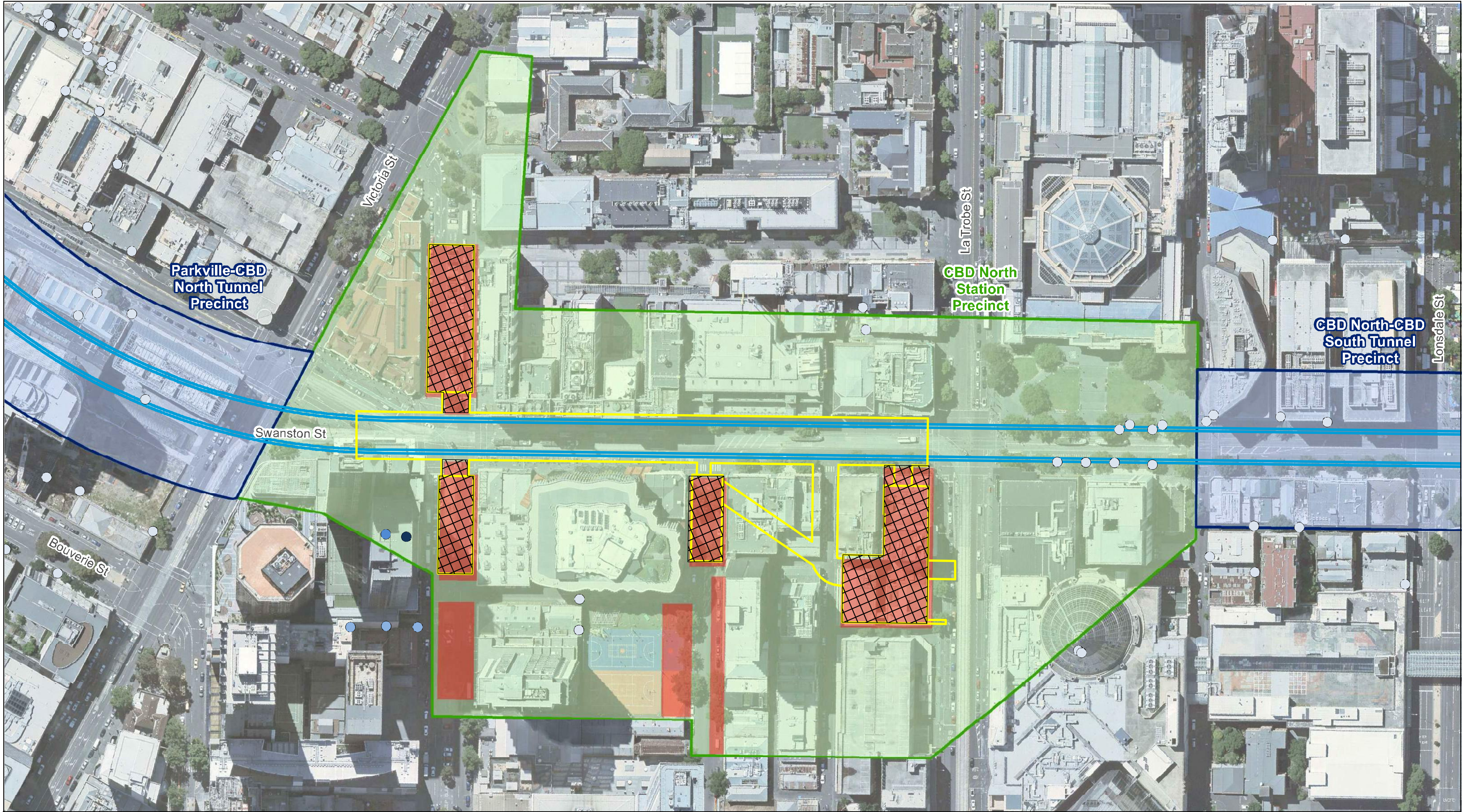
0 50 100
Metres

MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Figure B.89: Colour coded ground-borne noise assessment for Additional Construction Works – Parkville Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_5.mxd



Legend

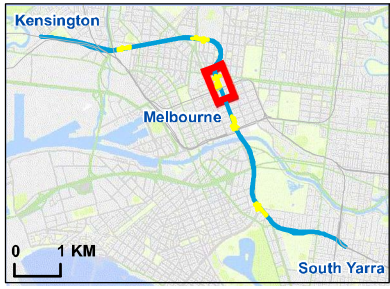
Result Set 5

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dBA above night guideline target / below evening guideline target
- 5 – 10 dBA above night guideline target / 0 – 5 dBA above evening guideline target
- > 10 dBA above night guideline target / > 5 dBA above evening guideline target

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 4 of 9



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Ground-borne Noise - CBD North Station

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500207			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.90: Colour coded ground-borne noise assessment for Additional Construction Works – CBD North Station Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_5.mxd

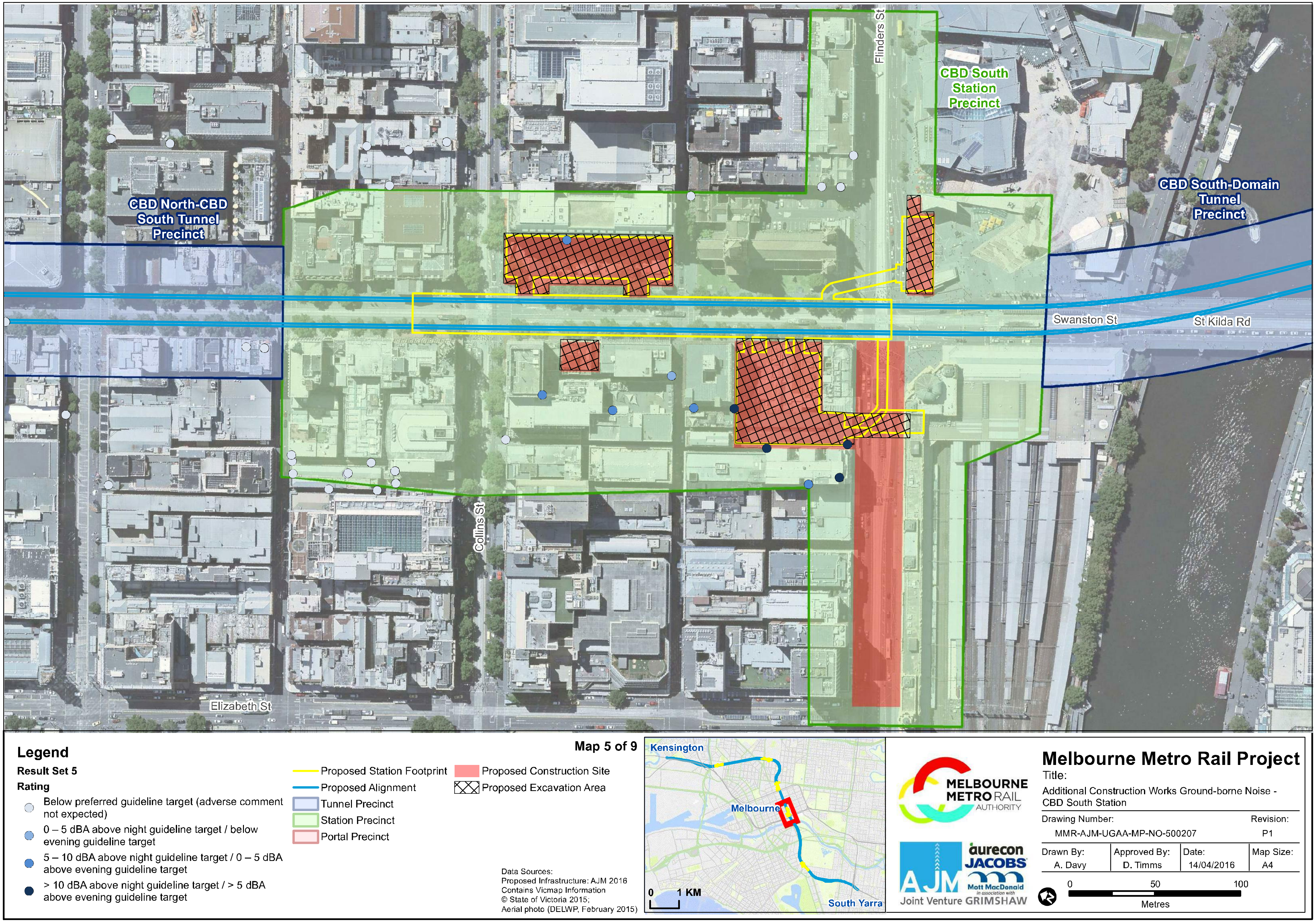
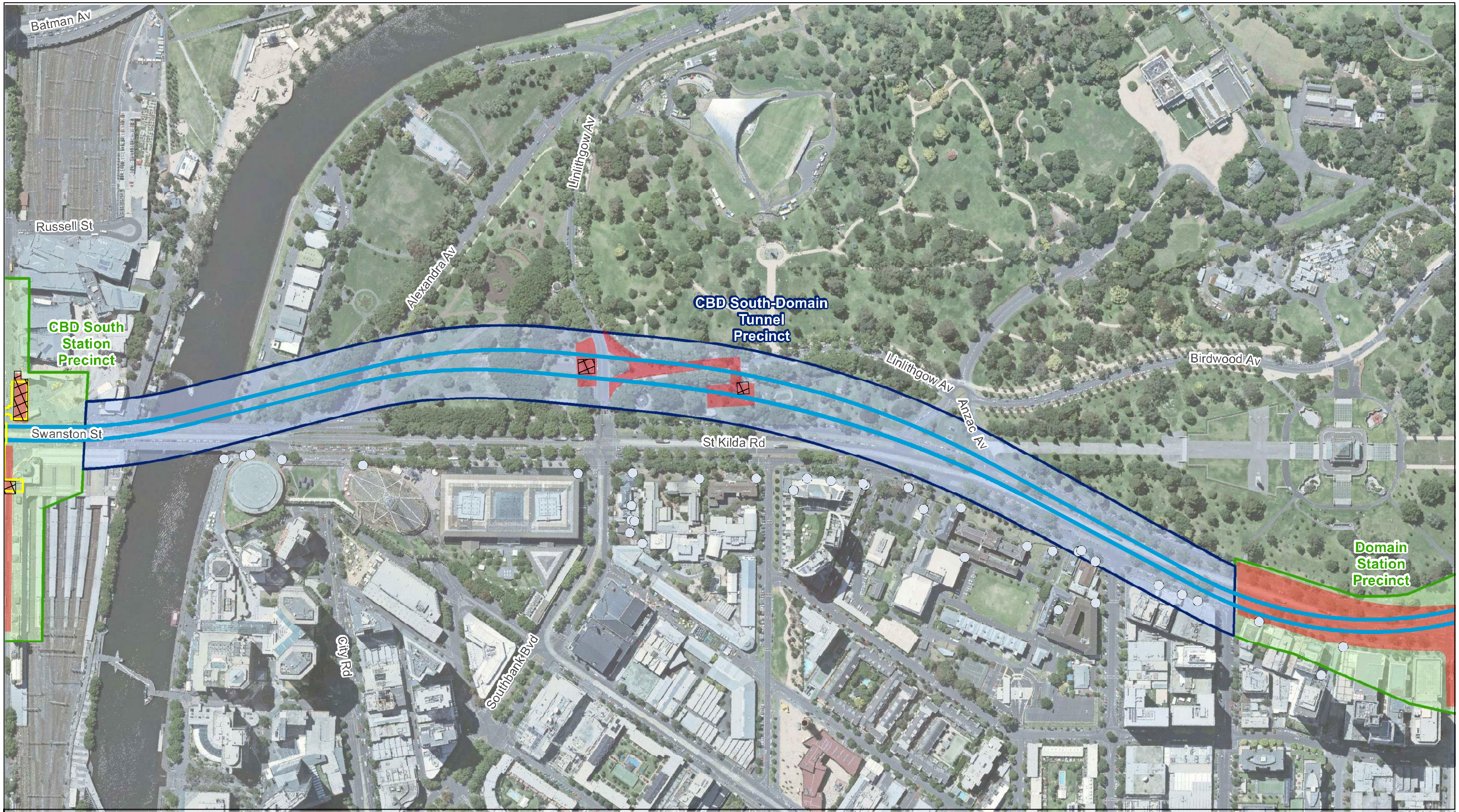


Figure B.91: Colour coded ground-borne noise assessment for Additional Construction Works – CBD South Station Precinct



Legend

Result Set 5

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dBA above night guideline target / below evening guideline target
- 5 – 10 dBA above night guideline target / 0 – 5 dBA above evening guideline target
- > 10 dBA above night guideline target / > 5 dBA above evening guideline target

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Ground-borne Noise - CBD South to Domain

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500207			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.92: Colour coded ground-borne noise assessment for Additional Construction Works – CBD South to Domain Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_5.mxd

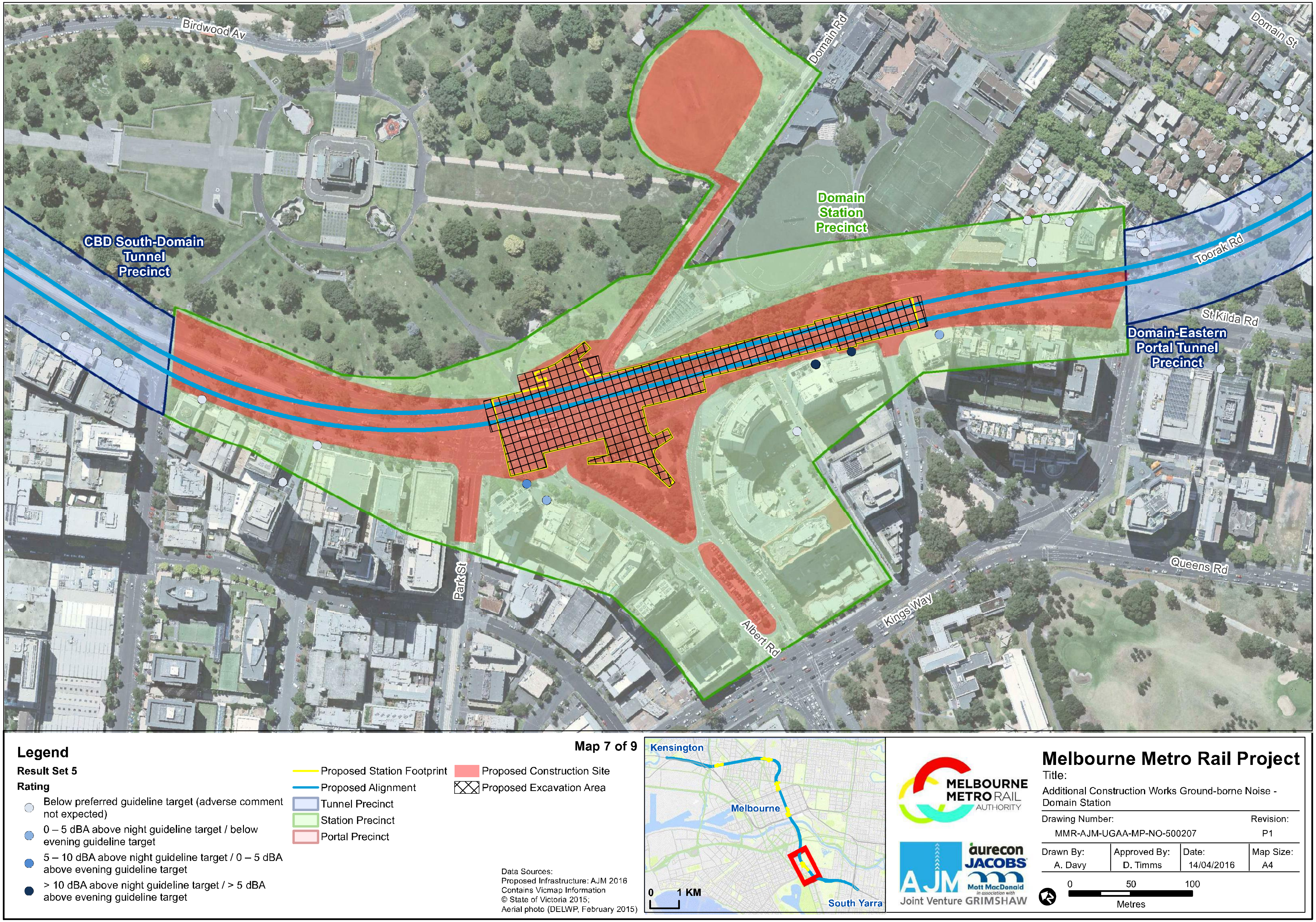

Figure B.93: Colour coded ground-borne noise assessment for Additional Construction Works – Domain Station Precinct

Legend

Result Set 5

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dBA above night guideline target / below evening guideline target
- 5 – 10 dBA above night guideline target / 0 – 5 dBA above evening guideline target
- > 10 dBA above night guideline target / > 5 dBA above evening guideline target

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 8 of 9

Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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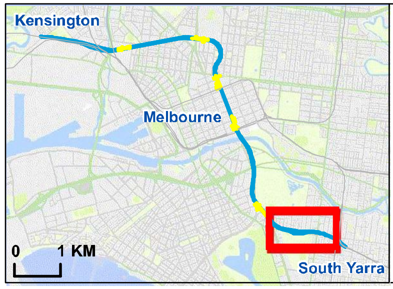


MELBOURNE METRO RAIL AUTHORITY

AJM Joint Venture

aurecon JACOBS Mott MacDonald in association with GRIMSHAW

Melbourne Metro Rail Project

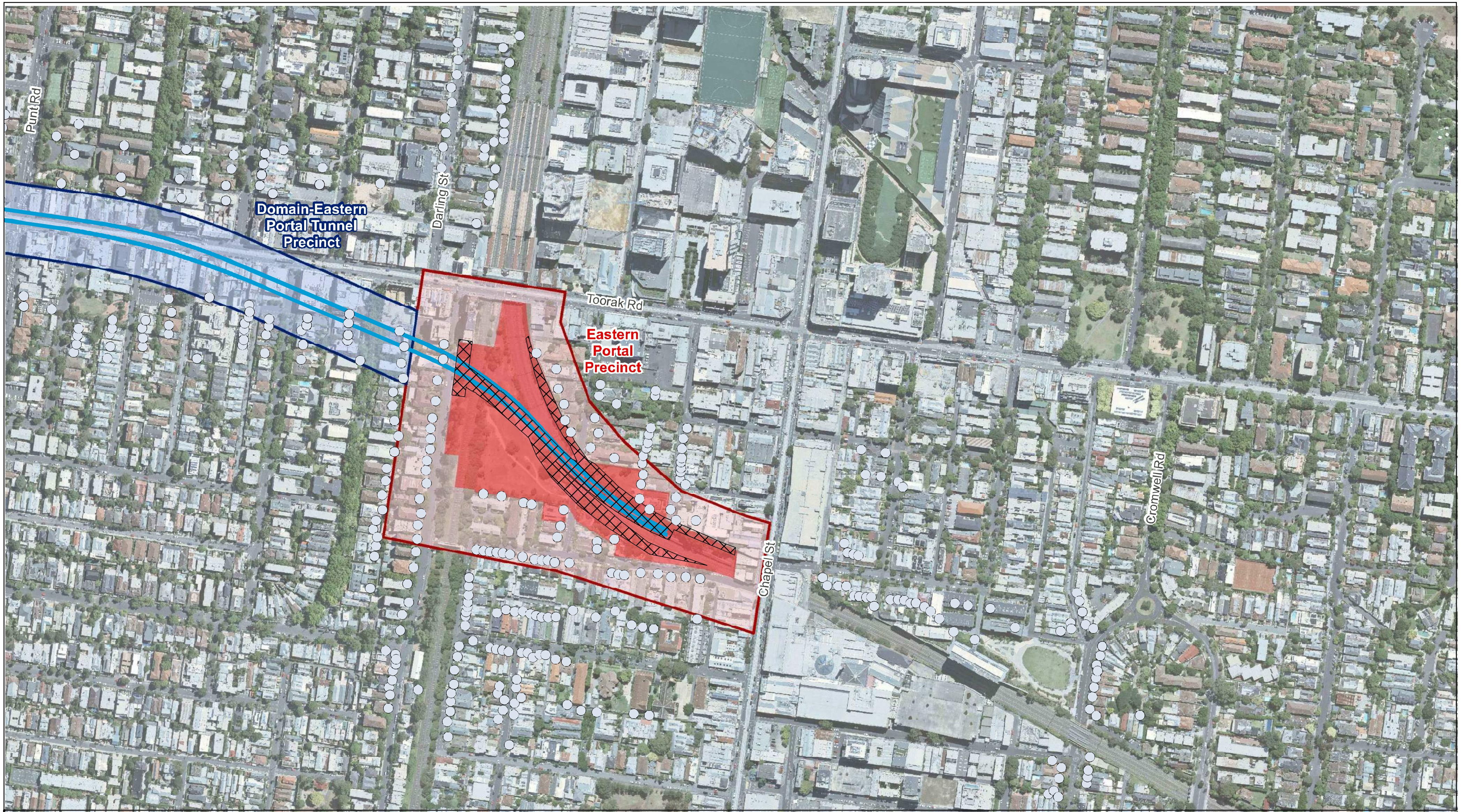
Title:	
Additional Construction Works Ground-borne Noise - Domain to Eastern Portal	
Drawing Number: MMR-AJM-UGAA-MP-NO-500207	Revision: P1

Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.94: Colour coded ground-borne noise assessment for Additional Construction Works – Domain to Eastern Tunnel Precinct

G:\MMR-AJM\01_WIP\PW-1-AA-KG_GIS\640_Site_plans\MMR_0322_NoiseVibration_EES\MMR_0322_Result_Set_5.mxd



Legend

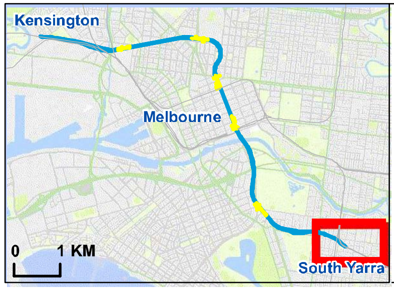
Result Set 5

Rating

- Below preferred guideline target (adverse comment not expected)
- 0 – 5 dBA above night guideline target / below evening guideline target
- 5 – 10 dBA above night guideline target / 0 – 5 dBA above evening guideline target
- > 10 dBA above night guideline target / > 5 dBA above evening guideline target

- Proposed Station Footprint
- Proposed Alignment
- Tunnel Precinct
- Station Precinct
- Portal Precinct
- Proposed Construction Site
- Proposed Excavation Area

Map 9 of 9



Data Sources:
Proposed Infrastructure: AJM 2016
Contains Vicmap Information
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MELBOURNE METRO RAIL AUTHORITY

aurecon JACOBS Mott MacDonald in association with

AJM Joint Venture GRIMSHAW

Melbourne Metro Rail Project

Title:
Additional Construction Works Ground-borne Noise - Eastern Portal

Drawing Number:			Revision:
MMR-AJM-UGAA-MP-NO-500207			P1
Drawn By:	Approved By:	Date:	Map Size:
A. Davy	D. Timms	14/04/2016	A4

0 50 100
Metres

Figure B.95: Colour coded ground-borne noise assessment for Additional Construction Works – Eastern Portal Precinct

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B.6 Discussion

B.6.1 Precinct 1 – Tunnels (Outside Other Precincts)

The Tunnels precinct includes the entire tunnel alignment that is not within the station or portal precincts. For construction activity this includes:

- Tunnels bored by TBM – Western portal to CBD North and CBD South to Eastern Portal
- Tunnels mined by road header – CBD North to CBD South
- Fawkner Park construction site, Fawkner Park emergency access shaft, Linlithgow Avenue emergency access shaft. A variety of construction equipment is proposed to be used at these sites. The vibration and ground-borne noise predictions are based on assessments of vibration for 20 tonne rockbreakers, as these are the most vibration intensive items of equipment. It has been assumed that the 20 tonne rockbreakers would work from a depth of 20 m and below.

B.6.1.1 Vibration – Assessment with respect to guideline targets for building damage

(i) Tunnelling

It is predicted that receivers greater than 5 to 10 m distance from the tunnelling would comply with the guideline targets (DIN 4150). Given that the tunnel is at least this distance underground, compliance is predicted to be achieved for all receiver types.

There are no predicted exceedances with respect to the guideline targets for building damage due to tunnelling.

The Victoria Barracks has been identified by the Commonwealth Department of the Environment as a structurally sensitive heritage site for which specific consideration is required with respect to vibration. The management of potential vibration impacts from construction on the Commonwealth-heritage-listed Victoria Barracks is the subject of a decision on the referral of the Melbourne Metro under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC 2015/7549), which requires that construction be carried out in a 'particular manner', incorporating vibration monitoring during construction in accordance with the requirements of the Australian Government Department of Environment.

Table B.10 presents the predicted vibration due to tunnelling, along with the measured baseline vibration levels.

Table B.10: Vibration levels at other sensitive sites

Sensitive Site	Baseline PPV (mm/s)	Predicted PPV (mm/s)	Comments
Tunnels Precinct			
Victoria Barracks	0.6	0.4	Predicted level is less than existing.

The predicted level is lower than both the DIN 4150 criterion for structurally sensitive (heritage) buildings and baseline vibration level measured at this site. Damage at this site due to tunnelling is therefore not anticipated.

(ii) Additional Construction Works

Vibration levels are predicted to comply with the applicable guideline targets for building damage (DIN 4150) in the tunnels precinct due to the Additional Construction Works.

B.6.1.2 Vibration – Assessment with respect to guideline targets for damage to utilities

(i) Tunnelling

There are a significant number of utilities that cross the tunnel alignment at various locations in the tunnels precinct. In general, the critical distance the tunnel should be from utilities to avoid damage is listed in Table B.11.

Table B.11: Critical distances from utilities

Equipment	Critical distance (m)	
	General utilities (20 mm/s)	Melbourne Water unreinforced assets (10 mm/s)
TBM	1.6	3.0
Road header	2.0	3.7

These distances are slope distance as defined in Figure B.5.

In most cases the depth of the tunnel would be sufficient to achieve the minimum distances to the various utilities. However, location of the assets should be confirmed by the Proponent prior to the commencement of work to assess compliance.

The tunnel alignment crosses the Citylink tunnel in section from the CBD South Station Precinct to Domain Tunnel Precinct. Two alternatives are being considered:

- Assessment Design: the tunnel alignment passes over the Citylink tunnel, within 1 m of the top of the Citylink tunnel
- Variation: the tunnel alignment passes under the Citylink tunnel, within 3 m of the bottom of the Citylink tunnel.

The operation of the TBM within 1 m of the top of the Citylink is predicted to result in vibration levels approaching or exceeding the DIN 4150 continuous vibration criterion of 10 mm/s PPV. It does not necessarily follow that the Citylink tunnel would be subject to damage, as DIN 4150 is considered to be a conservative standard. If this option is selected the Proponent may need to reduce vibration levels by changing the operating parameters for the TBM whilst monitoring vibrations on the Citylink structure.

Vibration levels due to the TBM operating within 3 m of the bottom of the Citylink are predicted to be below the DIN 4150 continuous vibration criterion of 10 mm/s PPV. The risk of damage to the Citylink tunnel for construction of the variation design is therefore low.

(ii) Additional Construction Works

In general, damage to utilities is not expected in the Tunnels Precinct due to the Additional Construction Works. The Proponent is to confirm the location of utilities and ensure that guideline vibration targets are met.

B.6.1.3 Vibration – Human Comfort

(i) Tunnelling

When the TBM / road header is tunnelling directly below residential receivers the trigger for management action is predicted to be met. For the TBM, receivers within approximately 25 - 45 m of the tunnel alignment are predicted to meet the trigger for management actions associated with a low probability of adverse comment during the day, while receivers within 40 – 55 m of the tunnel alignment are predicted to meet the trigger for management actions during the night. For the road header, receivers within approximately 30 – 45 m of the tunnel alignment are predicted to meet the trigger for management actions associated with a low probability of adverse comment during the day, while receivers within 40 – 60 m of the tunnel alignment are predicted to meet the trigger for management actions during the night.

Management actions for the TBM / road header include significant community consultation and potential respite / relocation if vibration levels are not well tolerated by a resident. Mitigation of vibration from TBMs or road headers is very challenging and there are few options available to reduce vibration aside from changing the tunnel alignment to increase distance from the affected receivers. Any change to the operating parameters of these machines which has the potential to reduce vibration would increase the duration of vibration impacts for receivers and significantly add to the project program. However, as the TBM/road header progresses along the tunnel the distance to the receiver changes relatively quickly, which has a significant effect on the predicted vibration. As the TBM/road header approaches the receiver, the vibration would increase to a peak and then reduce again as the TBM/road header moves further away.

An analysis of the change in vibration has been conducted for example residential and commercial receivers subject to vibration caused by TBM and road header tunnelling. The worst-case receivers in each tunnel segment (ie between station precincts) have been selected in order to show the maximum duration of exceedance predicted for the tunnel segment (i.e. at other locations the vibration would be lower).

The TBM has been assumed to move along the tunnel at a rate of 11.5 m per day, with the western alignment TBM following the eastern TBM with a spacing of approximately 300 m (30 days).

The road header has been assumed to move along the tunnel at a rate of approximately 5 m per day, with road headers at similar positions in both east and west tunnels at the same time. The road header is assumed to be operational for 60% of the time both day and night.

The receivers analysed are listed in Table B.12 along with the duration where the criterion level for management actions is triggered. Plots are provided of the predictions for:

- Residential receiver in the Parkville – CBD North segment (worst-case residential receiver for TBM tunnelling): Figure B.96
- Commercial receiver in the Parkville – CBD North segment (worst-case commercial receiver for TBM tunnelling): Figure B.97
- Residential receiver in the CBD North – CBD South segment (worst-case residential receiver for road header tunnelling): Figure B.98
- Commercial receiver in the CBD North – CBD South segment (worst-case commercial receiver for road header tunnelling): Figure B.99.

Figure B.96 and Figure B.97 show the VDV results with respect to construction time for a residential and a commercial receiver impacted by TBM boring. The criterion level for management actions is triggered for approximately one week (6-9 days) at the residential locations due to TBM tunnelling underneath the site (based on a maximum level which relates to low probability of adverse comments). At the commercial locations, the criterion level for management actions is triggered for up to half a week (based on a maximum level). At these sites this occurs during both east and west alignment tunnelling.

Figure B.98 and B.99 show the VDV results with respect to construction time for a residential and a commercial receiver impacted by road header mining of the tunnel in the CBD North – CBD South segment. At the receivers shown in the figures the trigger for management action for Vibration Dose Value is met during both east and west alignment tunnelling, so that the total vibration is a combination of the influence of both tunnels. The worst case combination, where road headers are at the same chainage in the two tunnels, is also presented in the figures. The criterion level for management actions is triggered for up to one month at residential receivers due to road header tunnel mining, and for up to 2 weeks at commercial receivers (based on a preferred level under which adverse comment is not expected). The duration is longer than for the TBM tunnelling primarily due to the slower progression of the road header along the tunnel.

Table B.12: Receiver Addresses and VDV Results for Duration Analysis

Receiver Type	Address	Time duration where the criterion level for management actions is triggered (days)*	
		Vibration Dose Value - Day	Vibration Dose Value – Night
Western Portal – Arden: TBM			
Residential	No exceedances for residential receivers in this segment		
Commercial	3 Lloyd St, Kensington	3½ days	3 days
Arden – Parkville: TBM			
Residential	193 Errol St, North Melbourne	5½ days	8 days
Commercial	99 Munster Terrace, North Melbourne	3½ days	3 days
Parkville – CBD North: TBM			
Residential	20-24 Church St, Carlton	6½ days	9 days
Commercial	213 Grattan St, Carlton	2 days	1 days
CBD North – CBD South: Road Header			
Residential	207 Swanston St, Melbourne	22 days	32 days
Commercial	119 Swanston St, Melbourne	15 days	13 days
CBD South – Domain: TBM			
Residential	340 St Kilda Rd, Melbourne	6 days	8 days
Commercial	336 St Kilda Rd, Melbourne	3½ days	3 days
Domain – Eastern Portal: TBM			
Residential	51 Myrtle St, South Yarra	6 days	9 days
Commercial	53 Myrtle St, South Yarra	3½ days	3 days

* For durations of approximately one week or less the *maximum* VDV guideline target has been used as the trigger for management actions (i.e. for all TBM durations). For the road header tunnelling in the CBD North – CBD South segment the *preferred* VDV guideline target has been used as the trigger for management action in accordance with the standard.

An assessment of the vibration at higher floors of the buildings in the CBD tunnel segment has been undertaken. For residential receivers the impact is predicted to affect floors up to and including level 10, with any higher floors having vibration levels below the criterion for management actions. For commercial receivers the impact is predicted to affect floors up to and including level 5, with level 6 and above having vibration levels below the criterion for management actions.

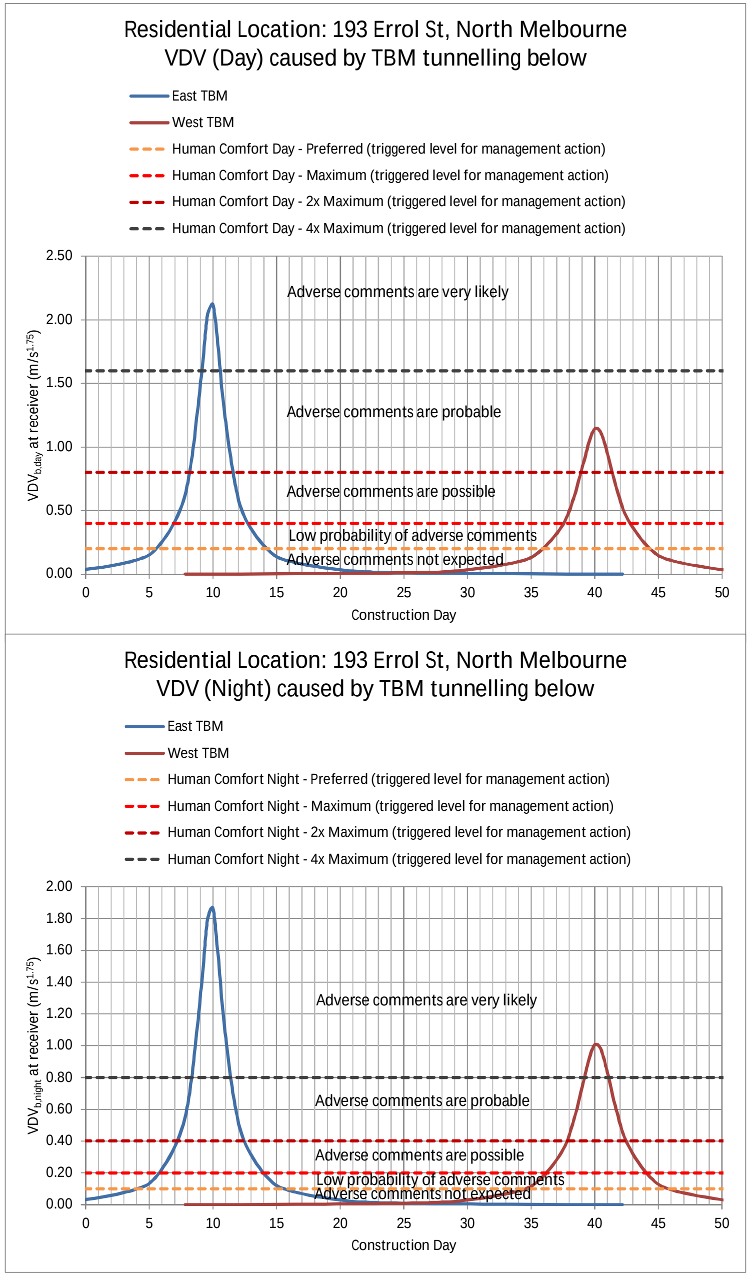

Figure B.96: Time of Duration of VDV Exceedances for Example Residential Receiver – Tunnelling using TBM

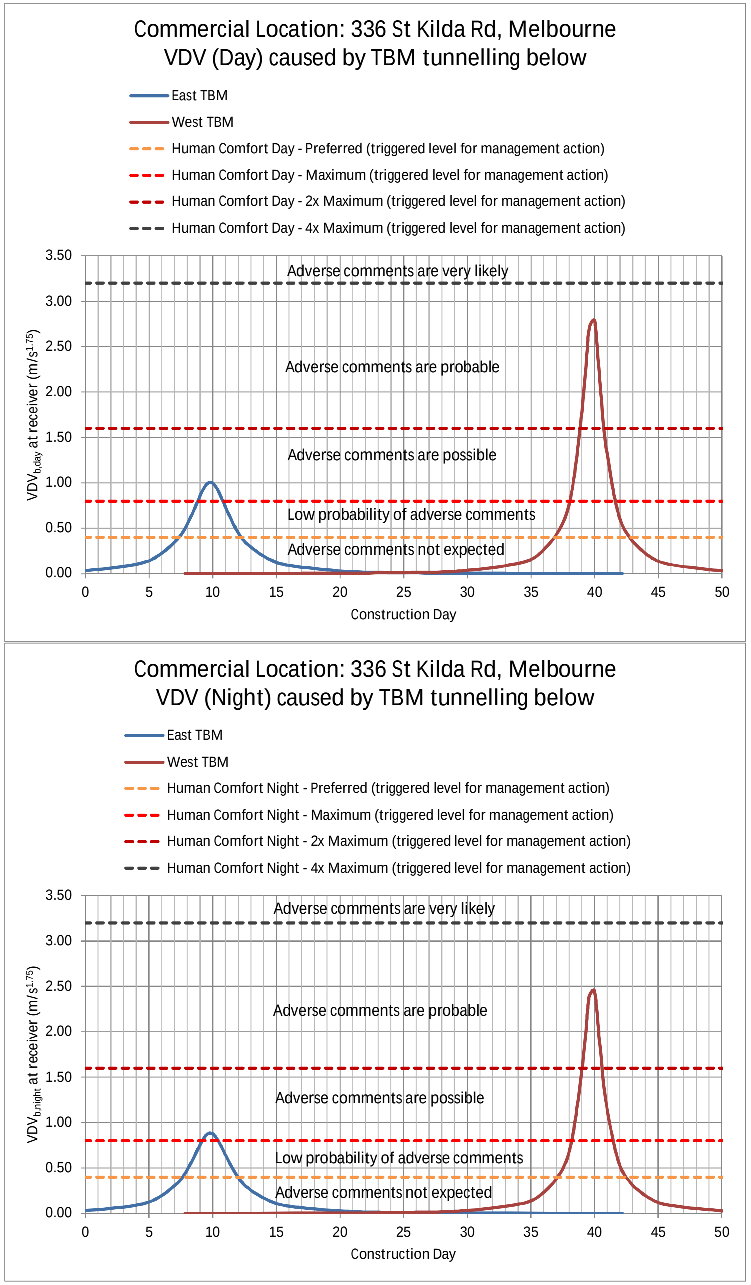

Figure B.97: Time of Duration of VDV Exceedances for Example Commercial Receiver – Tunnelling using TBM

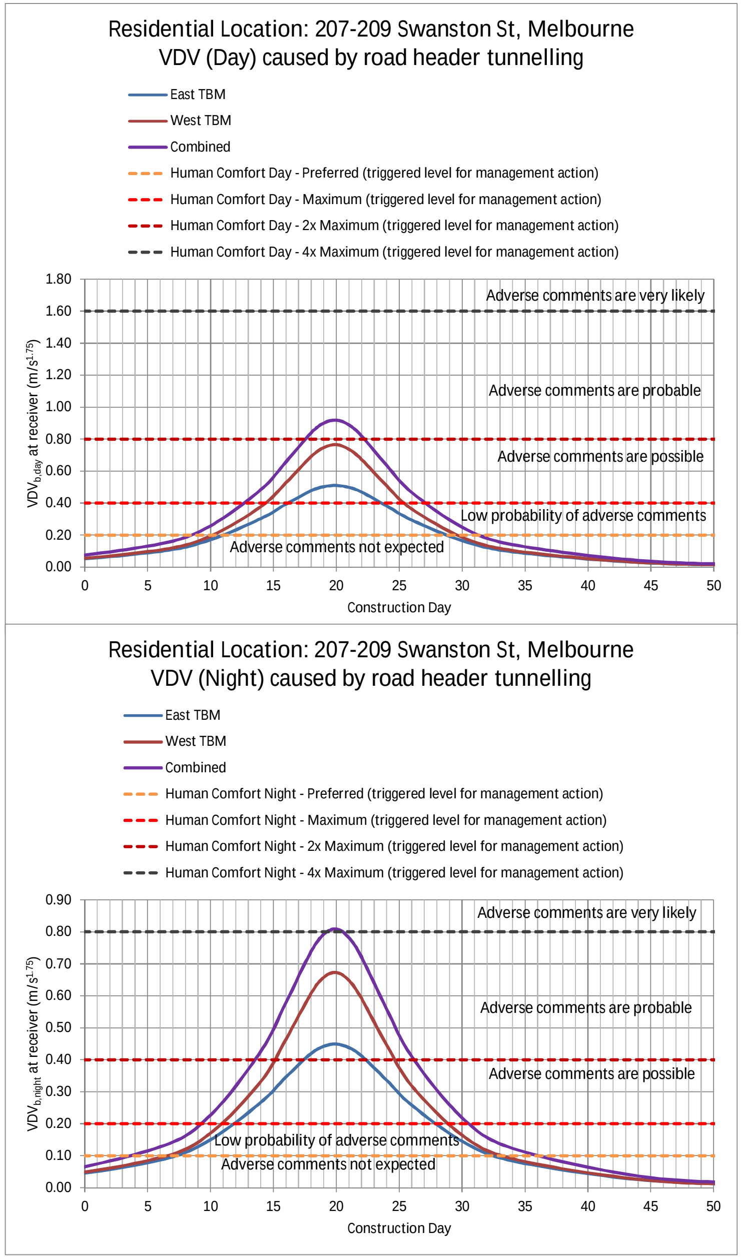

Figure B.98: Time of Duration of VDV Exceedances for Example Residential Receiver – Tunnelling using Road header

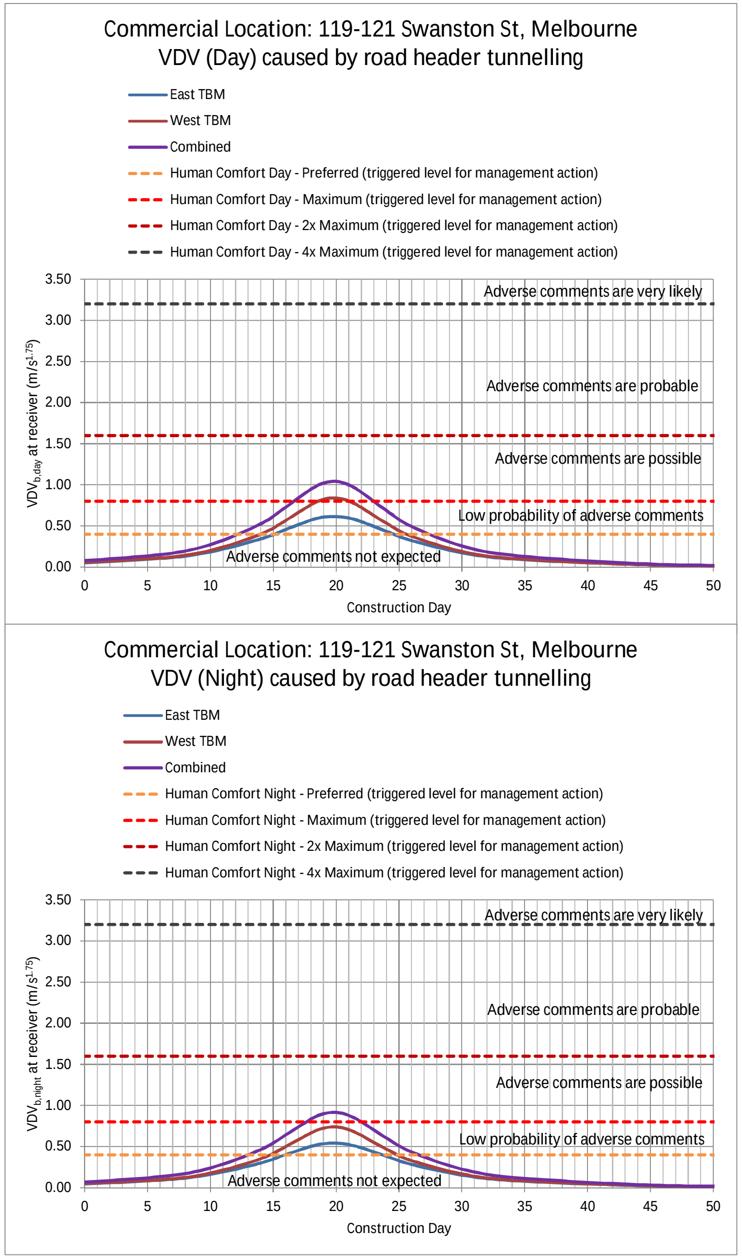

Figure B.99: Time of Duration of Exceedances for Example Commercial Receiver – Tunnelling using Road header

(ii) Additional Construction Works

The Linlithgow Avenue emergency access shaft site is located away from receivers and vibration levels are predicted to comply with the guideline targets.

A VDV of 0.3 $m/s^{1.75}$ is predicted at one residential address on Toorak Road which is located near the Fawkner Park Intervention Shaft excavation. This is less than the maximum guideline value (0.4 $m/s^{1.75}$) and relates to a low probability of adverse comment. Nevertheless, consultation and negotiation with residents at this address and adjacent buildings is recommended.

B.6.1.4 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

Vibration-sensitive equipment, Bio-resources and Highly Sensitive Areas have not been identified in the tunnels precinct.

B.6.1.5 Ground-borne Noise

(i) Tunnelling

Ground-borne noise levels at residential receivers located close to the alignment are predicted to trigger the requirement for management actions when the TBM / road header is tunnelling directly below. For the TBM, this occurs when receivers are within approximately 35 – 50 m of the tunnel alignment during the evening and when receivers are within 45 – 60 m of the tunnel alignment during the night. For the road header, this occurs for receivers within approximately 40 – 55 m of the tunnel alignment during the evening, and receivers within 50 – 65 m of the tunnel alignment during the night.

Management actions include extensive community consultation to determine the acceptable level of disruption and the provision of respite accommodation in some circumstances.

Mitigation of ground-borne noise from TBMs is very challenging and there are few options available aside from changing the tunnel alignment to increase distance from the affected receivers. Mitigation of ground-borne noise from the road header work is again very challenging but it may be possible to reduce hours of operation and/or modify the construction sequencing and operating practices to reduce impacts in some circumstances.

As the TBM/road header progresses along the tunnel the distance to the receiver changes relatively quickly, which has a significant effect on the predicted ground-borne noise. As the TBM/road header approaches the receiver, the ground-borne noise would increase to a peak and then reduce again as the TBM/road header moves further away. This results in noise exceedances for a limited time only.

An analysis of the change in ground-borne noise has been conducted for example residential and commercial receivers subject to ground-borne noise caused by TBM and road header tunnelling. The worst-case receivers in each tunnel segment (ie between station precincts) have been selected in order to show the maximum duration of exceedance predicted for the tunnel segment (i.e. at other locations the vibration would be lower).

The TBM has been assumed to move along the tunnel at a rate of 11.5 m per day, with the western alignment TBM following the eastern TBM with a spacing of approximately 300 m (30 days).

The road header has been assumed to move along the tunnel at a rate of approximately 5 m per day, with road headers at similar positions in both east and west tunnels at the same time.

The receivers analysed are listed in Table B.13 along with the duration where the criterion level for management actions is triggered. Plots are provided of the predictions for:

- Residential receiver in the Parkville – CBD North segment (worst-case residential receiver for TBM tunnelling): Figure B.100
- Residential receiver in the CBD North – CBD South segment (worst-case residential receiver for road header tunnelling): Figure B.101

Figure B.100 shows the ground-borne noise results with respect to construction time for a residential receiver impacted by TBM boring. The criterion level for management actions is triggered for approximately one week due to TBM tunnelling underneath the site during the evening and for up to one and a half weeks during the night. At these sites this occurs during both east and west alignment tunnelling.

Figure B.101 shows the ground-borne noise results with respect to construction time for a residential receiver impacted by road header mining of the tunnel in the CBD North – CBD South segment. The trigger for management action for ground-borne noise is met during both east and west alignment tunnelling, so that the total ground-borne noise is a combination of the influence of both tunnels. The worst case combination, where road headers are at the same chainage in the two tunnels, is also presented in the figures. The criterion level for management actions is triggered for up to two and a half weeks during the evening and three weeks at night. The duration is longer than for the TBM tunnelling primarily due to the slower progression of the road header along the tunnel.

An assessment of the vibration at higher floors of the building in the CBD tunnel segment has been undertaken. For residential receivers the impact is predicted to affect floors up to and including level 7, with higher floors having vibration levels below the criterion for management actions.

Table B.13: Receiver Addresses for Detailed Analysis

Receiver Type	Address	Time duration where the criterion level for management actions is triggered (days) for Ground-borne Noise	
		Evening	Night
Western Portal – Arden: TBM			
Residential	No exceedances for residential receivers in this segment		
Arden – Parkville: TBM			
Residential	193 Errol St, North Melbourne	7½ days	9 days
Parkville – CBD North: TBM			
Residential	20-24 Church St, Carlton	8 days	10 days
CBD North – CBD South: Road Header			
Residential	207 Swanston St, Melbourne	17 days	22 days
CBD South – Domain: TBM			
Residential	340 St Kilda Rd, Melbourne	7½ days	9 days
Domain – Eastern Portal: TBM			
Residential	51 Myrtle St, South Yarra	7 days	9 days

The potential for ground-borne noise impacts due to tunnelling also exists for performance spaces within the Arts Centre, Melbourne. These include the Hammer Hall (over 50 m from the nearest tunnel) and State Theatre (approximately 100 m from the nearest tunnel). The ground-borne noise level, based on a simplified calculation method, has been predicted to be of the order of 30 dB(A) in the Hamer Hall during tunnelling, for up to 3 days occurring twice (once for each tunnel). At this level it is possible that ground-borne noise may at times be audible within the performance spaces. These ground-borne noise impacts, should they eventuate, are expected to be manageable by undertaking early consultation and coordination with Arts Centre Management. Monitoring of ground-borne noise and vibration levels post commencement of TBM activity and a more detailed assessment should be used to verify any potential impacts ahead of the tunnels passing these sites.

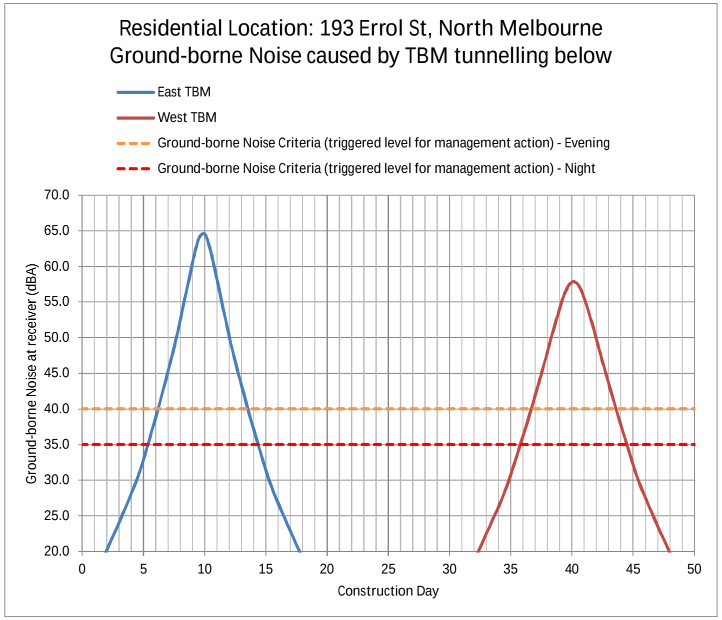

Figure B.100: Duration of Exceedances for Example Residential Receiver – Tunnelling using TBM

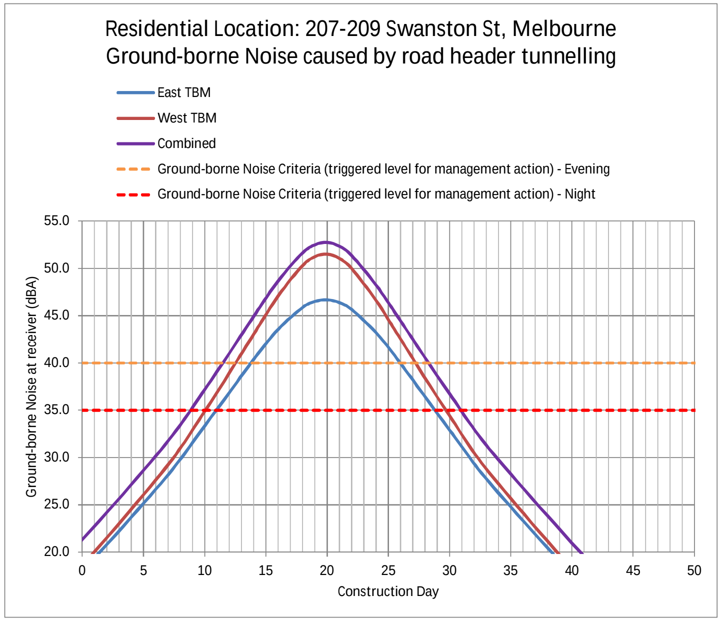

Figure B.101: Groundborne noise at Example Residential Receiver – Tunnelling using Road Header

(ii) Additional Construction Works

The Linlithgow Avenue emergency access shaft site is located away from receivers and it is predicted that ground-borne noise would comply with the guideline targets.

Construction works at the Fawkner Park construction work site and at the Fawkner Park emergency access shaft would be completed during Normal Working Hours. As such there are no exceedances of the guideline targets for evening or night-time ground-borne noise.

B.6.2 Precinct 2 – Western Portal (South Kensington)

A variety of construction equipment would be used at this site during Normal Working hours. The ground-borne noise and vibration predictions are based on assessments of vibration for 12-15 tonne rockbreakers, as these are the most vibration intensive items of equipment.

B.6.2.1 Vibration – Damage to Buildings

Vibration in this precinct is predicted to comply with the guideline targets for building damage.

B.6.2.2 Vibration – Damage to Utilities

There are a number of utilities, particularly clustered in the north-eastern part of the Western Portal precinct. To avoid damage, the critical distances construction work should be from utilities are:

- 3 m for general utilities
- 5.5 m for Melbourne Water unreinforced assets.

Location of the utilities is to be confirmed by the Proponent prior to the commencement of work.

B.6.2.3 Vibration – Human Comfort

A VDV of 0.84 $m/s^{1.75}$ is predicted at one residential building on Altona Street. This is approximately two times the maximum guideline target and relates to probable adverse comments. Possible adverse comments are predicted at four residential buildings (VDV greater than 0.4 $m/s^{1.75}$) and there is a low probability of adverse comments at four residential buildings (VDV between 0.2 and 0.4 $m/s^{1.75}$).

Management actions would be required for a short period of time when the rockbreaker is working in a region of the excavation which is close to residential receivers. It is predicted that the maximum guideline VDV target of 0.4 $m/s^{1.75}$ (low probability of adverse comment) is met when the rockbreaker is working outside a buffer zone of 25 m or more.

There are a number of management actions that the Proponent could use to minimise impacts on these residences:

- Consultation and negotiation with residences
- Based on the rock type in the Western Portal precinct it is expect that rock would fracture easily and that vibration levels may be lower than predicted. Vibration monitoring is recommended when construction commences in order to confirm the vibration levels and verify the buffer zone
- It is recommended that initial cuts should be made along the Northern boundary of the excavation so as to "buffer" residents from the vibration source
- The Proponent could consider the use of lower vibration methods of rock removal when working inside the buffer zone. These methods could include hydraulic splitting or chemical splitting (both of these methods would meet the guideline vibration targets). The Proponent may use other low vibration methods of rock removal, however, it is recommended that the vibration levels are assessed or measured.

B.6.2.4 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

Vibration-sensitive equipment, Bio-resources and Highly Sensitive Areas have not been identified in this precinct.

B.6.2.5 Ground-borne Noise

Construction works would be completed during Normal Working hours and as such there are no exceedances of the guideline targets for evening or night-time ground-borne noise.

B.6.3 Precinct 3 – Arden Station

A variety of construction equipment is proposed to be used at this site. Vibration predictions have been completed for vibration intensive equipment including piling rigs, excavators and heavy vehicles. Rockbreakers are not expected to be needed at Arden Station.

B.6.3.1 Vibration – Damage to Buildings

Vibration in this precinct is predicted to comply with the guideline targets for building damage.

B.6.3.2 Vibration – Damage to Utilities

There are a number of utilities within the Arden Station precinct and its surrounds. To avoid damage, the Highly Sensitive distances construction work should be from utilities are:

- 3 m for general utilities
- 5.5 m for Melbourne Water unreinforced assets.

Location of the utilities would be confirmed by the Proponent prior to the commencement of work.

B.6.3.3 Vibration – Human Comfort

Compliance with the guideline levels for human comfort is predicted.

B.6.3.4 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

Vibration-sensitive equipment, Bio-resources and Highly Sensitive Areas have not been identified in this precinct.

B.6.3.5 Ground-borne Noise

Compliance with the guideline targets for Ground-borne noise is predicted.

B.6.4 Precinct 4 – Parkville Station

A variety of construction equipment is proposed for this site. The ground-borne noise and vibration predictions are based on assessments of vibration for rippers and 20 tonne rockbreakers. It has been assumed that the rippers would operate from ground level to a depth of 25 m. 20 tonne rockbreakers would operate at depths greater than 25 m below ground level. It has been proposed that ripping and rockbreaking works continue 24 hours a day and 7 days a week once the station roof has been constructed.

Vibration predictions have also been made for the TBM which would be operating in the vicinity of receivers which are located in the western side of the Parkville precinct.

B.6.4.1 Vibration – Damage to Buildings

All buildings are predicted to meet the guideline targets for building damage. This includes heritage sites where a low vibration guideline target of 2.5 mm/s PPV applies.

It is noted that calculations are less accurate when predicting vibration levels that occur when equipment is operated in close proximity to a receiver (less than 5 m). Therefore it would be necessary for the Proponent to undertake vibration monitoring to verify vibration levels when equipment is operated within 5 m of a building. This applies to rockbreaking, ripping and piling equipment.

B.6.4.2 Vibration – Damage to Utilities

There are a number of utilities within the Parkville Station precinct and its surrounds. To avoid damage, the critical distances construction work should be from utilities are:

- 3 m for general utilities
- 5.5 m for Melbourne Water unreinforced assets.

Location of the utilities is to be confirmed by the Proponent prior to the commencement of work.

B.6.4.3 Vibration – Human Comfort

It is predicted that the maximum guideline VDV targets would be exceeded for a very brief period of time at buildings that are adjacent to the Parkville excavation. The affected buildings include the Peter Doherty Institute, Alan Gilbert Building, the University of Melbourne Faculty of Medicine, Howard Florey Laboratories, University of Melbourne Engineering Block and a small number of University of Melbourne buildings which are located on the Northern end of Barry Street.

The exceedances relate to ripping and would only occur when the ripper is working within 6.5 m of a receiver. The exceedances would only apply to receivers located on the ground floor of these buildings and in rooms that face the excavation. It is predicted that the duration of exceedance would be less than one day at the most affected receiver location. It is expected that the Proponent would be able to manage these exceedances through community consultation and careful scheduling of ripping works that are required in close proximity of receivers.

It is predicted that the maximum night-time guideline VDV target would be exceeded at the Vice Chancellor's House and at a small number of residential dwellings on Leicester Street. These exceedances relate to rockbreaking (not ripping). It is anticipated that the 20 tonne rockbreakers would only be required periodically and as such it is expected that any exceedances would be short in duration. It is expected that the proponent would be able to manage these exceedances by scheduling rockbreaking works in the vicinity of these receivers for the daytime (when the guideline VDV target is higher). A buffer distance of 35 m would be required for night-time rockbreaking.

B.6.4.4 Ground-borne Noise

It is predicted that the guideline target for ground-borne noise would be exceeded at one residential building on Barry St (141 Barry Street), the Vice Chancellor's House and a small number of residential dwellings on Leicester Street. Ground-borne noise is predicted to reach 38 dBA at the Barry St address, 43 dBA at the Vice Chancellor's House and up to 42 dBA at the Leicester Street dwellings. At most of these residential locations, the exceedances relate to rockbreaking (not ripping). It is anticipated that the 20 tonne rockbreakers would only be required periodically – when more competent material is encountered in the excavation. As such, it is expected that any exceedances would be short in duration. It is also expected that the proponent would be able to manage these exceedances by scheduling rockbreaking works in the vicinity of these receivers for normal working hours (when Ground-borne Noise targets do not apply). A buffer distance of 55 m would be required rockbreaking works outside of normal working hours.

It is also predicted that the 35 dBA night time target would be exceeded at the Vice Chancellor's House when the ripper is working within a buffer distance of 20 m. As such it is also recommended that the Proponent maintains a 20 m buffer distance when ripping at night.

B.6.4.5 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

(i) Vibration-sensitive Equipment

An assessment of vibration-sensitive equipment in the vicinity of the Parkville Construction site has been undertaken with respect to the ASHRAE Vibration Curves and the outcomes are provided in Table B14. Note that the reference for the vibration assessment is taken to be the greater of the VC-curve and baseline measurement (where available).Vibration guideline targets are predicted to be exceeded for some equipment at the following buildings:

- Royal Women's Hospital (due to TBM tunnelling activities)
- Royal Melbourne Hospital (due to both TBM tunnelling activities and rockbreakers used in the Additional Construction Works)
- VCCC (due to both TBM tunnelling activities and rockbreakers used in the Additional Construction Works)
- Peter Doherty Institute (due primarily to rockbreakers used in the Additional Construction Works)
- University of Melbourne (due primarily to rockbreakers used in the Additional Construction Works)
- Howard Florey Laboratories (ground floor and basement only due primarily to rockbreakers used in the Additional Construction Works).

Vibration exceedances due to TBM tunnelling activities (Royal Women's Hospital, Royal Melbourne Hospital and VCCC, University of Melbourne, Peter Doherty Institute and Howards Florey Laboratories) would be of limited duration as the TBM progresses along the tunnel. At the locations with the highest exceedances this impact is predicted to have a duration of up to 17 days. Mitigation should be used to manage any sensitive equipment vibration exceedances as follows:

- Consultation with stakeholders
- Temporarily reschedule the use of sensitive equipment to other times or non-affected facilities
- Monitoring of current vibration levels which may potentially increase the criterion for individual items (as applicable – some monitoring has already taken place and the results are included in the table for reference)
- Vibration monitoring during construction to ensure compliance with the vibration requirements.

The vibration predictions for Additional Construction Works are based on the maximum vibration levels predicted due to occur when rippers and rockbreakers are working in the nearest part of the excavation. The exceedances would reduce as the rippers and rockbreakers move away from sensitive receiver locations (both horizontally and as they move deeper underground).

Rockbreakers are expected to affect equipment in the VCCC and Royal Melbourne Hospital during excavation of the pedestrian entrance which is located in front of the VCCC building. Ripping and rockbreaking works in the main station excavation on Grattan Street are not expected to affect equipment in the Royal Melbourne Hospital. The VCCC linear accelerators are the only items of sensitive equipment in the VCCC that would be affected by works in the main station excavation (linear accelerators only affected when rockbreakers are working at the Western most 40 m of the excavation). There are a number of management actions that the Proponent would be able to take in order to mitigate vibration impacts on sensitive equipment in the VCCC and Royal Melbourne Hospital. These actions include:

- Consultation with stakeholders
- Vibration monitoring and monitoring of the performance of sensitive equipment when rippers and rockbreakers are working in the VCCC pedestrian entrance
- Temporarily reschedule the use of sensitive equipment to other times or non-affected facilities
- Careful scheduling of ripping rockbreaking works that are required in the VCCC pedestrian entrance
- The use of low vibration methods of material removal when excavating the pedestrian entrance outside the VCCC. Low vibration methods of rock removal could include methods such as hydraulic splitting or chemical splitting (both methods predicted to meet the guideline targets). The Proponent may also use other methods of rock removal provided that vibration levels meet the guideline targets.

Careful scheduling of ripping and rockbreaking works would be required in order to manage impacts on sensitive receivers that are immediately adjacent to the main station excavation (Howard Florey Laboratories, University of Melbourne and the Peter Doherty Institute). The Proponent would need to consult and negotiate closely with stakeholders in these buildings in order to develop a mutually acceptable schedule for ripping and rockbreaking work. It would also be necessary for the Proponent to maintain buffer distances between excavation machinery and vibration-sensitive equipment whilst the vibration-sensitive equipment is in use. It is expected that the Proponent would refine the buffer distances during the excavation works (using vibration monitoring and by monitoring the performance of sensitive equipment). For the most vibration-sensitive pieces of equipment it is predicted that buffer distances of up to 100 m for the 20 tonne rockbreaker and 60 m for the ripper would be required. The proponent may also consider the option of relocating certain pieces of sensitive equipment during construction.

Vibration predictions have also been made for bored piling which would be undertaken around the perimeter of the Parkville Station excavation. Vibration levels due to bored piling are expected to be significantly lower than the rockbreaker levels and exceedances are only predicted in three buildings. The exceedances include the Peter Doherty Institute (Electron microscope and photon laboratory), VCCC (linear accelerators and Level 5 MRI) and the University of Melbourne (confocal microscopes). The exceedances would only occur when piling works are occurring within a horizontal distance of 50 m of these pieces of equipment. It is expected that these exceedances would be managed through close consultation between the Proponent and the affected receivers and through careful scheduling of the piling works.

(ii) Biological Resources

An assessment of biological resources housed in the Parkville precinct has been undertaken and the outcomes are presented in Table B15. Management actions would be required due to vibration exceedances which are predicted for biological resources that are housed in the Howard Florey Laboratories, University of Melbourne Faculty of Medicine, and VCCC. The impact on biological resources due to TBM tunnelling is minor and predicted to have a duration of approximately one week. Slightly higher exceedances are predicted due to Additional Construction Work.

It is expected that the Proponent would consult with the relevant stakeholders to develop management actions. In most instances it is expected that vibration isolation mounting could be used to reduce vibration levels at the biological resources.

(iii) Highly Sensitive Areas

There are a number of Highly Sensitive areas identified in the Parkville precinct. These include wards and patient accommodation in the Royal Women's Hospital (RWH), the Royal Melbourne Hospital (RMH) and the Victorian Comprehensive Cancer Centre (VCCC).

An assessment of the Highly Sensitive areas has been undertaken and the outcomes are presented in Table B.16.

Human comfort vibration and ground-borne noise results indicate that management actions would be triggered for the following locations due to tunnelling:

- Wards and staff accommodation at the RWH (due to ground-borne noise above evening and night guidelines)
- ICU, south wards and cardiology ward at the RMH (due to vibration metrics and ground-borne noise being above guidelines)
- Country patient accommodation and wards at the VCCC (due to vibration metrics and ground-borne noise being above guidelines).

The duration of the impact at the worst affected area is predicted to be up to 9 days as the TBM moves past the location.

Mitigation is required for these areas and should include, in the first instance, consultation with stakeholders. Monitoring of current noise and vibration levels in some areas may be of assistance in potentially increasing the guideline limits. For some areas respite may be an option for the relatively short duration of the impact (typically expected to be less than one week).

Within each Highly Sensitive area there is expected to be a large variation in the noise and vibration impact. Locations directly adjacent the façade closest to the tunnel alignment would have the largest impact, with this impact reducing with distance from that façade. At most locations vibration metrics are within guidelines for positions on the far side of the Highly Sensitive area from the tunnel alignment, indicating that at least some portion of these Highly Sensitive areas may not have significant impact due to tunnelling works. Monitoring of noise and vibration during construction should be undertaken to guide management of facilities.

Further mitigation for this area may include reduced working hours for the TBM, which would reduce the extent of the impact but have the effect of extending the duration of the works and therefore the corresponding impact. Limiting working hours to daytime hours for the section of tunnel adjacent to these three buildings would result in noise and vibration meeting the guidelines for all locations except:

- ICU and cardiology ward (level 2) and Ward 3S at the Royal Melbourne Hospital are predicted to have some portion of the wards triggering management actions as a result of the VDV – Day metric
- Country patient accommodation (level 1) and the medical ward (level 3) at the VCCC are predicted to have some portion of the area triggering management actions as a result of the VDV – Day metric.

Management actions are not required due to additional construction works (guideline vibration and ground-borne noise targets are predicted to be met).

B.6.4.6 Assessment of Vibration and Ground-borne noise from Controlled Blasting - Parkville Station Box Excavation

In order to reduce the overall duration and severity of vibration and ground-borne noise impacts at Parkville that are associated with excavating the station box, an alternative construction methodology has been assessed based on the use of controlled blasting. Controlled blasting involves the use of multiple small explosive charges set off in a short sequence to remove a segment of rock whilst minimising vibration and ground-borne noise impacts. Blasts typically occur once or twice per day or every other day and potential impacts are limited to a short time window (a few seconds) rather than extended periods of heavy rockbreaker usage. Blasting would occur once the concrete cover is placed over the excavation and would therefore not involve air overpressure, dust and fly rock impacts. This technique has been used on numerous other tunnelling projects in urban areas within Australia including, CLEM7, Legacy Way and the Inner City Bypass in Brisbane as well as East Link in Melbourne. Controlled blasting has also been approved for the Brisbane Bus and Train Tunnel in Brisbane CBD and for NorthConnex tunnel in Sydney.

An assessment of the use of controlled blasting for the Parkville Station excavation was carried out to determine the potential impacts as well as any likely restrictions in terms of maximum charge weight size, buffer zones and other measures. The assessment was conducted for potential impacts including damage to structures, human comfort, sensitive equipment and highly sensitive areas.

The method used to conduct the assessment of impacts from controlled blasting is based on AS2187.2 using the following expression, where R is the source-receiver separation distance (m), W is the Maximum Instantaneous Charge weight (kg), K and B are site-specific constants dependent on geotechnical conditions and blast design.

$$V = K\left(\frac{R}{W^{0.5}}\right)^{-B}$$

For the purpose of estimating the mean (50% probability of exceedance) peak particle velocities for when blasting is carried out to a free face in average field conditions, K is taken as 1140 and B is 1.6. For the purpose of estimating 95th percentile peak particle velocities for the blasting carried out to a free face in average field conditions for comparison with vibration limits in AS2187.2, K is taken as 2462 and B is 1.6.

The assessment assumes that controlled blasting begins at 25 m below ground level in relatively hard rock that would otherwise require removal using heavy rockbreakers.

The results of the assessment indicate that controlled blasting using productive charge weights is likely to be feasible at the Parkville Station excavation and could assist in limiting the duration and severity of vibration impacts from an excavation plan based purely on the use of heavy rockbreakers. Vibration and ground-borne noise impacts from controlled blasting are expected to be manageable using appropriate mitigation measures as outlined below. Potential mitigations required to limit vibration and ground-borne noise impacts on nearby receivers include:

- Restricting blasting to outside the hours when nearby research buildings are normally occupied
- Observing exclusion zones or reducing charge weights close to the perimeter of the excavation, heritage and residential structures and within 20 m of the western end of the excavation
- Managing the risks associated with non-base-isolated sensitive instrument calibration and/or damage at Peter Doherty Institute and the University of Melbourne Faculty of Medicine building 181 by providing base isolation for equipment that is not currently base isolated, relocating equipment, preparing non-essential equipment by placing it in a transport mode, reducing charge weights local to the affected areas or using lower vibration excavation techniques as determined on site.

The following diagram (Figure B.102) shows the charge weights and probable buffer and restriction zones for blasting at the Parkville Station excavation based on the following analysis of blasting impacts and the constraints noted therein. These issues should be reviewed when trial blasting is carried out on site and site-specific factors and blast vibration mitigation mechanisms such as trenches, excavation walls and optimisation of the blast design are accounted for. In that case, the Proponent may modify the charge weights and buffer distances shown.

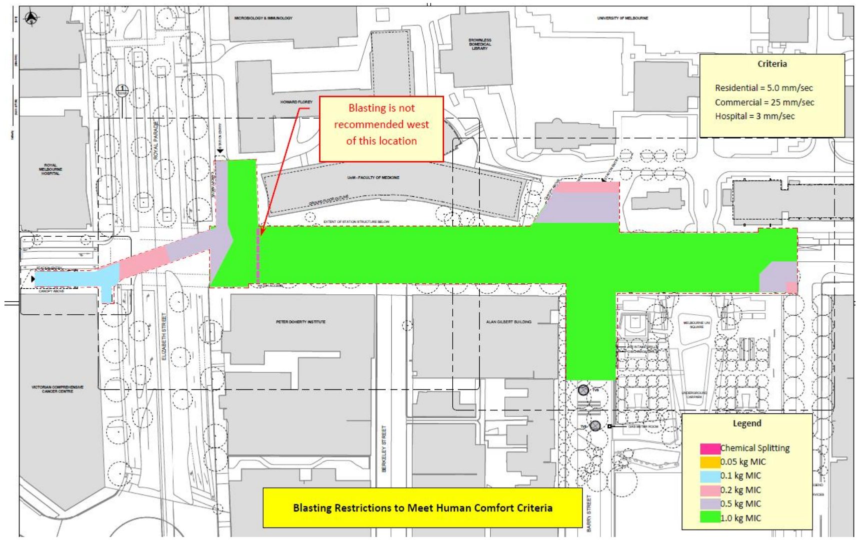

Figure B.102: Controlled blasting charge weights and probable buffer and restriction zones for the Parkville Station excavation for human comfort (contours based on a structural assessment of heritage buildings showing them to be no more vulnerable to vibration than a residential property)

(i) **Vibration – Damage to buildings**

The Parkville Station box excavation is surrounded by large commercial buildings belonging to research institutions and hospitals. There are also a small number of terrace houses on Barry Street and Leicester Street that are regarded as being of heritage construction as is the Vice Chancellor's residence at the University of Melbourne. The gatekeeper's cottage belonging to the University of Melbourne is specifically listed as a heritage structure. Each of these structural types attracts a different vibration guideline target for blasting based on AS2187.2 and DIN4150-3, being 50 mm/s PPV, 12.7 mm/s PPV and 3 mm/s PPV respectively.

The assessment of vibration levels due to blasting indicates that a typical Maximum Instantaneous Charge weight (MIC) of 1 kg could be used with a buffer distance of 12 m to commercial buildings, 30 m for residential building types and 70 m to heritage buildings. Smaller charges could be used at closer distances to commercial and residential structures in conjunction with a buffer zone of 15 m to the heritage building, inside which low vibration techniques would need to be used in place of blasting. The restriction on blasting within 70 m slope distance of the heritage structures may limit productive blasting to about half of the footprint of the excavation site. It is possible that a structural and building condition assessment could be made of the heritage buildings to increase the blasting vibration limit to 12.7 mm/s matching the residential structures, in which case the limitations on blast sizes and distances would be the same as for the residential structures and a significantly increased productive blast area could be achieved based solely on structural damage considerations.

(ii) **Vibration – Human Comfort**

Vibration limits for blasting that relate to human comfort are 25 mm/s PPV for commercial receivers, 5 mm/s for residential receivers based on AS2187.2. A 3 mm/s PPV human comfort vibration limit has been proposed for hospital receivers based on research by Lenzen (1966) indicating that this should be no more noticeable than a heel drop or foot slam and therefore likely to be acceptable for human comfort in hospitals for a small number of events per day.

An assessment of the potential vibration impacts on human comfort from blasting indicates that when using a 1kg MIC a buffer of about 20 m (slope distance) would be required for commercial receivers, and 50 m for residential receivers, in order to preserve human comfort. Commercial receivers are in close proximity to much of the excavation site and this may significantly limit the use of controlled blasting even if smaller charge weights were to be used when closer than 20 m. In any use of controlled blasting it would be necessary to conduct trial blasts on site to verify buffer distances and charge weights and this may lead to higher charge weights than forecast being feasible without increasing impacts. However, based on the analysis it is recommended that if controlled blasting is carried out that the blasts be conducted outside normal working hours and in close consultation with the affected parties in order to minimise potential impacts whilst enabling blasting to be productive. If blasting were to be conducted outside of the hours when the commercial buildings are normally occupied, then there are some restrictions at the western end of the excavation associated with buffer distances and reduced charge weights for preserving human comfort at the Royal Melbourne Hospital and restrictions at the eastern end of the excavation related to human comfort for residential occupancies. Other limitations in terms of buffer distances and charge weights relate to the requirements for the avoidance of structural damage and for sensitive equipment and highly sensitive areas as described below.

(iii) **Vibration – Sensitive Equipment and Highly Sensitive Areas**

Vibration limits for the operation of vibration-sensitive imaging equipment and for highly sensitive areas are the most stringent of the vibration requirements for the Parkville station site. In general, vibration-sensitive equipment is many times more sensitive to vibration than people. It is therefore not considered to be practicable to meet the vibration requirements for the operation of vibration-sensitive equipment during blasting and it is recommended that mitigation involve close consultation with the affected parties, notification of any blasting schedule and that sensitive imaging equipment not be used during blasting. Negotiation would be required with stakeholders having special need for the use of sensitive imaging equipment, which may require scheduled breaks in the blasting program.

There are no recognised vibration limits relating to the prevention of calibration issues or damage to the vibration-sensitive equipment due to vibration from controlled blasting, however, this is a risk that needs to be managed. It is recommended that a 3 mm/s PPV threshold on the base of vibration-sensitive equipment be considered as a trigger level for identifying potential issues. Discussions with equipment providers and trial blasts on site may be used to determine whether higher vibration limits can apply for avoidance of equipment recalibration issues. Equipment that is base isolated or remote from the excavation site is not expected to be at risk. If controlled blasting is avoided until approximately 20 m from the western end of the main Grattan Street excavation, then potential issues are expected to be limited to non-base isolated vibration-sensitive equipment in the Peter Doherty Institute and the University of Melbourne Faculty of Medicine building 181. Potential mitigations for these sites include providing base isolation for equipment that is not currently base isolated, relocating equipment, preparing non-essential equipment by placing it in a transport mode, reducing charge weights local to the affected areas or using lower vibration excavation techniques.

Highly sensitive areas include operating theatres and wards at the Royal Melbourne Hospital, Melbourne Private Hospital, Royal Women's Hospital and the VCCC as well as biological resources at the Peter Doherty Institute, VCCC, the Howard Florey Laboratories and the Royal Melbourne Hospital. A blast vibration assessment for a nominal 1 kg MIC and 20 m blast exclusion zone at the western end of the Grattan Street excavation indicates that all highly sensitive areas at the Royal Melbourne Hospital, Royal Women's Hospital, Melbourne Private Hospital and VCCC would experience vibration levels of less than 3 mm/s PPV, which is considered to be acceptable. Biological resources at the Peter Doherty Institute and at the University of Melbourne Faculty of Medicine building 181 are also predicted to have vibration levels below 3 mm/s PPV.

Ground-borne noise estimates for controlled blasting have been generated for biological resources for comparison with guideline targets of 85 dBL (short exposure) and ambient noise measurements taken at some of the biological resource locations. Ground-borne noise estimates were developed based on a vibration spectra for construction blasts derived from US Bureau of Mines research and noise radiation characteristics of a typical brick/concrete room construction. Based on this approach a vibration level of 3 mm/s PPV in the receiver space would generate a noise level inside the room that is less than the 85 dBL guideline noise target for biological resources once the frequency thresholds for biological resources are applied (the frequency range relating to the 85 dBL guideline target must be determined in relation to each facility depending on its usage). This means that if vibration levels are maintained at below 3 mm/s PPV in biological resource receiver spaces then the ground-borne noise guideline target is also likely to be achieved. Therefore it is likely that biological resources in buildings adjacent to the Grattan Street excavation, which are located at high levels within those buildings would experience ground-borne noise levels that are below the guideline target for the blast design analysed and that ground-borne noise impacts on biological resources at Parkville would be manageable without placing significant additional restrictions on the blast design.

Table B.14: Vibration predictions for vibration-sensitive equipment due to construction activities

Location	Vibration-sensitive Equipment	Vibration assessment reference see note e		Vibration assessment (maximum 1/3 octave vibration level (RMS) for comparison with VC curve see Note d)			Comments
		Vibration guideline target (magnitude of peak 1/3 octave band, RMS)	Baseline measurements (magnitude of peak 1/3 octave band, RMS)	Due to tunnelling activities	Due to Rockbreaking	Due to Ripping	
Royal Women's Hospital							
Level 1 adjacent to Grattan Street	CT Scanner MRI	VC-A 50 µm/s VC-C 12.5 µm/s	VC-B 17 µm/s	Exceeds (69 µm/s)	Complies (4 µm/s)	Complies (1 µm/s)	Equipment was not impacted upon by construction at VCCC
Level 2: Infertility	Microscopy	VC-A 50 µm/s	N/A	Minor exceedance (55 µm/s)	Complies (3 µm/s)	Complies (1 µm/s)	
Level 3: Theatres	Typical equipment	Operating Room 100 µm/s	N/A	Complies (43 µm/s)	Complies (3 µm/s)	Complies (1 µm/s)	
Royal Melbourne Hospital, Building							
Ground Level	Gamma cameras, PET Scanner	VC-A 50 µm/s	N/A	Complies (13 µm/s)	Complies (21 µm/s)	Complies (6 µm/s)	Adjacent to Royal Parade RMH Nuclear medicine department
Ground Level	CT scanner	VC-A 50 µm/s	N/A	Exceeds (72 µm/s)	Complies (12 µm/s)	Complies (4 µm/s)	Emergency Department
Level 1	MRI (1.5 T, MRI (3 T) CT Scanner	VC-C 12.5 µm/s VC-A 50 µm/s	VC-B 13 µm/s	Exceeds (217 µm/s) Exceeds (112 µm/s)	Exceeds (67 µm/s) Minor exceedance (57 µm/s)	Exceeds (25 µm/s) Complies (4 µm/s)	
Level 2	Sensitive equipment	VC-A 50 µm/s	N/A	Complies (16 µm/s)	Complies (46 µm/s)	Complies (16 µm/s)	Haematology
Level 3	Operating theatres	100 µm/s	N/A	Exceeds near façade (180 µm/s) Becomes compliant approximately 13m from facade	Complies (46 µm/s)	Complies (16 µm/s)	
Level 3	MRI	VC-C 12.5 µm/s	N/A	Exceeds (22 µm/s)	Minor exceedance (15 µm/s)	Complies (4 µm/s)	Cardio and neurology surgery General and Angiography theatres
Level 5 (north corner)	MRIs	VC-C 12.5 µm/s	VC-B 20 µm/s	Complies (3 µm/s)	Complies (9 µm/s)	Complies (3 µm/s)	
Level 8 East Wing Main Block	Instrument Lab	VC-A 50 µm/s	N/A	Complies (6 µm/s)	Complies (5 µm/s)	Complies (1 µm/s)	Belonging to WEHI
Melbourne Private Hospital							
Ground Level	MRI (1.5 T), MRI (3 T) CT scanner, X-ray equipment Ultra sound, Mammography	VC-C 12.5 µm/s VC-A 50 µm/s 100 µm/s	N/A	Complies (7 µm/s) Complies (7 µm/s) Complies (72 µm/s)	Complies (12 µm/s) Complies (12 µm/s) Complies (12 µm/s)	Complies (4 µm/s) Complies (4 µm/s) Complies (4 µm/s)	Private Medical Centre Radiology
Level 2	Sensitive equipment	VC-A 50 µm/s	N/A	Complies (16 µm/s)	Complies (46 µm/s)	Complies (16 µm/s)	Micro Biology Lab
Level 7	Brain navigation systems	Operating Room 100 µm/s	N/A	Complies (3 µm/s)	Complies (3 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 (19 µm/s)	Minor exceedance (19 µm/s)	Complies (6 µm/s)	
Basement 1 (adjacent to Grattan Street)	Linear accelerators	VC-C 12.5 µm/s	N/A	Exceeds (405 µm/s)	Exceeds (>300 µm/s)	Exceeds (>300 µm/s)	
Basement 1 (towards Flemington Road)	CT Scanners	VC-A 50 µm/s	N/A	Minor exceedance (51 µm/s)	Complies (33 µm/s)	Complies (10 µm/s)	

Location	Vibration-sensitive Equipment	Vibration assessment reference [see note e]		Vibration assessment (maximum 1/3 octave vibration level (RMS) for comparison with VC curve[see Note d])			Comments
		Vibration guideline target (magnitude of peak 1/3 octave band, RMS)	Baseline measurements (magnitude of peak 1/3 octave band, RMS)	Due to tunnelling activities	Due to Rockbreaking	Due to Ripping	
Level 4	MRIs	VC-A 50 µm/s[see note c]	N/A	Complies (13 µm/s)	Complies (10 µm/s)	Complies (3 µm/s)	
Level 5	MRI, Xray, Ultrasounds, PET, CT	VC-A 50 µm/s [see note c] 100 µm/s VC-A 50 µm/s	N/A	Exceeds (104 µm/s) Complies (85 µm/s) Complies (13 µm/s)	Exceeds (123 µm/s) Complies (58 µm/s) Complies (8 µm/s)	Exceeds (123 µm/s) Complies (56 µm/s) Complies (2 µm/s)	
Level 6	Operating theatre Future MRI	100 µm/s VC-A 50 µm/s[see note c]	N/A	Complies (64 µm/s) Exceeds (58 µm/s)	Complies (47 µm/s) Complies (41 µm/s)	Complies (45 µm/s) Complies (28 µm/s)	
Peter Doherty Institute							
Basement	Electron microscope	VC-A 50 µm/s (on floor slab)	VC-D 6 µm/s	Exceeds (57 µm/s)	Exceeds (178 µm/s)	Exceeds (172 µm/s)	Located on independent concrete inertia block with pneumatic isolation. Criterion is based on information from Marshall Day Acoustics Report dated 13 February 2011 Reference SP0032010065.
Ground	Auditorium	Operating Room 100 µm/s	N/A	Complies (79 µm/s)	Minor exceedance (158 µm/s)	Minor exceedance (105 µm/s)	
Level 1	Genomics room	VC-C 12.5 µm/s	N/A	Exceeds (45 µm/s)	Exceeds (80 µm/s)	Exceeds (32 µm/s)	
Level 7	Microscopy	VC-A 50 µm/s	VC-A 48 µm/s	Complies (17 µm/s)	Complies (33 µm/s)	Complies (22 µm/s)	
Level 8	Photon	VC-C 12.5 µm/s	N/A	Minor exceedance (14 µm/s)	Exceeds (63 µm/s)	Exceeds (63 µm/s)	Located on vibration table
University of Melbourne							
Ground, Bio21	Electron microscope	VC-D 6 µm/s	VC-B 20 µm/s	Complies (5 µm/s)	Complies (0 µm/s)	Complies (0 µm/s)	Electron microscope isolated from structure.
Ground, Building 170	Laser diagnostics equipment	VC-A 50 µm/s	N/A	Exceeds (85 µm/s)	Complies (10 µm/s)	Complies (3 µm/s)	
Level 1, Building 170	Fluroscopes and Robotic Gantry Equipment	100 µm/s	N/A	Complies (77 µm/s)	Complies (8 µm/s)	Complies (2 µm/s)	
Ground, Building 261	Helium Ion Microscope	VC-D 6 µm/s	N/A	Minor exceedance (7 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	
Basement, Building 175	Network Analysers and Dielectric Permittivity Probes	200 µm/s	N/A	Complies (153 µm/s)	Complies (170 µm/s)	Complies (138 µm/s)	
Ground, Building 165	Thermal Gravity Analysis	100 µm/s	N/A	Complies (5 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	
Ground, Building 165	Sorption Analyser	VC-A 50 µm/s	N/A	Complies (5 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	
Ground, Building 165	Nanomaterials Nanoindenter	VC-C 12.5 µm/s	N/A	Complies (5 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	On air isolated table
Level 1, Building 165	JPK Nanowizard	VC-C 12.5 µm/s	N/A	Complies (4 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	
Level 1, Building 165	3D Atomic Force Microscope	VC-D 6 µm/s	VC-B 15 µm/s	Complies (4 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	Located on air dampened table
Level 1, Building 165	20nm Resolution Microscope	VC-B 25 µm/s	N/A	Complies (4 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	On air isolated table
Level 1, Building 165	200nm Resolution Microscope	VC-B 25 µm/s	N/A	Complies (4 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	
Level 2, Building 165	3D Atomic Force Microscope	VC-D 6 µm/s	N/A	Complies (3 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	Located on air dampened table
Level 3, Building 181	Confocal Microscope (Leica SP2)	VC-C 12.5 µm/s	VC- 24 µm/s	Exceeds (40 µm/s)	Exceeds (51 µm/s)	Complies (21 µm/s)	Vibration limit from supplier data. On isolation table
Ground, Building 181	Confocal Microscope	314 µm/s on floor	VC- 28 µm/s	Complies (173 µm/s on floor)	Complies (178 µm/s on floor)	Complies (172 µm/s on floor)	On isolation table. Vibration limit from supplier data.

Location	Vibration-sensitive Equipment	Vibration assessment reference [see note e]		Vibration assessment (maximum 1/3 octave vibration level (RMS) for comparison with VC curve [see Note d])			Comments
		Vibration guideline target (magnitude of peak 1/3 octave band, RMS)	Baseline measurements (magnitude of peak 1/3 octave band, RMS)	Due to tunnelling activities	Due to Rockbreaking	Due to Ripping	
Howard Florey Laboratories							
Basement	MRI	VC-C 12.5 µm/s	VC-C 11 µm/s	Exceeds (31 µm/s)	Exceeds (99 µm/s)	Exceeds (41 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	Complies (7 µm/s)	Complies (6 µm/s)	Complies (2 µm/s)	Potential Crystallography facility
Level 3C WEHI 1	Laser and analysis equipment	VC-A 50 µm/s	N/A	Complies (4 µm/s)	Complies (3 µm/s)	Complies (1 µm/s)	
Level 4C WEHI 1	High sensitivity microscopes	VC-B 25 µm/s	VC-A 58 µm/s	Complies (4 µm/s)	Complies (2 µm/s)	Complies (1 µm/s)	
Level 7W WEHI 2		VC-A 50 µm/s	N/A	Complies (2 µm/s)	Complies (1 µm/s)	Complies (0 µm/s)	Structural Biology Crystal Store
Kenneth Myer Building							
Basement Level	Small bore MRI (4.7 T)	VC-B 25 µm/s	VC-D 5 µm/s	Complies (5 µm/s)	Complies (10 µm/s)	Complies (3 µm/s)	
Ground Level	MRI (7 T), PET CT Camera	VC-C 12.5 µm/s VC-A 50 µm/s	N/A	Complies (5 µm/s)	Complies (10 µm/s)	Complies (3 µm/s)	
All Levels	Extremely sensitive equipment	VC-C 12.5 µm/s	N/A	Complies (5 µm/s)	Complies (10 µm/s)	Complies (3 µm/s)	Equipment that is extremely sensitive to vibration
Level 1	Nano PET	VC-C 12.5 µm/s	N/A	Complies (4 µm/s)	Complies (10 µm/s)	Complies (3 µm/s)	Some equipment is pneumatically isolated
Level 2	2 photon microscopes	VC-C 12.5 µm/s	N/A	Complies (4 µm/s)	Complies (6 µm/s)	Complies (2 µm/s)	Equipment pneumatically isolated
Level 3	Advanced microscopy	VC-B 25 µm/s	N/A	Complies (3 µm/s)	Complies (5 µm/s)	Complies (1 µm/s)	Advance microscopy Equipment pneumatically isolated
Level 4	Mass spectroscopy	VC-C 12.5 µm/s	N/A	Complies (3 µm/s)	Complies (4 µm/s)	Complies (1 µm/s)	Mass spectroscopy
Level 7	Sensitive equipment	VC-A 50 µm/s	N/A	Complies (2 µm/s)	Complies (2 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	Complies (3 µm/s)	Complies (5 µm/s)	Complies (1 µm/s)	In the Pittard Room (desk-mounted teaching resource)

a) The list in this table is representative of the most sensitive equipment at closest proximity to the alignment. Other vibration-sensitive equipment may also be present at some sites.

b) AHSRAE does not provide vibration guideline targets 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. Bio-resource facilities must comply with the VC curve for laboratories VC-A curve *50 µm/s*
2. X-Rays, Ultrasound, Mammography, Gamma Cameras must comply with the VC curve for laboratories VC-A curve *50 µm/s*
3. Generally sensitive equipment must comply with VC-A curve *50 µm/s*
4. PET scanners and Mass Spectroscopy machines have similar vibration requirements to MRI machines (VC-C *12.5 µm/s*)
5. CT scanners must comply with the VC-A curve *50 µm/s*
6. Hospital operating rooms are **not** used for microsurgery, eye surgery, or neurosurgery (ie they can be classified as a standard "Operating Room" *100 µm/s*)
7. Electron microscopes have a magnification of 30,000 x or greater (VC-D *6 µm/s*)
8. Photon Microscopes, Crystallography sites, Linear accelerators and Cyclotrons have similar vibration requirements to Electron microscopes and MRIs (VC-C *12.5 µm/s*)
9. General microscopes (for which the magnification is not listed are assumed) must comply with VC-A curve *50 µm/s*
10. Advanced or sensitive microscopes (for which the magnification is not listed are assumed) must comply with VC-B curve *25 µm/s*

c) MRIs located in the VCCC have a limit of 50µm/s as specified in *Victorian Comprehensive Cancer Centre Project, Volume 2, Part C, Technical Specification* (DH-PDOC-F84-C-000_04-150525-rm.docx).

d) For rockbreaking, PPV vibration levels were first converted in to overall RMS vibration using a crest factor of 4 (consistent with the FTA guideline). A factor of 1.5 reduction in overall vibration was used to calculate the 1/3rd Octave vibration. This factor of 1.5 reduction is intended to reflect some spread in vibration across the different frequency bands.

e) Note that the reference for the vibration assessment is taken to be the greater of the VC-curve and baseline measurement (where available).

Table B.15: Vibration and ground-borne noise predictions for biological resources due to construction activities

Location	Vibration target		Ground-borne noise target		Vibration assessment (maximum 1/3 octave vibration level (RMS) for comparison with VC curve[see Note c])		Ground-borne Noise Assessment	
	Guideline Target (magnitude of peak 1/3 octave band, RMS)	Baseline measurements (magnitude of peak 1/3 octave band, RMS)	Guideline Target	Baseline measurements (Leq)	Due to tunnelling activities	Due to additional construction works (ripping and rockbreaking)	Due to tunnelling activities	Due to additional construction works (ripping and rockbreaking)
Royal Melbourne Hospital, Building								
Basement	VC-A 50 µm/s	VC-D 6 µm/s	50 dB	78 dB	Minor exceedance (69 µm/s)	Exceeds (117 µm/s)	Complies (75 dBL)	Complies (77 dBL)
Level 6	VC-A 50 µm/s	N/A	50 dB (>500Hz)	60 dB	Complies (18 µm/s)	Complies (31 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Peter Doherty Institute								
Level 8	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Complies (11 µm/s)	Complies (16 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 9	VC-A 50 µm/s	VC-A 35 µm/s	50 dB (>500Hz)	N/A	Complies (9 µm/s)	Complies (13 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 9	VC-A 50 µm/s	VC-A 35 µm/s	50 dB	70 dB	Complies (9 µm/s)	Complies (13 µm/s)	Complies (58 dBL)	Complies (58 dBL)
Howard Florey Laboratories								
Ground Floor	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Minor exceedance (53 µm/s)	Minor exceedance (79 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 3	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Complies (27 µm/s)	Complies (40 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 4	VC-A 50 µm/s	N/A	50 dB (>100Hz)	N/A	Complies (21 µm/s)	Complies (32 µm/s)	Complies (19 dBL)	Complies (<50 dBL)
Level 5	VC-A 50 µm/s	N/A	50 dB (>100Hz)	N/A	Complies (17 µm/s)	Complies (26 µm/s)	Complies (16 dBL)	Complies (<50 dBL)
Level 7	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Complies (12 µm/s)	Complies (17 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Walter and Eliza Hall Institute (WEHI)								
Level 1C, WEHI 1	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Complies (6 µm/s)	Complies (4 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 2 WEHI 2	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Complies (5 µm/s)	Complies (4 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 4C WEHI 1	VC-A 50 µm/s	VC-A 43 µm/s	50 dB (>500Hz)	61 dB	Complies (4 µm/s)	Complies (1 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
University of Melbourne Faculty of Medicine								
Level 9	VC-A 50 µm/s	VC-B 20 µm/s	50 dB (>500Hz)	49 dB	Complies (18 µm/s)	Complies (35 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 9	VC-A 50 µm/s	VC-A 29 µm/s	50 dB (>500Hz)	45 dB	Complies (18 µm/s)	Complies (18 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
VCCC								
Level 4	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Complies (9 µm/s)	Complies (7 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)
Level 8	VC-A 50 µm/s	N/A	50 dB (>500Hz)	N/A	Minor exceedance (63 µm/s)	Minor exceedance (63 µm/s)	Complies (<50 dBL)	Complies (<50 dBL)

Note: Targets for noise and vibration are taken as the greater of the guideline target and the baseline measurement (where available).

Table B.16: Vibration and ground-borne noise predictions for Highly Sensitive areas due to construction activities

Location	Highly Sensitive Area	Noise and vibration due to tunnelling See note 1			Noise and vibration due to additional construction works (ripping and rockbreaking)			Comments
		Vibration - VDV day ($m/s^{1.75}$)	Vibration - VDV Night ($m/s^{1.75}$)	Ground-borne Noise (dBA)	Vibration - VDV day ($m/s^{1.75}$)	Vibration - VDV Night ($m/s^{1.75}$)	Ground-borne Noise (dBA)	
Trigger levels for management action:		0.4 (maximum)	0.2 (maximum)	35	0.4 (maximum)	0.2 (maximum)	35	
Royal Women's Hospital								
Level 4	Wards	Complies (0.23)	Complies (0.20)	Minor exceedance (21-37)	Complies (0.01)	Complies (0.00)	Complies (< 20)	
Level 5	Staff Accommodation	Complies (0.18)	Complies (0.16)	Complies (19-35)	Complies (0.00)	Complies (0.00)	Complies (< 20)	
Level 7	Maternity	Complies (0.12)	Complies (0.11)	Complies (15-31)	Complies (0.00)	Complies (0.00)	Complies (< 20)	
Royal Melbourne Hospital								
Level 2	ICU	Exceeds (0.14-0.71)	Exceeds (0.12-0.62)	Exceeds (30-50)	Complies (0.04)	Complies (0.04)	Complies (24)	
Level 3	Ward 3S	Exceeds (0.11-0.57)	Exceeds (0.10-0.50)	Exceeds (28-48)	Complies (0.03)	Complies (0.03)	Complies (22)	
Level 5	Ward 5S	Complies (0.37)	Exceeds (0.07-0.33)	Exceeds (24-44)	Complies (0.02)	Complies (0.02)	Complies (< 20)	
Level 6	Ward 6S	Complies (0.30)	Exceeds (0.05-0.27)	Exceeds (22-42)	Complies (0.02)	Complies (0.02)	Complies (< 20)	
Level 7	Ward 7S	Complies (0.25)	Exceeds (0.04-0.22)	Exceeds (20-40)	Complies (0.01)	Complies (0.01)	Complies (< 20)	
Level 2	Cardiology ward 2b	Exceeds (0.09-0.82)	Exceeds (0.08-0.72)	Exceeds (24-51)	Complies (0.19)	Complies (0.16)	Minor exceedance (37)	Minor exceedance relates to the 20 tonne rockbreaker
Level 2	Ward 2W	Complies (0.07)	Complies (0.06)	Complies (22)	Complies (0.01)	Complies (0.01)	Complies (<20)	
Level 5	Ward 5E	Complies (0.04)	Complies (0.03)	Complies (15)	Complies (0.01)	Complies (0.01)	Complies (< 20)	
Level 7	Ward 7W	Complies (0.03)	Complies (0.02)	Complies (11)	Complies (0.00)	Complies (0.00)	Complies (< 20)	
Level 9	Ward 9E & 9W	Complies (0.02)	Complies (0.02)	Complies (7)	Complies (0.00)	Complies (0.00)	Complies (< 20)	
Victorian Comprehensive Cancer Centre								
Level 1	Country patient accommodation	Exceeds (0.23-0.88)	Exceeds (0.2-0.77)	Exceeds (35-52)	Complies (0.05)	Complies (0.05)	Complies (26)	
Level 3	Medical ward	Exceeds (0.11-0.57)	Exceeds (0.09-0.50)	Exceeds (27-48)	Complies (0.07)	Complies (0.06)	Complies (29)	
Level 5	Haematology ward	Complies (0.37)	Exceeds (0.06-0.33)	Exceeds (23-44)	Complies (0.05)	Complies (0.04)	Complies (25)	
Level 6	Surgical ward	Complies (0.30)	Exceeds (0.05-0.27)	Exceeds (21-42)	Complies (0.04)	Complies (0.03)	Complies (23)	
Peter Doherty Institute								
Ground	Auditorium	Complies (0.26) See note 2	N/A	37 See note 3	Complies (0.6) See note 2	N/A	44 See note 3	

Note 1: Some results are presented as ranges with the largest values occurring adjacent to the closest facade to the alignment. The smaller values are predicted for the regions furthest from the alignment. Where results are presented as a single figure it is the worst-case prediction for the area.

Note 2: A VDV day maximum guideline target of 0.8 applied to the Auditorium space.

Note 3: There is no guideline target for ground-borne noise for educational receivers (such as the Peter Doherty Auditorium). Predicted ground-borne noise levels of up to 44 dBA are not expected to impact on impact on persons using the auditorium.

B.6.5 Precinct 5 – CBD North Station

The CBD North Station assessment has taken into account two main areas of construction:

- The station cavern mined using multiple road headers
- Additional Construction Work using a variety of other equipment. The ground-borne noise and vibration predictions for this are based on assessments of vibration for rockbreakers and rippers, as these are the most vibration intensive items of construction equipment. Vibration predictions have been made under the following assumptions:
  - Franklin Street excavation: Rippers would be used to remove material to a depth of 25 m below ground level. 20 tonne rockbreakers would be used to remove material from depths greater than 25 m below ground
  - A'Beckett Street shaft excavation: Rippers would be used to remove material to a depth of 15 m below ground level. 20 tonne rockbreakers would be used to remove material between 15 and 25 m below ground level. 32 tonne rockbreakers would be used to remove material that is greater than 25 m below ground level
  - Southern entrance excavation: Rippers would be used to remove material to a depth of 20 m below ground level. 20 tonne rockbreakers would be used to remove material that is between 20 and 30 m below ground level. 32 tonne rockbreakers would be used to remove material that is greater than 30 m below ground level.

B.6.5.1 Vibration – Damage to Buildings

(i) Tunnelling (Station Cavern Road Headers)

Compliance with DIN 4150 guideline targets for structural damage is predicted due to road header excavation of the station cavern.

Several structurally sensitive (heritage) sites have been identified in this precinct and Table B.17 presents the predicted PPV levels at these sites along with current measured levels. At all locations the predicted vibration level due to road header activity complies with the DIN 4150 guideline target and is less than the baseline peak vibration level measured. Consequently, damage from tunnelling is not expected.

Table B.17: Vibration levels at other sensitive sites

Sensitive Site	Baseline PPV (mm/s)	Predicted PPV (mm/s)	Comments
CBD North			
City Baths	1.6	0.3	Predicted level less than existing
RMIT Microelectronics and Material Technology Centre	5.2	0.7	Predicted level less than existing
State Library	3.2	0.2	Predicted level less than existing

(ii) Additional Construction Works

A guideline PPV target of 10 mm/s applies to most of the buildings in the vicinity of the excavations. It is predicted that the 10 mm/s target would be met provided that a buffer distance of 1.5 m is maintained between the ripper and buildings. Rockbreaker works are not predicted to be an issue due to the depth of operation (25 m or more).

Most buildings in the CBD North precinct are greater than 1.5 m from the excavations and as such it is predicted that vibration would be lower than the 10 mm/s guideline target. Management actions may be required at one building on Swanston St (RMIT building 393-397 Swanston Street) which is immediately adjacent to the Southern Entrance excavation. The potential for cosmetic building damage to at this location could be mitigated by adopting lower vibration methods of excavation when removing material in the immediate vicinity of the building. Lower vibration methods could include the use of smaller sized ripper attachments. Pre-splitting could also be used to lessen the vibration associated with the removal of any hard material. Vibration measurements would need to be undertaken in order to verify the vibration levels.

Heritage sites, where a low guideline target of 2.5 mm/s PPV applies, have been assessed. It is predicted that this guideline target may be exceeded at three buildings that are on the Heritage Overlay. These buildings include the Old Cyclone Wire Fence Co. building (HO1042), the Oxford Hotel (HO1085) and 411-423 Swanston Street (HO1084). It is recommended that vibration monitoring is conducted at these locations during construction. If vibration levels exceed the 2.5 mm/s guideline target, the proponent should seek to use lower vibration methods of construction. Dilapidation surveys should also be conducted. It is noted that baseline vibration levels of up to 5.2 mm/s have been recorded in the vicinity of these buildings and that the proponent may be able to justify the adoption of higher vibration limits for construction.

Whilst vibration levels do not exceed 2.5 mm/s at the City Baths (Victorian Heritage Register H0466), vibration monitoring and dilapidation surveys are recommended as a precautionary measure.

It is important to note that vibration predictions can be inaccurate at distances of less than 5 m. As such it is recommended that vibration monitoring is conducted whenever equipment is operated within 5 m of a building. This applies to rippers, rock-breakers and piling rigs.

B.6.5.2 Vibration – Damage to Utilities

(i) Tunnelling (Station Cavern Road Headers)

There are a number of utilities within the CBD North station precinct and its surrounds. To avoid damage, the critical distances construction work should be from utilities are:

- 2.0 m for general utilities
- 3.7 m for Melbourne Water unreinforced assets

Location of the utilities is to be confirmed by the Proponent prior to the commencement of work.

The tunnel alignment crosses the Melbourne Underground Rail Link (MURL) tunnels in the CBD North station precinct. The peak vibration level predicted at the MURL due to road header mining of the CBD North-CBD South tunnel is predicted to be 12 mm/s. This level is the peak predicted to occur when the road header is excavating soil from the top of the tunnel and the closest alignment to the MURL tunnels. Vibration would reduce as the cutter face moves away from the top of the tunnel and as the road header progresses along the tunnel. Predicted vibration levels at such a close distance is beyond the typical limits for the regression formula derived for the road header vibration attenuation curve, and as such may be somewhat overly conservative.

This predicted vibration level is slightly in excess of the DIN 4150 long-term criterion of 10 mm/s. This standard is considered to be conservative and the British Standard BS 7385-2:1993 gives a guide value for vibration criterion relating to cosmetic damage of 25 mm/s (50% of transient vibration guide value, for industrial and heavy commercial buildings). Thus, while at the MURL predicted vibration exceeds the DIN 4150 guideline target selected for this project, the risk should be able to be addressed by utilising vibration monitoring at the MURL tunnel during road header mining.

(ii) Additional Construction Works

The critical distance that Additional Construction Works should be from the utilities to avoid damage is:

- 3 m for general utilities
- 5.5 m for Melbourne Water unreinforced assets

Location of the assets should be confirmed prior by the Proponent to the commencement of work.

B.6.5.3 Vibration – Human Comfort

(i) Tunnelling (Station Cavern Road Headers)

It is predicted that adverse comment due to vibration VDV may occur at a small number of receivers in the CBD North Station Precinct. Mitigation of vibration from the road header may be possible by utilising reduced hours of operation and/or modifications to the construction sequencing.

The methodology of construction of the station caverns involves four road headers working concurrently in various sections of the cavern. Three separate passes of each section of cavern are required with the heading (top) completed first, then the bench (middle) and finally the invert (bottom). The predictions have been based on two road headers working at the header level, with one road header working continually at the cross-sectional position of the cavern that is closest to the receiver in question, and the second working on the opposite side of the cavern at a 15 m longitudinal offset. In reality, each road header would work in a methodical way over the entire cross-section of the area which would result in periodic reductions in vibration and ground-borne noise as the road header cutter face moves away from the receiver location. Therefore, these results are expected to be conservative and show the upper bound of vibration and ground-borne noise generated during the station cavern construction.

As for the tunnel predictions, the road header progresses along the station cavern which changes the distance to the receiver. Due to the much larger cross section of the station cavern, the road headers would progress at a slower rate. Furthermore, due to the three separate passes required the same receiver would experience the exceedances over three distinct periods of time. For receivers that have foundations or piles in bedrock there may be no reduction in levels of vibration and ground-borne noise during the excavation of the bench and invert.

An analysis of the change in VDV over time due to road header station cavern works has been conducted for two sample receivers in the CBD North station precinct – one residential and one commercial:

- Residential Receiver Address: 8 Franklin Street, Melbourne (see Figure B.103)
- Commercial Receiver Address: 393-397 Swanston Street, Melbourne (see Figure B.103).

These receivers have been selected as they present some of the highest preliminary vibration results and therefore are expected to have some of the longest durations of high vibration/noise.

The road header has been assumed to move along the station cavern at a rate of approximately 3.5 m per day, with a 15 m longitudinal offset between road headers on each side of the cavern. The road headers are assumed to be operational for 60 per cent of the time during the day and night periods.

Figure B.104 and Figure B.105 show the VDV results with respect to construction time for the residential and commercial locations respectively.

Note that at these two particular receivers the criterion level for management actions is triggered by road headers working on both sides of the station cavern, so that the combined noise and vibration is a combination of the influence of both road headers. The impact of both road headers is presented in the figures.

The criterion level for management actions is triggered at the residential location for up to 2 weeks during the day and up to 5 weeks at night (based on a preferred level which relates to no expected adverse comment). At the commercial location the criterion level is triggered for approximately 4 weeks during the day or night (based on a preferred level which relates to no expected adverse comments). This duration is longer than for road header tunnelling primarily due to the staggered position of the two road headers, as well as a slightly slower assumed advance rate. The human comfort vibration level at the commercial receiver remains within the 'low probability of adverse comment' range while for the residential receiver the level is in the 'adverse comments are possible' range for approximately 10 days.

These management triggering vibration levels may occur up to three times as the heading, the bench and the invert are excavated.

An assessment of the vibration at higher floors of these buildings has been undertaken. For residential receivers the impact is limited to the ground floor, with higher floors having vibration levels below the criterion for management actions. For commercial receivers the impact is limited to the ground, first and second floors, with level 3 and above having vibration levels below the criterion for management actions.

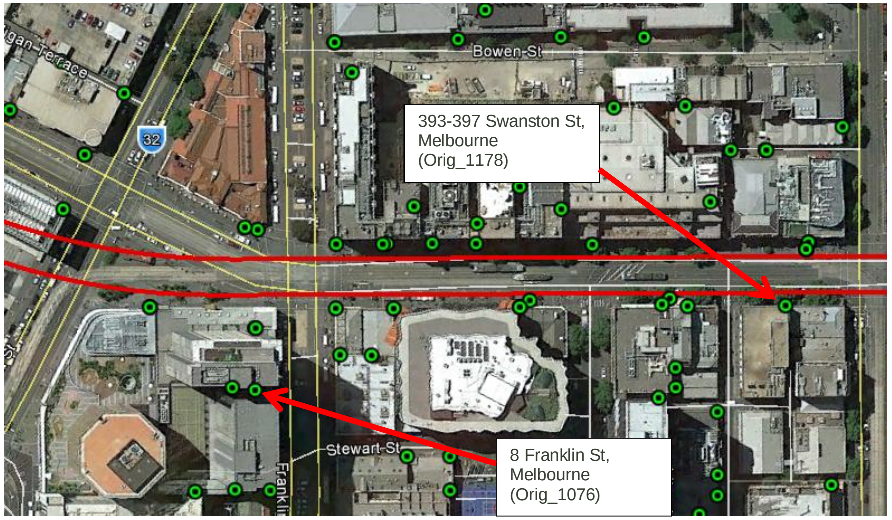

Figure B.103: Example Receivers for CBD North road header station cavern works calculations

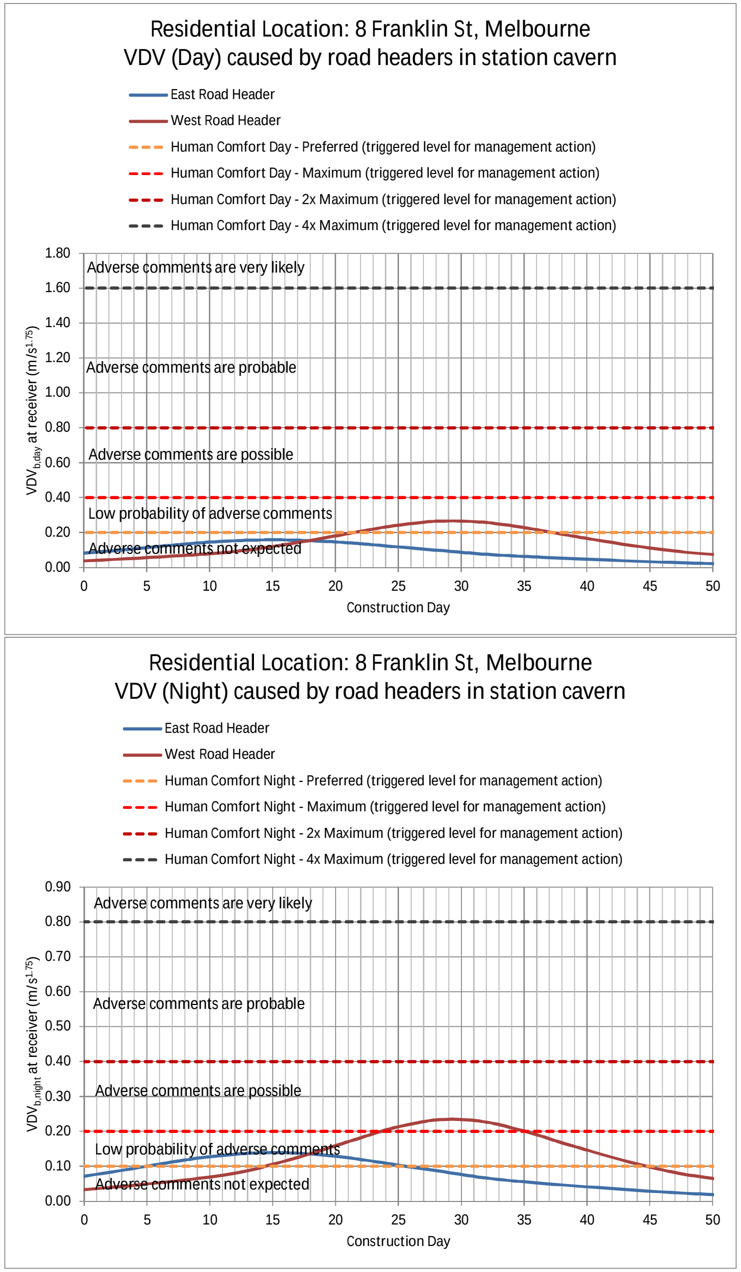

Figure B.104: Time of Duration of Exceedances at Example Residential Receiver – North CBD Station Cavern Works using Road header

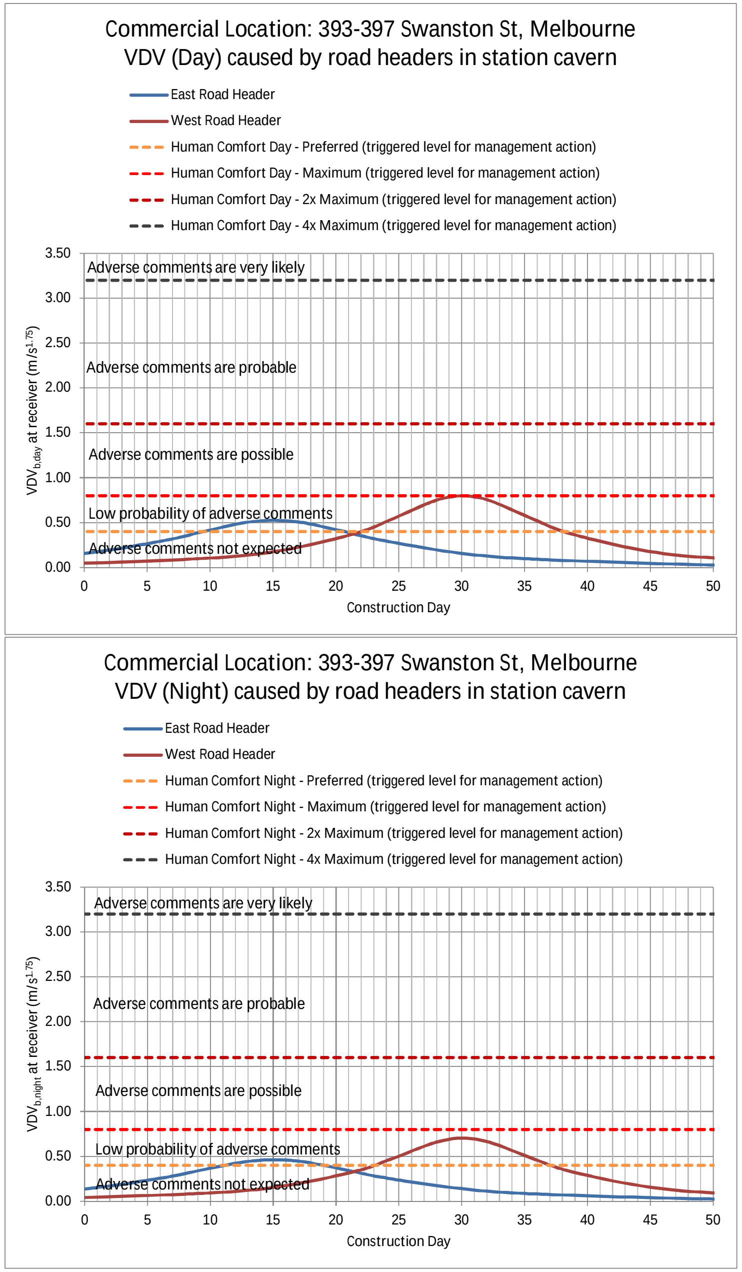

Figure B.105: Time of Duration of Exceedances at Example Commercial Receiver – North CBD Station Cavern Works using Road header

(ii) Additional Construction Works

There are residential receivers on the lower levels of buildings on Franklin Street where VDV levels are expected to exceed the day and night guideline targets. The exceedances are only expected to occur when rippers and rockbreakers are working in close proximity to these buildings. The maximum daytime VDV guideline target of 0.4 $m/s^{1.75}$ (low probability of adverse comment) would only be exceeded when the ripper is working within a slope distance of 12 m and the 20 tonne rockbreaker is working within a slope distance of 30 m from the building façade. The maximum night VDV guideline target of 0.2 $m/s^{1.75}$ would only be exceeded when the ripper is working within a slope distance of 18 m and the 20 tonne rockbreaker is working within a slope distance of 45 m from these buildings. The VDV exceedances are only predicted for residential receivers that reside on the lower levels of these buildings (ground up to level 4). It is expected that the Proponent would manage these VDV exceedances through a combination of community consultation and scheduling of the excavation works. The VDV night exceedances would be managed by maintaining buffer distances of 18 m (ripper) and 45 m (rockbreaker) during the night. In order to maintain these distances, the Proponent would need to schedule ripping and rockbreaking works west of Swanston Street during daytime hours only. It is expected that VDV exceedances arising from daytime excavation works within close proximity of residential buildings would be managed though close consultation and negotiation with residents.

It is predicted that adverse comments due to vibration are possible from occupants at a number of commercial receivers and RMIT buildings located on Franklin Street. Adverse comments due to vibration are also possible at a number of commercial receivers on Swanston Street, Little Latrobe and Latrobe Streets. The exceedances are predicted to be very short in duration (only occurring when rippers are working within 7 m slope distance of receivers). It is predicted that the maximum guideline VDV target for commercial and educational receivers would be met when rippers are working at a slope distance greater than 7 m from receivers. Due to the depth of operation, a low probability of compliant is predicted regardless of the location of the 20-tonne and 32-tonne rockbreakers. It is expected that the Proponent would be able to manage the vibration impacts of rippers by maintaining a 7 m buffer zone whilst buildings are occupied. Alternatively, the Proponent may use lower vibration methods of material removal within 7 m of receivers.

B.6.5.4 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

An assessment of vibration-sensitive equipment in the vicinity of the CBD North construction worksite has been undertaken with respect to the ASHRAE Vibration Curves and measurements of existing vibration levels. The outcomes of this assessment are presented Table B.18.

Ground-borne vibration from the road header excavating the station cavern could potentially impact on the operation of the RMIT Photonics Lab which is located on level 9 of building 12. Vibration levels are predicted to exceed existing vibration levels due to road header excavation of the CBD North station cavern. It is expected that this exceedance can be managed through consultation with RMIT and monitoring of the laboratory during the station cavern excavation. Mitigation may also be possible by utilising reduced hours of operation and/or modification to the construction sequencing at this location.

The 20 tonne rockbreaker and ripper could potentially impact on the operation of the RMIT electron microscope which is located on level 7 of building 14 as well as the confocal microscope located on level 5 of building 14. Vibration levels are only expected to exceed existing vibration levels when the rockbreaker and ripper are working in the Eastern end of the Franklin Street excavation (when the rockbreaker is within a slope distance of 65 m of building 14 and the ripper is working within a 30m slope distance of building 14). It is expected that the Proponent would be able to manage this exceedances through consultation with the RMIT and monitoring the performance of the microscopes when the rockbreaker and ripper are working within the buffer zones noted above. The Proponent may need to negotiate with the RMIT and alter the schedule for the rockbreaking works if the performance of the electron and confocal microscopes are affected. It may also be feasible to temporarily reschedule the use of sensitive equipment to other times or non-affected facilities.

Bio-resources and Highly Sensitive Areas have not been identified in this precinct.

B.6.5.5 Ground-borne Noise

(i) Tunnelling (Station Cavern Road Headers)

Ground-borne noise levels are predicted to trigger management actions at a very small number of receivers in the CBD North Station Precinct. Mitigation of ground-borne noise and vibration from the road header may be possible by utilising reduced hours of operation and/or modifications to the construction sequencing.

An analysis of the change in ground-borne noise over time due to road header station cavern works has been conducted for a sample residential receiver in the CBD North station precinct:

- Residential Receiver Address: 8 Franklin Street, Melbourne (see Figure B.103).

The same assumptions have been used as were applied to the prediction of VDV values in Section B.6.5.3.

Figure B.106 shows the ground-borne noise results with respect to construction time for this location.

At this particular receiver management actions for ground-borne noise are predicted to be triggered by road headers working on both sides of the station cavern, consequently, noise and vibration is a combination of the influence of both road headers. The impact of both road headers is presented in the figure.

Mitigation actions for the ground-borne noise guideline target are predicted to be triggered for the residential receiver for approximately 2 weeks during the night.

These management triggering levels may occur up to three times as the heading, the bench and the invert are excavated.

An assessment of the vibration at higher floors of this building has been undertaken. The impact is limited to the ground and first floor, with higher floors having vibration levels below the criterion for management actions based on the night guideline target.

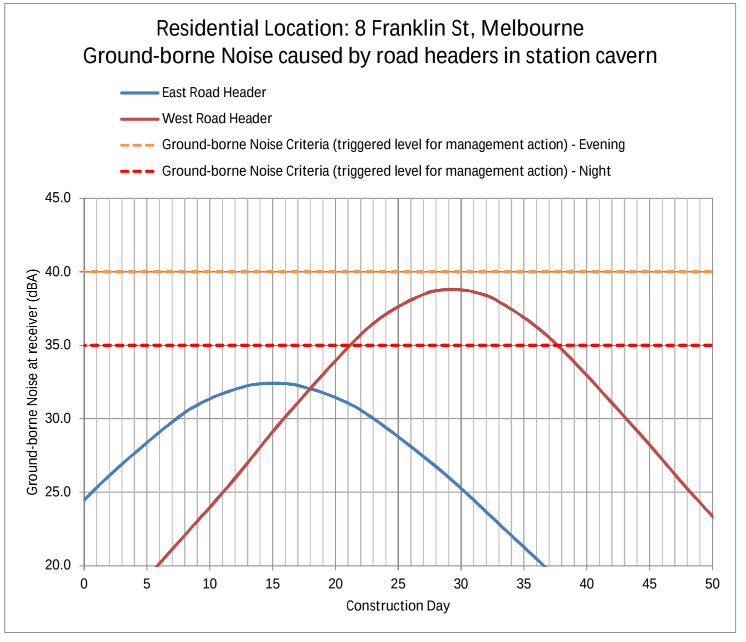

Figure B.106: Time of Duration of Exceedances for Example Residential Receiver –CBD North Station Cavern Works using Road header

(ii) Additional Construction Works

There residential addresses on Franklin Street (west of Swanston) where the ground-borne noise levels are predicted to reach up to 48 dBA. Buffer distances to achieve compliance with the 35 dBA night-time guideline target are: 25 m and 55 m for the ripper and 20 tonne rockbreaker respectively. These distances are slope distances. It is expected that the Proponent would be able to maintain these buffer distances by scheduling ripping and rockbreaking works in the western section of the Franklin Street excavation (the section West of Swanston Street) for daytime hours only.

Table B.18: Vibration predictions for vibration-sensitive equipment due to construction activities

Location	Vibration-sensitive Equipment	Vibration guideline target (magnitude of peak 1/3 octave band, RMS)	Baseline measurements (magnitude of peak 1/3 octave band, RMS)	Vibration assessment (magnitude of peak 1/3 octave band, RMS)		Comments
				Due to tunnelling activities (including road header excavation of station cavern)	Due to excavation (ripping and rockbreaking)	
RMIT						
Basement 2, Building 100	Robotics lab	100 µm/s	VC-D 3 µm/s	Complies (35 µm/s)	Complies (5 µm/s)	
Level 7, Building 14	Electron microscope	6 µm/s	VC-B 18 µm/s	Complies (9 µm/s)	Minor exceedance (31 µm/s)	Exceedance relates to the 20 tonne rockbreaker. 19 µm/s is predicted for the ripper.
Level 5, Building 14	Confocal microscope	VC-C 12.5 µm/s	VC-B 14 µm/s	Complies (10 µm/s)	Exceeds (50 µm/s)	Exceedance relates to the 20 tonne rockbreaker as well as ripper. 32 µm/s is predicted for the ripper.
Ground Floor, Building 3	NMR Spectrometer	VC-C 12.5 µm/s	VC-D 6 µm/s	Complies (12 µm/s)	Complies (7 µm/s)	
Building 12	Acoustic Chambers	200 µm/s	N/A	Complies (149µm/s)	Complies (76 µm/s)	
Level 4, Building 7	The Fib (Ion beam manufacturing tool)	12.5 µm/s	VC-B 22 µm/s	Complies (15 µm/s)	Complies (21 µm/s)	
Level 9, Building 12	Photonics Lab	VC-C 12.5 µm/s	VC-B 19 µm/s	Exceeds (44 µm/s)	Complies (9 µm/s)	

Note: Vibration has been assessed against the highest of either the guideline target level or the baseline vibration level.

B.6.6 Precinct 6 – CBD South Station

The CBD South Station Precinct assessment has taken into account two main areas of construction:

- The station cavern mined using multiple road headers
- Additional Construction Work using a variety of other equipment. The ground-borne noise and vibration predictions for this are based on assessments of vibration for rockbreakers and rippers, as these are the most vibration intensive items of construction equipment. Vibration predictions have been made under the following assumptions:
  - City Square excavation: Rippers would be used to remove material to a depth of 10 to 20 m below ground level. 20 tonne rockbreakers would be used to remove material from depths greater than 20 m below ground level
  - Southern Entrance excavation: Rippers would be used to remove material to a depth of 20 m below ground level. 20 tonne rockbreakers would be used to remove material from depths greater than 20 m below ground level
  - Federation Square excavation: Rippers would be used to remove material to a depth of 15 m below ground level. 12 tonne rockbreakers would be used to remove material from depths greater than 15 m below ground level.

B.6.6.1 Vibration – Damage to Buildings

(i) Tunnelling (Station Cavern Road Headers)

There are no predicted vibration exceedances with respect to building damage issues due to tunnelling.

Several sensitive sites have been identified in this precinct and Table B.19 presents the predicted PPV results along with current measured vibration levels. At all locations the predicted vibration level due to road header activity is less than or equal to the current peak vibration experienced. The predicted vibration at all locations complies with the DIN 4150 guideline target for structural damage.

Table B.19: Vibration levels at other sensitive sites

Sensitive Site	Baseline PPV (mm/s)	Predicted PPV (mm/s)	Comments
CBD South			
St Paul's Cathedral	2.1	0.5	Predicted level less than existing
Young and Jacksons Hotel	7	1.0	Predicted level less than existing
Flinders Street Station	1.3	0.5	Predicted level less than existing
Federation Wharf Vaults	0.2	0.4	Predicted vibration is below the sensitive structure DIN 4150 guideline target
The Arts Centre	3.1	0.2	Predicted level less than existing
Melbourne Recital Centre and MTC Theatre		<0.1	Trams passing and turning corner at close proximity expected to be higher than predicted vibration levels

(ii) Additional Construction Works

A guideline PPV targets of 10 mm/s applies to the non-heritage buildings in the vicinity of the CBD South excavations. For these buildings, the 10 mm/s guideline PPV target would be met when the ripper is working at a distance of 1.5 m or more from buildings. Exceedances are not predicted for the 12 tonne or 20 tonne tonne rockbreakers due to the depth at which these rockbreakers would be working. The Proponent would need to take management actions if it is necessary to use rippers within 1.5 m of buildings. Management actions could include the use of lower vibration methods of material removal such as hydraulic splitting or chemical splitting. The Proponent would need to undertake vibration monitoring in order to ensure that the 10 mm/s guideline PPV target is achieved. Alternatively, the Proponent may be able to justify higher vibration limits based on detailed assessments of the buildings.

Heritage sites, where a low guideline target of 2.5 mm/s PPV has been applied, have been assessed separately. Vibration levels are only predicted to exceed the 2.5 mm/s target when rippers are working within 5 m of heritage buildings. Vibration levels are not expected to exceed 2.5 mm/s due to rockbreaking because of the depth at which the rockbreakers would be operating. Most heritage buildings in CBD South are located more than 5 m from the excavations and as such vibration levels are predicted to be less than the 2.5 mm/s target. However, there are six heritage structures that are located immediately adjacent to the station entrance excavations and vibration levels are predicted to exceed 2.5 mm/s PPV. These heritage buildings are identified in Table B.20. Specific mitigation measures for each of the buildings are provided in the table.

It is also important to note that ground vibration calculations can be inaccurate when predicting vibration levels that occur when equipment is operated in close proximity to a receiver (less than 5 m). Therefore it would be necessary for the Proponent to undertake vibration monitoring to verify vibration levels when high vibration equipment is operated within 5 m of a building. In the CBD South precinct, this applies to ripping, rockbreaking, piling, and diaphragm wall construction.

B.6.6.2 Vibration – Damage to Utilities

(i) Tunnelling (Station Cavern Road Headers)

There are a variety of utilities within the CBD South Station Precinct and its surrounds. In general, the critical distance utilities should be from the station cavern excavation to avoid damage is:

- 2.0 m for general utilities
- 3.7 m for Melbourne Water unreinforced assets.

The location of the assets should be confirmed prior to the commencement of work.

Construction in this area is likely to be close to the 2.0 m critical distance of sewer pipework at the south end of the station cavern. The pipework may be subject to vibration up to 20 mm/s. The Proponent should use less vibration intensive methods for excavating the station cavern roof section in the vicinity of these sewer lines. This may include reduction in power of the road headers.

(ii) Additional Construction Works

The critical distance utilities should be from the Additional Construction Works to avoid damage to utilities is:

- 3 m for general utilities
- 5.5 m for Melbourne Water unreinforced assets.

The location of the assets should be confirmed prior to the commencement of work.

B.6.6.3 Vibration – Human Comfort

(i) Tunnelling (Station Cavern Road Headers)

It is predicted that adverse comment due to vibration VDV may occur at a number of receivers in the South CBD Station Precinct. Mitigation of vibration from the road header may be possible by utilising reduced hours of operation and/or modifications to the construction sequencing.

The methodology of construction of the station caverns involves four road headers working concurrently in various sections of the cavern. Three separate passes of each section of cavern are required with the heading (top) completed first, then the bench (middle) and finally the invert (bottom). The predictions have been based on two road headers working at the header level, with one road header working continually at the cross-sectional position of the cavern that is closest to the receiver in question, and the second working on the opposite side of the cavern at a 15 m longitudinal offset. In reality, each road header would work in a methodical way over the entire cross-section of the area which would result in periodic reductions in vibration and ground-borne noise as the road header cutter face moves away from the receiver location. Therefore, these results are expected to be conservative and show the upper bound of vibration and ground-borne noise generated during the station cavern construction.

As for the tunnel predictions, the road header progresses along the station cavern which changes the distance to the receiver. Due to the much larger cross section of the station cavern, the road headers would progress at a slower rate. Furthermore, due to the three separate passes required the same receiver would experience the exceedances over three distinct periods of time. For receivers that have foundations or piles in bedrock there may be no reduction in levels of vibration and ground-borne noise during the excavation of the bench and invert.

An analysis of the change in VDV over time due to road header station cavern works has been conducted for two sample receivers in the South CBD Station Precinct – one residential and one commercial:

- Residential Receiver Address: Level 1, 233-239 Collins Street, Melbourne (see Figure B.107)
- Commercial Receiver Address: 31-41 Swanston Street, Melbourne (see Figure B.107).

These receivers have been selected as they present the highest preliminary vibration results and therefore are expected to have some of the longest durations of high vibration/noise.

The road header has been assumed to move along the station cavern at a rate of approximately 3.5 m per day, with a 15 m longitudinal offset between road headers on each side of the cavern. The road headers are assumed to be operational for 60 per cent of the time during the day and night periods.

Figure B.108 and Figure B.109 show the VDV results with respect to construction time for the residential and commercial locations respectively.

Note that at these two particular receivers the criterion level for management actions is triggered by road headers working on both sides of the station cavern, so that the combined noise and vibration is a combination of the influence of both road headers. The impact of both road headers is presented in the figures.

The criterion level for management actions is triggered at the residential location for up to 4 weeks during the day and up to 6 weeks at night (based on a preferred level which relates to no expected adverse comment). At the commercial location the criterion level is triggered for approximately 5 weeks during the day or night (based on a preferred level which relates to no expected adverse comments). This duration is longer than for road header tunnelling primarily due to the staggered position of the two road headers, as well as a slightly slower assumed advance rate.

These management triggering vibration levels may occur up to three times as the heading, the bench and the invert are excavated.

An assessment of the vibration at higher floors of these buildings has been undertaken. For residential receivers the impact is predicted to affect floors up to and including level 7, with higher floors having vibration levels below the criterion for management actions. For commercial receivers the impact is predicted to affect floors up to and including level 6, with level 7 and above having vibration levels below the criterion for management actions.

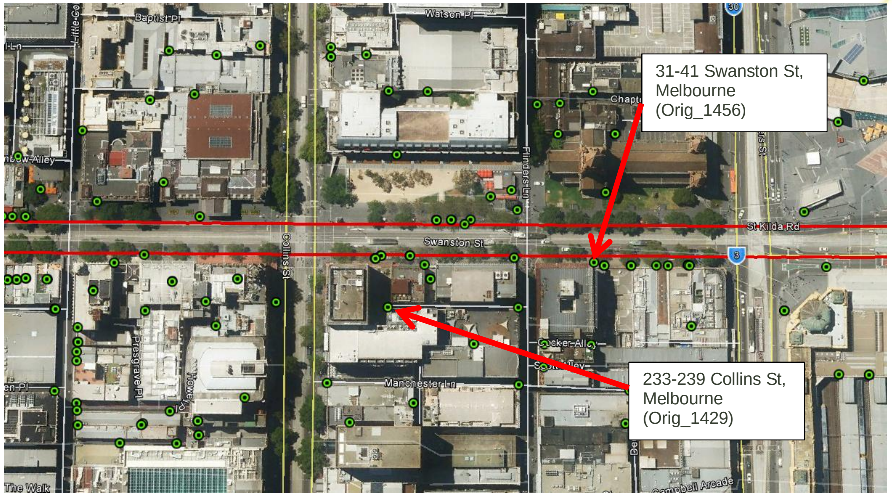

Figure B.107: Example Receivers for Road header Station Cavern Works Calculations

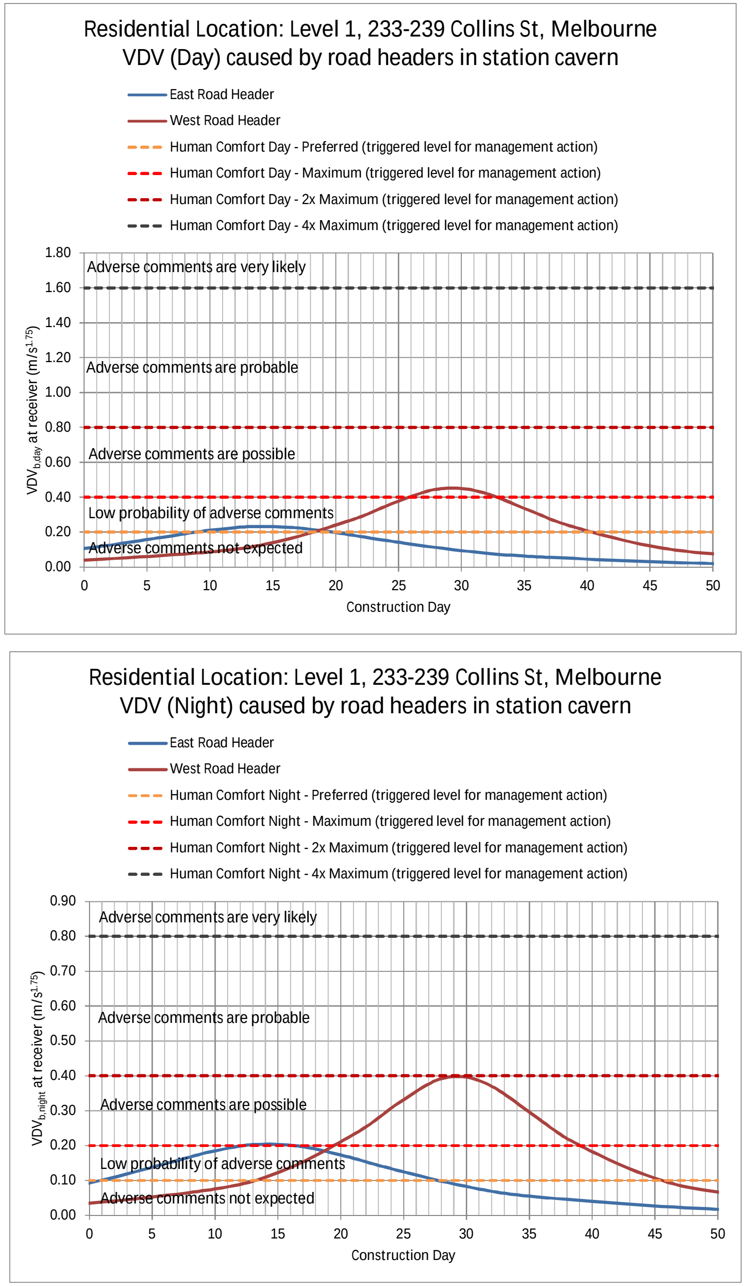

Figure B.108: Time of Duration of Exceedances for Example Residential Receiver – Station Cavern Works using Road header

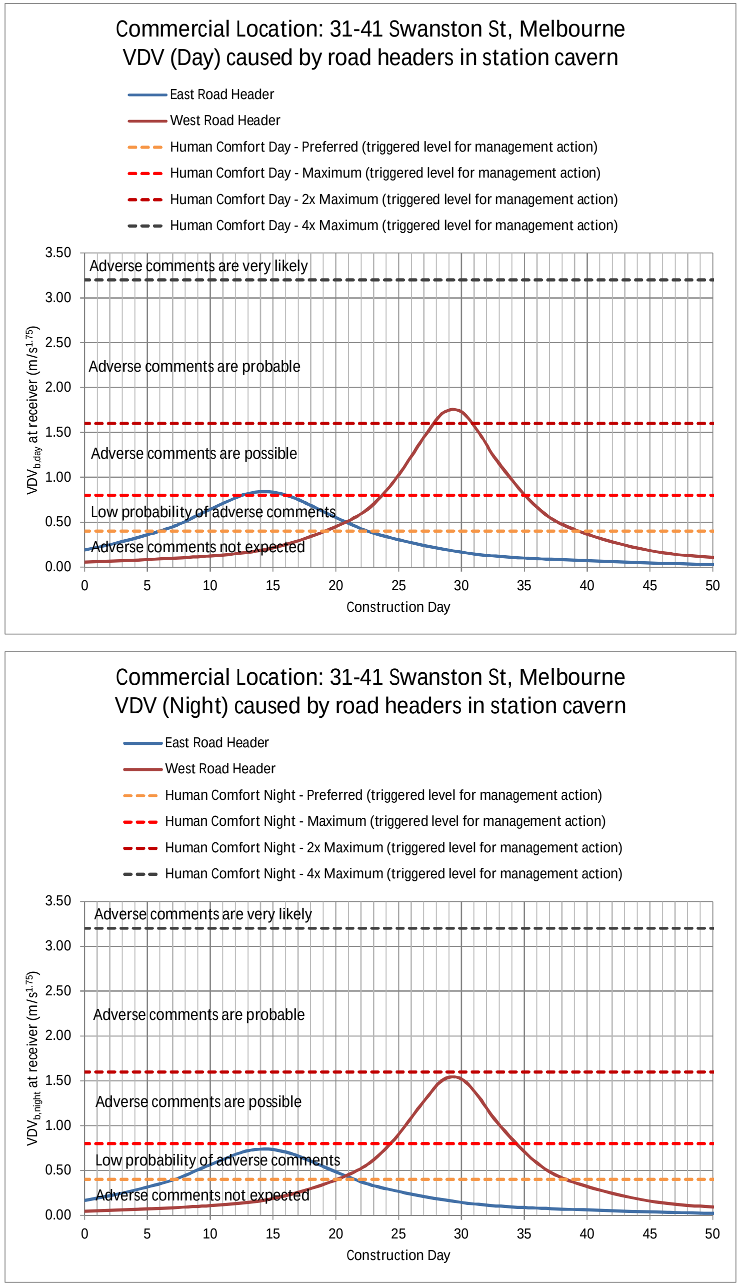

Figure B.109: Time of Duration of Exceedances for Example Commercial Receiver – Station Cavern Works using Road header

(ii) Additional Construction Works

It is predicted that the maximum daytime VDV target for residential receivers (0.4 $m/s^{1.75}$) would be exceeded when rippers are working within a slope distance of 12 m and when 20 tonne rockbreakers are working within a slope distance of 30 m. It is predicted that the maximum night VDV target for residential receivers (0.2 $m/s^{1.75}$) would be exceeded when rippers are working within a slope distance of 18 m and when the 20 tonne rockbreaker is working within a slope distance of 45 m. There are several residential buildings that are located within these buffer zones. There are some residential buildings that are located on the perimeter of the Flinders/Swanston Street excavation. For a residential receiver located on the perimeter of the excavation, it is predicted that the daytime VDV target would be exceeded for approximately 3% of the ripper work. The night VDV target would be exceeded for approximately 9% of the ripping work. It is expected that rockbreakers would only be needed periodically (when more competent rock is encountered) and the duration of VDV exceedances due to rockbreaking is expected short.

The Proponent would be able to meet the night-time VDV targets through careful scheduling and sequencing of the ripping and rockbreaking works. Night-time VDV targets would be achieved by maintaining an 18 m buffer distance between the ripper and residential buildings during the night (Rippers would need to work to the East of Cocker Alley during the night). Rockbreaking works would also need to be scheduled for daytime hours.

Daytime vibration impacts on residential receivers would need to be managed through close consultation and negotiation with the affected receivers. Compensation and/or respite may need to be provided when rippers and rockbreakers are working in close proximity of residential receivers.

The guideline VDV targets (0.2 $m/s^{1.75}$ day and 0.4 $m/s^{1.75}$ night) are also predicted to be exceeded at the Westin Hotel when rockbreakers are working in the City Square excavation. VDV levels are predicted to each up to 0.54 $m/s^{1.75}$ during the day (possible adverse comment) and 0.48 $m/s^{1.75}$ during the night (adverse comment probable). It is expected that the Proponent would be able to manage the daytime VDV exceedances through close consultation and negotiation with the Westin Hotel. Night-time VDV exceedances could be avoided by scheduling rockbreaking works for normal working hours only. Alternatively, the Proponent would be able to meet the day and night VDV targets by using low vibration methods of rock removal such as hydraulic splitting or chemical splitting. VDV levels are predicted to meet the maximum guideline targets during ripping works (management actions are not required during ripping works).

It is predicted that the guideline night VDV target (0.2 $m/s^{1.75}$) would be exceeded at two residential buildings that are adjacent to the potential station entrance at 65 – 73 Swanston Street. The exceedances can be mitigated by conducting any rockbreaking works during daytime hours. Rippers can be used during the day and night.

Possible adverse comments due to vibration are predicted for receivers in the Australian Centre for the Moving Image (ACMI) when rippers are working in the Federation Square excavation. This can be mitigated by either using lower vibration methods of excavation or by scheduling the work for outside of opening hours.

Exceedances of the guideline VDV targets are predicted when rippers are working within 7 m of commercial buildings. There are a small number of commercial buildings that fall within 7 m of the Flinders/Swanston excavation (eg the Nicholas building and the Young and Jackson Hotel). There are also a small number of commercial buildings that would fall within 7 m of the potential station entrance at 65 – 73 Swanston Street. It is expected that the proponent would manage this by maintaining a 7 m buffer zone when these commercial buildings are occupied. Alternatively, the Proponent could use lower vibration methods to remove material within this buffer zone. VDV exceedances are not predicted for commercial receivers during rockbreaking (this is due to the depth of operation).

B.6.6.4 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

Vibration-sensitive equipment, Bio-resources and Highly Sensitive Areas have not been identified in this precinct.

B.6.6.5 Ground-borne Noise

(i) Tunnelling (Station Cavern Road Headers)

Ground-borne noise levels are predicted to trigger management actions at a number of receivers in the South CBD Station Precinct. Mitigation of ground-borne noise and vibration from the road header may be possible by utilising reduced hours of operation and/or modifications to the construction sequencing.

An analysis of the change in ground-borne noise over time due to road header station cavern works has been conducted for a sample residential receiver in the CBD South station precinct:

- Residential Receiver Address: Level 1, 233-239 Collins Street, Melbourne (see Figure B.107).

The same assumptions have been used as were applied to the prediction of VDV values in Section B.6.6.3.

Figure B.110 shows the ground-borne noise results with respect to construction time for this location.

At this particular receiver management actions for ground-borne noise are predicted to be triggered by road headers working on both sides of the station cavern, consequently, noise and vibration is a combination of the influence of both road headers. The impact of both road headers is presented in the figure.

Mitigation actions for the ground-borne noise guideline target are predicted to be triggered for the residential receiver for approximately 2 weeks during the evening hours and 5 weeks at night.

These management triggering levels may occur up to three times as the heading, the bench and the invert are excavated.

An assessment of the vibration at higher floors of these buildings has been undertaken. For residential receivers the impact is predicted to affect floors up to and including level 7, with higher floors having vibration levels below the criterion for management actions. For commercial receivers the impact is predicted to affect floors up to and including level 6, with level 7 and above having vibration levels below the criterion for management actions.

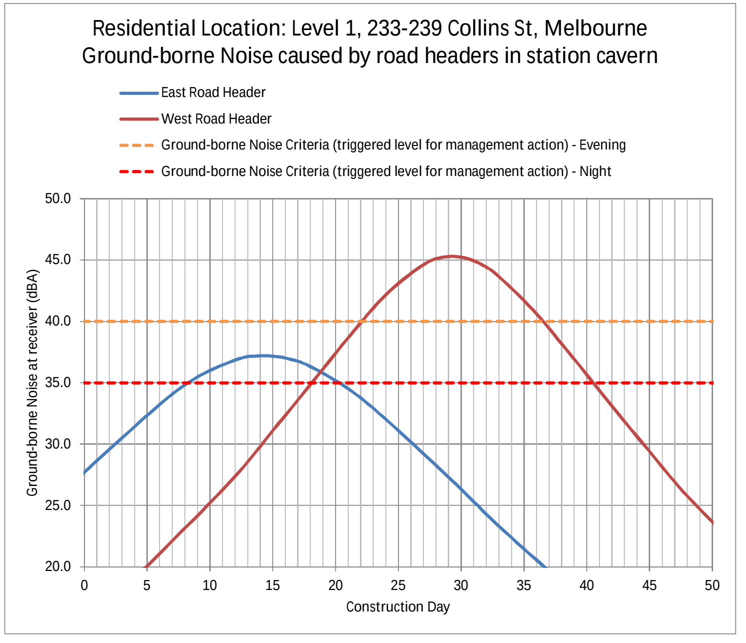

Figure B.110: Time of Duration of Exceedances for Example Residential Receiver – Station Cavern Works using Road header

(ii) Additional Construction Works

There are a small number of residential buildings that are located immediately adjacent to the Flinders/Swanston excavation where exceedances of guideline ground-borne noise targets are predicted. Guideline targets for ground-borne noise are also predicted to be exceeded at the Westin Hotel (near the City Square excavation) and at two residential buildings (near the proposed 65-73 Swanston Street excavation). It is predicted that the night guideline target of 35 dBA would be exceeded when rippers are working within a slope distance of 25 m and when rockbreakers are working within a slope distance 55 m of from residential receivers. The evening target (40 dBA) would be exceeded when rippers are working within a slope distance of 17 m and rockbreakers are working within a slope distance of 40 m. It is expected that the Proponent would mitigate ground-borne noise exceedances by maintaining these buffer distances during the evening and night.

Table B.20: Heritage sites where PPV exceeds DIN 4150-3 guideline targets

Victorian Heritage Register Listing and Heritage Overlay identifier	Heritage Site	Location	Reason for exceedance	Detailed assessment and mitigation strategy
CBD South Station Construction Work Site				
H2119 / HO745	Nicholas Building	31-41 Swanston Street	This building is < 5 m from the Southern Entrance excavation. The PPV vibration level is predicted to exceed 2.5 mm/s due to ripping and bored piling.	There is a possibility that vibration levels would exceed 2.5 mm/s PPV when during ripping and piling. It is expected that the Proponent would be able to manage this by monitoring vibration levels and adjusting construction techniques in order to meet the 2.5 mm/s PPV target. If it is necessary, it is expected that vibration levels could be reduced by using smaller ripper attachments or by pre-drilling and pre-splitting harder material. Alternatively, it may be possible for the Proponent to justify the use of a higher vibration target based on a detailed assessment of this building. Dilapidation surveys should also be completed. It is noted that vibration levels ranging from 0.2 up to 7.0 mm/s PPV have been measured on Swanston St (peak vibrations are associated with the passage of trams). Based on the existing vibration levels, it would be reasonable for the Proponent to adopt a higher vibration target for this building.
H0708 / HO744	Young and Jackson's Princes Bridge Hotel	Corner of Swanston and Flinders Streets	This building is < 5 m from the Southern Entrance excavation. The PPV vibration level is predicted to exceed 2.5 mm/s due to ripping and bored piling.	See above
H0627 / HO642	Ross House	247-251 Flinders Lane	This building is < 5 m from the Southern Entrance excavation. The PPV vibration level is predicted to exceed 2.5 mm/s due to ripping and bored piling.	See above
H1083 / HO649	Flinders Street Railway Station Complex		This building is < 5 m from the Southern Entrance excavation. The PPV vibration level is predicted to exceed 2.5 mm/s due to ripping and bored piling.	See above
HO505	Flinders Gate Precinct		Some buildings in the Heritage Overlay Flinders Gate Precinct are within 5 m of the Southern Entrance Excavation. The PPV vibration level is predicted to exceed 2.5 mm/s due to ripping and bored piling.	See above
HO502	The Block Precinct		Some buildings in the Heritage Overlay Block Precinct are within 5 m of the potential 65 to 73 Swanston Street Station Entrance. The PPV vibration level is predicted to exceed 2.5 mm/s due to ripping and bored piling.	See above

B.6.7 Precinct 7 – Domain Station

A variety of construction equipment would be used at this site. The ground-borne noise and vibration predictions are based on assessments of vibration for 20 tonne rockbreakers, as these are the most vibration intensive items of equipment. The predictions are based on the assumption that the rockbreakers would be operating up to 24 hours a day and 7 days a week once the station roof has been constructed.

B.6.7.1 Vibration – Damage to Buildings

Vibration levels comply with applicable guideline PPV targets for all buildings in the Domain Station Precinct.

B.6.7.2 Vibration – Damage to Utilities

The critical distance utilities should be from the Additional Construction Works to avoid damage is:

- 3 m for general utilities
- 5.5 m for Melbourne Water unreinforced assets.

The location of the assets should be confirmed prior to the commencement of work.

The South Yarra Sewer Main currently passes directly under the Domain Station Precinct and would sit at the bottom of the completed station floor. It is understood that the South Yarra Sewer Main would be diverted prior to the construction works.

B.6.7.3 Vibration – Human Comfort

It is predicted that the guideline targets for VDV would be exceeded at five buildings. These buildings include four residential buildings on St Kilda Road and the Melbourne Grammar School building on the corner of St Kilda Road and Domain Road. For the buildings on St Kilda Road, the probability of adverse comments range from "low probability" for two buildings through to "probable" at the building with the highest VDV. Possible adverse comments are predicted from receivers occupying the Melbourne Grammar School building. For the residential receivers it is predicted that exceedances of the maximum guideline target would only occur during a relatively short period of the construction work in which rockbreakers are working within 20 m (day) and 40 m (night) of the residential buildings. It is expected that this can be mitigated as follows:

- Scheduling rockbreaking works within 40 m of residential buildings for normal working hours only. This 40 m restriction would only affect a relatively small proportion of the excavation (south eastern end of the excavation and north western corner of the excavation)
- Close consultation and negotiation with residential receivers on St Kilda Road
- Monitoring of vibration levels during construction and adjustment of buffer zones as appropriate
- Use of low vibration methods of rockbreaking when removing rock from within 20 m of residential receivers.

Scheduling rockbreaking works in the immediate vicinity of the Melbourne Grammar School building for hours in which the building is not occupied.

B.6.7.4 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

Vibration-sensitive equipment, Bio-resources and Highly Sensitive Areas have not been identified in this precinct.

B.6.7.5 Ground-borne Noise

Ground-borne noise guideline targets (40 dBA evening and 35 dBA night) are predicted to be exceeded for four residential buildings on St Kilda Road (predicted levels ranging from 37 dBA up to 50 dBA). Full compliance with the guideline targets can be achieved by maintaining a 40 m buffer distance between rockbreakers and residential buildings during the evening and night.

B.6.8 Precinct 8 – Eastern Portal (South Yarra)

A variety of construction equipment would be used at this site. The ground-borne noise and vibration predictions are based on assessments of vibration for piling rigs and rockbreakers, as these are the most vibration intensive pieces of equipment. At the Eastern Portal it is expected that 7 tonne rockbreakers would be sufficient for removing a small amount of rock which is located near Osborne St and at a depth of 10 m. Works would be undertaken during normal working hours only.

B.6.8.1 Vibration – Damage to Buildings

There are no predicted building damage issues due to vibration in this precinct.

B.6.8.2 Vibration – Damage to Utilities

The critical distance utilities should be from the Additional Construction Works to avoid damage is:

- 3 m for general utilities
- 5.5 m for Melbourne water unreinforced assets

Location of the assets should be confirmed prior to the commencement of work.

B.6.8.3 Vibration – Human Comfort

It is predicted that VDV levels could exceed the maximum guideline target of 0.4 $m/s^{1.75}$ (day) at three residential addresses on Osborne St. The highest VDV is 0.63 $m/s^{1.75}$ and it relates to a possible of adverse comments. There is a low probability of adverse comment for one residential receiver located further away from the excavation. It is expected that these guideline target exceedances would be very short in duration (in the order of days) due to the small amount of rock removal that is required. There is also a possibility that vibration levels would be lower than the predicted levels due to the ground condition at the Eastern Portal.

It is expected that the impacts on these residential receivers can be adequately managed through consultation and negotiation.

B.6.8.4 Vibration-sensitive Equipment, Bio-resources and Highly Sensitive Areas

Vibration-sensitive equipment, Bio-resources and Highly Sensitive Areas have not been identified in this precinct.

B.6.8.5 Ground-borne Noise

Construction works are expected to be undertaken during normal working hours. As such there are no exceedances with respect to the guideline targets for ground-borne noise.

B.7 Results Summary and Recommendations for Tunnelling and Additional Construction Works

A summary of results and recommendations is provided in Table B.21.

Table B.21: Results summary table

Construction Methodology	Building damage (minor cosmetic damage)	Ground-borne noise, VDV and Sensitive equipment.	Recommended mitigation
Precinct 1: Tunnels (Outside other precincts)			
Tunnelling	None predicted	Management actions are predicted to be triggered for ground-borne noise for dwellings within 45 m to 60 m of the alignment where TBMs are used for tunnelling and within 50 m to 65 m where road headers are used (in the CBD tunnel). Management actions are predicted to be triggered due to ground-borne noise for up to 10 days due to the TBM, and up to 3 weeks for the road header. VDV levels for adverse comment are predicted for receivers within 40 m to 55 m of the alignment where the TBM is used, and within 40 to 60 m where road headers are used (in the CBD tunnel). VDV levels for adverse comment are predicted for 8-9 days for the TBM and 4-5 weeks for the road header.	• Community consultation • If vibration and/or ground-borne noise guideline targets are exceeded and the level and duration of disturbance is considered unacceptable, then temporary relocation may be an option.
Additional Construction Works	None predicted.	Management actions are predicted to be triggered at one residence on Toorak Road immediately located immediately opposite Fawkner Park emergency access shaft (minor exceedance of guideline target for daytime VDV).	• Community consultation
Precinct 2: Western Portal			
Additional Construction Works	None predicted.	Management actions are predicted to be triggered at a small number of residential dwellings that are located close to the nominated area of excavation. This is due to rockbreaking (35 tonne). Adverse comments due to VDV are also predicted from receivers located immediately adjacent to excavation sites.	• Community consultation • Vibration monitoring to verify vibration levels during construction • Use of low vibration rockbreaking techniques when rockbreaking in within 25 m of residential dwellings
Precinct 3: Arden Station			
Additional Construction Works	None predicted.	None predicted	None required

Construction Methodology	**Building damage** (minor cosmetic damage)	**Ground-borne noise, VDV and Sensitive equipment.**	**Recommended mitigation**
Precinct 4: Parkville Station			
Tunnelling	None predicted.	Vibration-sensitive equipment in several buildings (laboratories and hospitals) may to be impacted during tunnelling.	• Community consultation • Vibration monitoring during construction
Additional Construction Works	None predicted.	Vibration-sensitive equipment in several buildings (laboratories and hospitals) likely to be impacted during rockbreaking works. Adverse comments from some workers due to vibration (VDV) are also possible. Management actions are predicted to be triggered at one residential dwellings located on Barry Street and Leicester Street.	Mitigations for Ground-borne noise, VDV and sensitive equipment include: • Community consultation • Scheduling of rockbreaking works so as to minimise impact on vibration-sensitive equipment • Vibration monitoring during construction Mitigations for residential receivers include: • Community consultation and careful scheduling of rockbreaking works • Alternatively, relocation of residences
Precinct 5: CBD North			
Road header excavation of station cavern and tunnels	None predicted due to excavation of station caverns. Ground vibration at MURL exceeds the vibration guideline targets during road header mining of tunnels.	Management actions are predicted to be triggered at several receiver locations. Duration is expected to be up to 2 for ground-borne noise and 4 to 5 weeks for VDV and may occur up to 3 times. Vibration-sensitive equipment in one RMIT building may be impacted during tunnelling and station cavern excavation.	• Vibration monitoring on MURL during mining of tunnels • Community consultation • Modification of construction sequencing to reduce high vibration during critical periods • If vibration and/or ground-borne noise guideline targets are exceeded and the level and duration of disturbance is considered unacceptable, then temporary relocation may be an option.
Additional Construction Works	It is predicted that the guideline target for PPV may be exceeded at one building which is located next to the southern entrance excavation.	Adverse comments due to VDV are also possible for receivers located immediately adjacent to excavation sites. Management actions are predicted to be triggered at several receiver locations due to ground-borne noise.	Mitigations for building damage include: • Vibration monitoring • Use of low vibration techniques when construction equipment is working immediately adjacent to buildings Key mitigations for Ground-borne noise, VDV and sensitive equipment include: • Community consultation and negotiation • Careful scheduling of excavation works

Construction Methodology	**Building damage** (minor cosmetic damage)	**Ground-borne noise, VDV and Sensitive equipment.**	**Recommended mitigation**
Precinct 6: CBD South			
Road header excavation of station cavern	None predicted for buildings. Sewer and other services within 2.0 m of the station cavern may exceed vibration guideline targets.	Management actions are predicted to be triggered at several receiver locations. Duration is expected to be 2 to 5 weeks for ground-borne noise and 4 to 6 weeks for VDV and may occur up to 3 times.	• Vibration monitoring to accurately assess risk to sewer pipework • Community consultation • Modification of construction sequencing to reduce high vibration during critical periods • If vibration and/or ground-borne noise guideline targets are exceeded and the level and duration of disturbance is considered unacceptable, then temporary relocation may be an option.
Additional Construction Works	It is predicted that the 2.5 mm/s PPV guideline target for heritage buildings would be exceeded at four buildings including the Nicholas Building, Young and Jackson Hotel, Ross House & Flinders Street Railway Station.	Management actions are predicted to be triggered at several receiver locations.	Mitigations for building damage: • Dilapidation surveys • Vibration monitoring during construction • Modification to work practices Mitigations for Ground-borne noise, VDV and sensitive equipment include: • Community consultation • Modification of construction sequencing to reduce high vibration during critical periods
Precinct 7: Domain Station			
Domain Station	None predicted.	Management actions are predicted to be triggered at a small number of residential dwellings on St Kilda Road (exceedances of the VDV and Ground-borne noise guideline targets). Management actions are predicted to be triggered at one Melbourne Grammar School building where VDV levels exceed the guideline target.	Mitigations for Ground-borne noise, VDV and sensitive equipment include: • Community consultation • Scheduling of rockbreaking works so as to minimise impact on receivers • Vibration monitoring during construction • Use of low vibration rockbreaking techniques when rockbreaking in close vicinity of residential receivers
Precinct 8: Eastern Portal			
Eastern Portal	None predicted.	Management actions are predicted to be triggered at a very small number of residential addresses during rockbreaking works due to minor exceedances of the guideline VDV targets.	• Community consultation • Vibration monitoring during construction

Note 1: Receiver sites that exist inside the nominated construction areas were not included in the vibration assessment.
Note 2: Predictions are less accurate for equipment operating in close proximity to buildings (i.e. less than 5 m). The Proponent should undertake vibration monitoring when equipment is to be operated within 5 m of a building.

B.8 Critical distances for different equipment types involved in Construction Works

Critical distances for compliance with various guideline targets are listed in the following tables for reference:

- Table B.22: building damage
- Table B.23: ground-borne noise (residential receivers)
- Table B.24: utility damage

The distances in these tables are provided as a guide and can be used in order to determine whether or not a PPV or ground-borne noise impact is likely. The distances presented in these tables relate to buildings with the lowest coupling loss factor. Critical distances would be lower for large multi-story buildings and buildings with more substantial foundations.

Table B.22: Critical distances for building damage

Vibration source	Receiver type		
	Heritage structures (PPV guideline target = 2.5 mm/s)	Residential construction (PPV guideline target = 5 mm/s)	Warehouse, industry, office, commercial construction (PPV guideline target = 10mm/s)
	Critical distance from source to receiver (m)		
TBM	5-10	3-6	1-3
Road header	7-12	4-7	2-4
32 tonne rock breaker	18	10	5.5
20 tonne rock breaker	13	7.5	4
12-15 tonne rock breaker	10	5.5	3
7 tonne rock breaker	7.5	4	2
Ripper	4.5	2.5	1.5
Hydromill	4.5	3	2
Piling rig (bored)	9	5	3
Heavy vehicle traffic	6	4	3

Table B.23: Critical distances for ground-borne noise (residential receivers)

Vibration source	Evening	Night
	Critical distance from source to receiver (m)	
TBM	35 to 50	45 to 60
Road header	40 to 55	50 to 65
32 tonne rock breaker	50	65
20 tonne rock breaker	40	55
12-15 tonne rock breaker	32	45
7 tonne rock breaker	26	37
Ripper	17	25

Table B.24: Critical distances for utility damage

Vibration source	Critical distance from source to receiver (m)			
	25 mm/s ground vibration limiting guideline target based on DIN 4150, long term vibration for masonry/plastic pipework (worst case)	20 mm/s ground vibration limiting guideline target for utilities	10 mm/s ground vibration limiting guideline target for Melbourne Water unreinforced assets	2 mm/s ground vibration limiting guideline target for South Yarra Sewer Main
TBM	1.3	1.6	3	12
Road header	1.6	2.0	3.7	14
32 tonne rock breaker	2.5	3	5.5	21
20 tonne rock breaker	2	2	4	16
12-15 tonne rock breaker	1.5	1.5	3	12
7 tonne rock breaker	1	1	2	9
Ripper	1	1	1.5	5
Piling rig (bored)	1	1	2	5
Heavy vehicle	1.5	2	3	8
Hydromill (in rock)	1	1	1	3

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