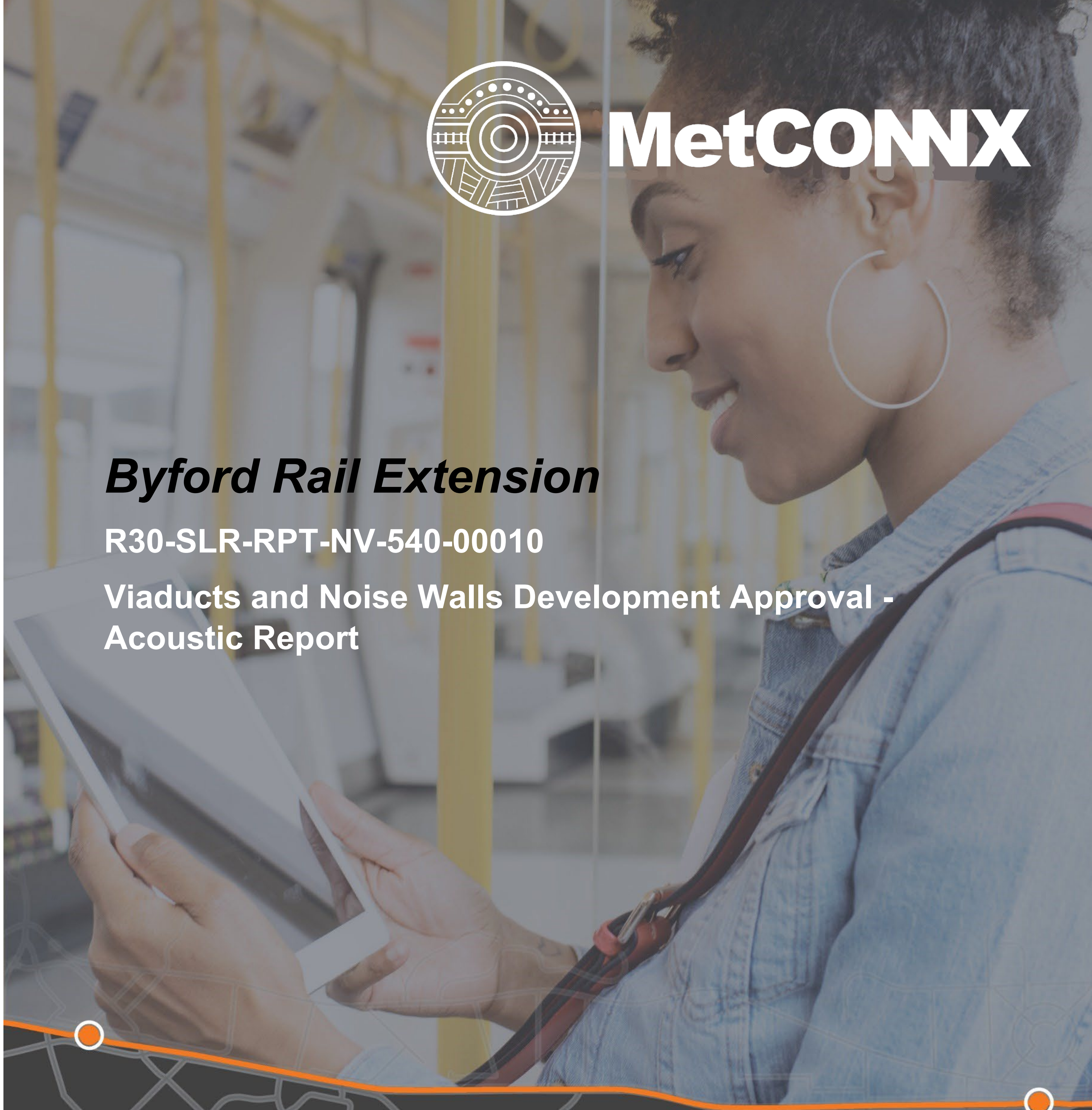
Appendix G: Operational Noise and Vibration



Byford Rail Extension

R30-SLR-RPT-NV-540-00010

Viaducts and Noise Walls Development Approval - Acoustic Report

Connecting communities.
Creating opportunities.

GOVERNMENT OF WESTERN AUSTRALIA

METRONET

BYFORD RAIL EXTENSION

Document details	
Title	Viaducts and Noise Walls Development Approval - Acoustic Report
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Laing O'Rourke Project No.	R30
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A03	17-Mar-2023	Issued for Review	Ying Liu	Luke Zoontjens	
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A01	11-Aug-2022	Issued for Review	Luke Zoontjens	Arvind Deivasigamani	

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1. Executive Summary

This report presents an assessment of environmental noise and vibration associate with viaducts and noise walls at Armadale Station to support development approval.

This report provides the rationale and context of proposed noise and vibration management for review by relevant stakeholders.

Predicted noise and vibration emissions from the railway have been compared with targets derived from a review of relevant state noise policies and guidelines.

The predicted results indicate that, with the mitigation extent indicated in **Appendix B**,

- Airborne noise levels at 2 meters above the ground are forecast to comply with set targets at all sensitive receivers; and
- Airborne noise levels at 9 meters above the ground are forecasted to comply with set targets of day period level $L_{Aeq,day}$ and night period level $L_{Aeq,night}$, and marginally exceed (within prediction error) the maximum passby target L_{max} mainly at the edges of Gateway North Precinct and current Armadale shopping Centre for future development of multi-storeyed buildings; and
- Ground borne vibration and ground borne noise levels are forecast to comply with set targets at all sensitive receivers within the study are.

On this basis, noise and vibration from railway operations associated with the viaducts at Armadale Station can be practicably managed to comply with applicable criteria.

The extents and type of mitigation indicated are subject to refinement as detail in the design develops. Further effective treatments within the viaduct are available to suit development at the locations and heights indicated in the Armadale City Centre Activity Centre Plan and City Centre West of Railway Precinct Plan.

Acknowledgment of Country

MetCONNX acknowledges the Whadjuk People and the Gnala Karla Booja People as the Traditional Custodians of the land and waters on which Byford Rail Extension Project is located.
We pay our respects to Elders, past, present and emerging, and thank them for their continuing connection to country, culture and community.

2. Project overview

2.1 METRONET Vision and Objectives

As one of the largest single investments in Perth's public transport, METRONET will transform the way the people of Perth commute and connect. It will create jobs and business opportunities and stimulate local communities and economic development to assist communities to thrive. The METRONET vision is for a well-connected Perth with more transport, housing and employment choices. In delivering METRONET, the WA Government has considered peoples' requirements for work, living and recreation within future urban centres with a train station at the heart.

The objectives are to:

- Support economic growth with better-connected businesses and greater access to jobs
- Deliver infrastructure that promotes easy and accessible travel and lifestyle options
- Create communities that have a sense of belonging and support Perth's growth and prosperity
- Plan for Perth's future growth by making the best use of our resources and funding
- Lead a cultural shift in the way government, private sector and industry work together to achieve integrated land use and transport solutions for the future of Perth.

2.2 Byford Rail Extension Overview

The Byford Rail Extension (BRE) Project has been identified as an essential component of the METRONET program. The Project will extend the electrified passenger rail service from Armadale to Byford, providing a strong transport connection between these two centres, supporting economic growth and providing greater access to jobs. The Project has been developed in line with policy objectives for highly integrated transport and land use planning.

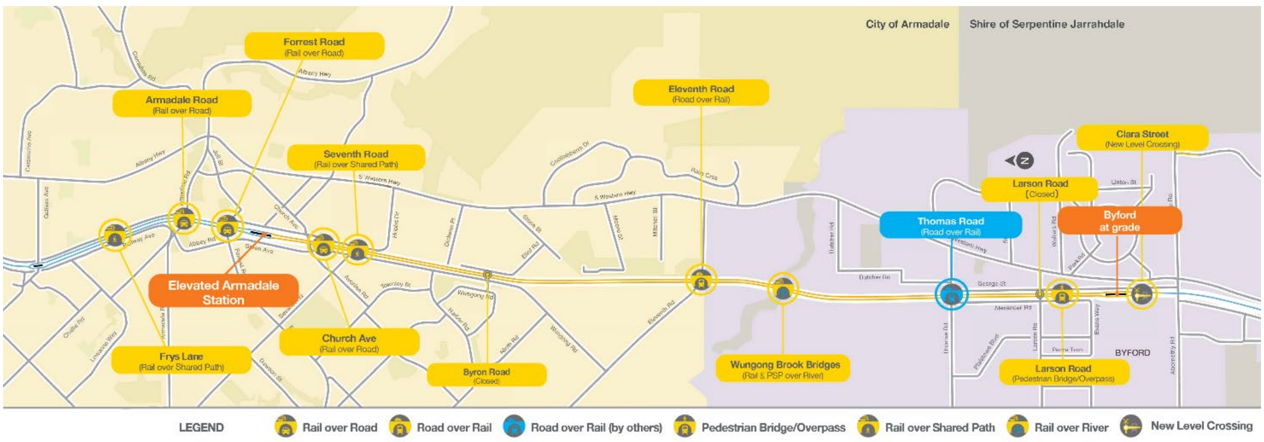

Figure 1: METRONET Byford Rail Extension Project

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2.2.1 Project Features

Transport infrastructure works for the BRE Project include:

- Demolition of existing station at Armadale and construction of a new elevated station
- Construction of a new Byford station at grade (Base Case)
- Construction of approximately 8km of dual track narrow gauge electrified passenger railway line extending from Byford station to the newly created Byford station, with a dedicated platform for the Australind line
- Removal of level crossings between the Armadale and Byford stations
- Construction of PSPs and associated infrastructure (including 'rail over road' and 'road over rail' bridges and roads)
- Parking areas at Armadale and Byford stations
- Bus interchange at Armadale and Byford stations
- Upgrade of local roads surrounding both Armadale and Byford stations.

2.2.2 General Scope of Works

The Project's general scope of works includes designing, procuring, manufacturing, constructing, installing and commissioning all rail infrastructure and ancillary works to support an electrified operational passenger rail between Armadale and Byford Stations. Also, in the case of the Australind train service, tying into the non-electrified rail network south of Byford Station.

The Project activities include all site investigation, design, planning, scheduling, procurement, cost control, approvals, construction, OH&S management, environmental management, quality management, testing and commissioning, Entry into Service (EIS), training and operational readiness required to tie the rail extension to Byford into the existing rail network including the associated road, utilities and other required works to interface with adjacent works and contracts. This will include bulk earthworks and retaining structures, grade separations, roads, and drainage, the demolition and removal and treatment of waste material and contaminated material resulting from construction of the Works, and temporary works constructed for the purpose of facilitating the Works.

The project scope also includes any new road works, modifications to existing roads and signalised intersections, utilities (diversion, protection, and new installation) and any other ancillary works to enable the BRE Project.

2.2.3 Future Proofing the Works

As part of the Project, space must be allowed within the rail corridor for the option of a 4-track scenario for a potential high-speed regional service from Bunbury. The additional 2 tracks shall be constructed in the eastern half of the rail corridor, so that future infrastructure can be constructed without impacting on existing rail operations. The Project should also allow for the possibility of future extension of the electrified line south of Byford to Mundijong, and a future stabling yard south of Abernethy Road.

2.3 Alliance Vision and Delivery Approach

The BRE Project will be delivered under an alliance contract to support the management of project and stakeholder interfaces and to mitigate project risks. A collaborative alliance approach will see the Works carried out in a cooperative, coordinated and efficient manner, in compliance with the Alliance Principles.

MetCONNX understands that the successful delivery of the Project is critically linked to meeting the PTA's Key Project Objectives. These objectives have shaped our vision for the Project that is around delivering a high-quality product and creating exceptional value-for-money. We are committed to a no-blame culture and to the prompt and mutual resolution of any issues that may arise.

During the AD Stage, an interactive ALT Visioning Workshop was held with representatives from the PTA and MetCONNX to develop a suitable Alliance Vision for the Project, refer Figure 2.

> "**Collaborating** to **deliver excellence** in transport infrastructure with **certainty** which **connects and activates the community,** for current and future generations"

Figure 2: AD Stage Alliance Vision Development Outcomes (developed with the PTA)

To support the realisation of this vision, we will develop a robust and highly collaborative alliance culture in which everyone challenges 'business-as-usual' and pursues better outcomes in the design and construction of the Project. In line with this, during the AD Stage the MetCONNX team refined their priorities for the Project as being:

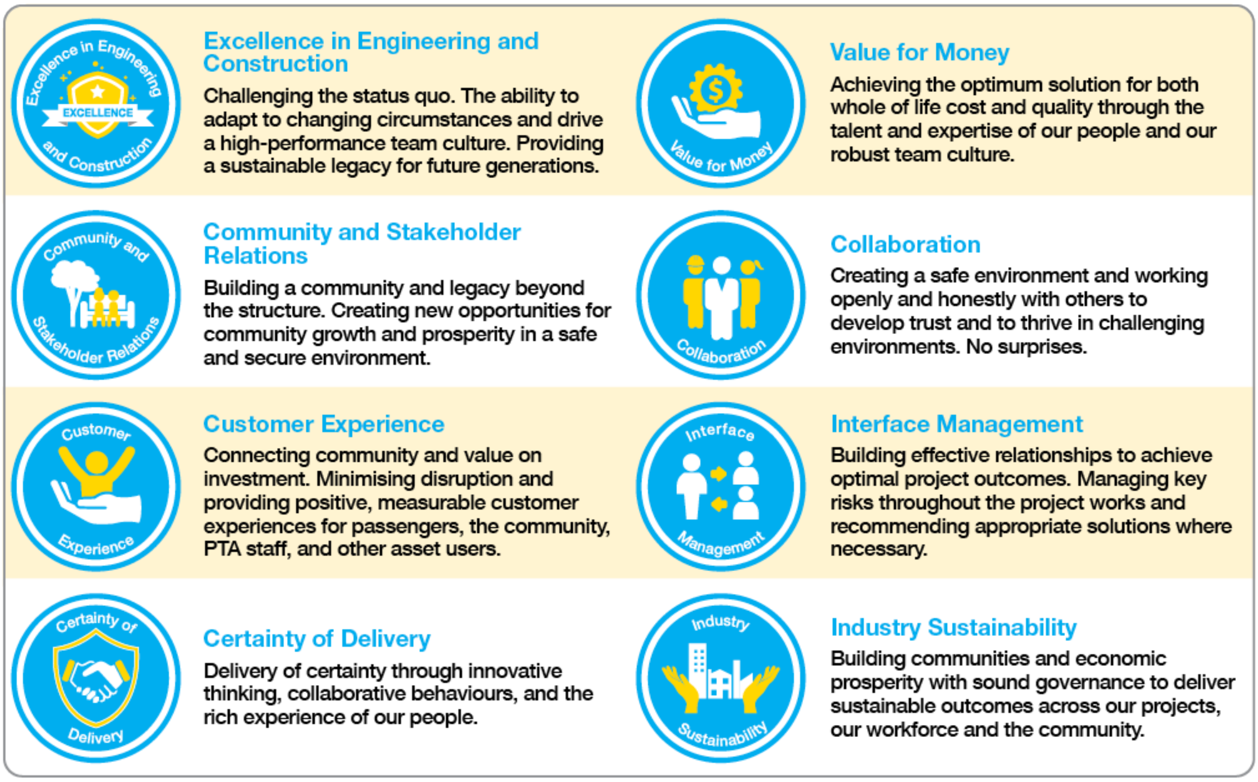

Figure 3: MetCONNX Priorities aligned with Key Project Objectives

2.4 Purpose

This report presents an assessment of environmental noise and vibration to support development approval of viaducts and noise walls at Armadale Station.

This report provides the rationale and context of proposed noise and vibration management for review by relevant stakeholders.

The extent of the viaduct and study area is indicated in **Figure 4**.

Key terms used in this assessment are provided in **Appendix A**.

Figure 4: Annotated aerial image indicating extent of study area

2.5 Structure

Section 3 presents a summary of relevant design criteria used. The basis of assessment in terms of input assumptions are provided in **Section 4**. **Sections 5 and 6** present assessments of environmental noise and vibration respectively.

3. Environmental Standards

3.1 Generally

The following table outlines the proposed noise and vibration assessment framework for this project. Key aspects are discussed further in the following subsections.

Table 1: Noise and Vibration Assessment Framework

Aspect / Source		Statutory / Government Policy	Australian / International Standards	Industry best practice
Operational environmental noise	Airborne noise from trains, rail operations	SPP5.4[1] EPA EFG Social Surroundings[2]	-	SPP5.4
	Road vehicle movements (scheduled roads)		-	-
	Car parking areas, bus loops, kiss and ride areas	EPNR1997[3]	EU Parking Area Noise 2007[4]	-
	Station mechanical ventilation plant	-	AS/NZS 2107:2016[5]	-
Operational vibration	Ground-borne vibration (GBV) from rail operations	-	AS/ISO 2631.2:2014[6] ISO 14837[7] BS 6472:2008	AS 2670.2:1990[8] NSWRING[9]

[1] Western Australia State Planning Policy 5.4, Road and Rail Transport Noise 2019 ("SPP5.4", "The Policy").

[2] Environmental Protection Authority 2016, Environmental Factor Guideline: Social Surroundings, EPA, Western Australia. Available from http://www.epa.wa.gov.au/policies-guidance/environmental-factor-guideline-social-surroundings

[3] Western Australia Environmental Protection (Noise) Regulations 1997 ("EPNR1997", "The Regulations") as amended under the *Environmental Protection Act 1986* (EP Act).

[4] Bayer, Landesamt für Umwelt 2007, *Parking Area Noise - Recommendations for the Calculation of Sound Emissions of Parking Areas, Motorcar Centers and Bus Stations as well as of Multi-Storey Car Parks and Underground Car Parks*, Bayerisches Landesamt für Umwelt, Parkplatzlämstudie 6, Aufl., August 2007.

[5] Australian/New Zealand Standard 2107:2016 'Recommended design levels and reverberation times for building interiors'.

[6] AS ISO 2631.2:2014 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Vibration in buildings (1 Hz to 80 Hz).

[7] International Standard ISO 14837-1 2005 "*Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General guidance*".

[8] Australian Standard AS 2670.2 1990 "*Evaluation of Human Exposure to Whole Body Vibration - Part 2: Continuous and Shock Induced Vibration in Buildings (1 Hz to 80 Hz)".*

[9] New South Wales Rail Infrastructure Noise Guideline, NSW EPA, May 2013.

Aspect / Source		Statutory / Government Policy	Australian / International Standards	Industry best practice
	Ground-borne noise (GBN) ('regenerated noise') noise from rail operations	-	-	NSW DEC Guidelines[10] ASHRAE 2011[11] FTA guidelines[12]

3.2 Noise

Sound from operation of the Project as experienced by nearby residents is here termed 'airborne noise', assuming the sound is by default not wanted and travels via air pathways only.

In Western Australia (WA), airborne noise from new or major upgrades of roads and railways is addressed in State Planning Policy 5.4[13] (SPP5.4), which is administered under Part Three of the *Planning and Development Act 2005*[14].

SPP5.4 provides outdoor noise level targets for the management of transport noise at sensitive receptors and land-uses. At the planning stage, the Project is applying the SPP5.4 rail noise targets as non-mandatory criteria. Where rail noise levels are above the targets, the Project will investigate reasonable and practicable mitigation measures with the aim of reducing noise levels to meet the targets and minimising potential noise impacts at sensitive receptors and land-uses.

The railway noise targets are specific to the daytime period of 6.00 am to 10.00 pm and the night-time period of 10.00 pm to 6.00 am. The noise targets are lower for the night-time period due to the greater sensitivity of communities to noise during the night. There are different targets for new railways and for upgrading existing railway infrastructure; the targets for new railways are 5 dB lower (more stringent) based on the assumption that noise mitigation can be more readily implemented on newly constructed sections of railway infrastructure.

The table below outlines the adopted noise objective levels in regard to airborne noise during rail operations. Noise mitigation must be provided where the noise level is above these targets.

[10] Department of Environment and Conservation NSW, "Assessing Vibration: a technical guideline" (2006)

http://www.environment.nsw.gov.au/resources/noise/vibrationguide0643.pdf

[11] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 2011, HVAC Applications – SI Edition, Chapter 47.

[12] Federal Transit Administration 2006, Transit Noise and Vibration Impact Assessment, Report FTA-VA-90-1003-06.

[13] Department of Planning, Lands and Heritage, 2019. Stage Planning Policy 5.4 – Road and rail noise, 6 September 2019.

[14] Western Australia Government, 2020. Planning and Development Act 2005, as of 1 May 2020.

Table 2: Airborne noise criteria

Metric	Application	Value(s) [15]	Notes
Period average noise levels	Major upgrade of existing railway (Applicable to this project)	$L_{Aeq,day}$ 60 dB	SPP5.4
		$L_{Aeq,night}$ 55 dB	
Maximum noise levels	Line wide	L_{Amax} 80 dB	95% of trains (5th percentile)

These objectives are assessed outdoors, 1 metre from the main building on a lot associated with a noise sensitive usage. Consistent with SPP5.4, the criteria are assessed:

- Only at premises that are occupied or designed for occupation or use for residential purposes (including dwellings, residential buildings or short-stay accommodation), caravan parks, camping grounds, educational establishments, childcare premises, hospital, nursing home, corrective institution.

  Note that this excludes recreational parks, commercial and industrial premises along the alignment – results will be determined for these locations, but mitigation would not be recommended; and

- at all floor levels where identified from surveys, noting that sufficient mitigation (in the context of the targets) may not reasonable or practicable at higher floors.

In addition, Section 4.2 (Planning Horizon) of SPP5.4 specifies that "*The application of SPP5.4 should consider future developments and associated increases in traffic anticipated for the next 20 years from when the noise assessment has been undertaken. This includes any transport corridor proposals where there is sufficient certainty regarding the corridor proposals where there is sufficient certainty regarding the corridor's alignment and function.*"

3.3 Vibration

3.3.1 Ground Borne Vibration

If levels of railway vibration are sufficiently high, then this vibration can be felt as tactile vibration by the occupants of nearby buildings. People can perceive floor vibration at levels well below those likely to cause damage to buildings or their contents.

Accordingly, the vibration criteria applied to manage potential impacts to human comfort at residences are usually the most stringent and it is generally not necessary to set separate criteria for vibration effects on typical building contents and structures. The Project has adopted the ground-borne vibration levels in the following table.

[15] Airborne noise criteria are referenced to 20 microPascals (dB re 20µPa). Vibration criteria are referenced to 1nm/s (dB re 1nm/s), use the subscript 'v' and are assessed on the basis of 1 second root mean square (RMS) values.

Table 3: Vibration criteria

Criterion[16]	Value
Mitigation of vibration via ground or structural pathways must be considered where the vector sum rail operations building vibration trigger level is exceeded as applicable to the 95th percentile train passby event measured at a reasonably representative location of the building occupancy, with appropriate use of frequency weightings from ISO 2631.1:1997 as amended or AS ISO 2631.2:2014.	
Medical clinical treatment, surgery or recovery areas, or facilities operating precision equipment	Curve 1 (L_{vSmax} 100dB)
Residential and hotel accommodation	Curve 2 (L_{vSmax} 106dB)
Commercial premises, public buildings, Churches and community centres and the like	Curve 4 (L_{vSmax} 112dB)
Light and general industrial buildings	Curve 8 (L_{vSmax} 118dB)

3.3.2 Ground Borne Noise

The ground-borne vibration from train passbys can be sufficient to cause floors or walls of the structure to vibrate and this can result in an audible low frequency rumble inside buildings. This is termed as ground-borne or regenerated noise. From a review of relevant guidelines and relevant project experience, ground-borne noise objectives are anticipated to be the main influence on potential impacts and will drive the design of vibration mitigation within the rail corridor.

Table 4: Ground borne noise criteria

Criterion	Value
Mitigation of vibration via ground or structural pathways must be considered where the rail operations regenerated noise trigger level is exceeded as applicable to the 95th percentile train passby event and measured at centre of reasonably representative interior space(s) of each building usage.	
Residential and hotel accommodation, 10pm to 6am	L_{ASmax} 35dB
Residential and hotel accommodation, 6am to 10pm	L_{ASmax} 40dB
Commercial buildings, public buildings, Churches and community centres and the like	L_{ASmax} 45dB
Retail and point of sale areas, occupiable light and general industrial buildings	L_{ASmax} 50dB

4. Basis of Assessment

4.1 Operational Volumes

This assessment refers to the 'Build' (including mitigation) scenario that represents the scenario approximately 20 years after completion of the BRE project, nominally the design year 2044 in accordance with the requirements of Section 4.2 Planning Horizon of SPP5.4.

[16] Airborne noise criteria are referenced to 20 microPascals (dB re 20µPa). Vibration criteria are referenced to 1nm/s (dB re 1nm/s), use the subscript 'v' and are assessed on the basis of 1 second root mean square (RMS) values.

Table 5: Rail operational volumes by scenario

Scenario, Year	Service	Train type	Volumes[1] Day / Night[2]	Comments, Rationale
Build year 2044	Perth – Byford (DN)	Series B (6-car)	82 / 7	Based on PTA Concept Train Operating Plan, with up to +5% tolerance.
		Series B (3-car)	9 / 9	
	Byford – Perth (UP)	Series B (6-car)	82 / 7	
		Series B (3-car)	9 / 9	

Note 1 Excludes the Australind services to Bunbury – See Section 4.1.3.5

Note 2 Normal Monday to Friday services, one way. Day period refers to 6 am to 10 pm period; Night refers to 10 pm to 6 am period.

4.2 Speeds

Train speed has a critical influence on noise and vibration emissions. Based on signal speeds and Series B acceleration rates, speeds for each line are indicated in **Figure 5**.

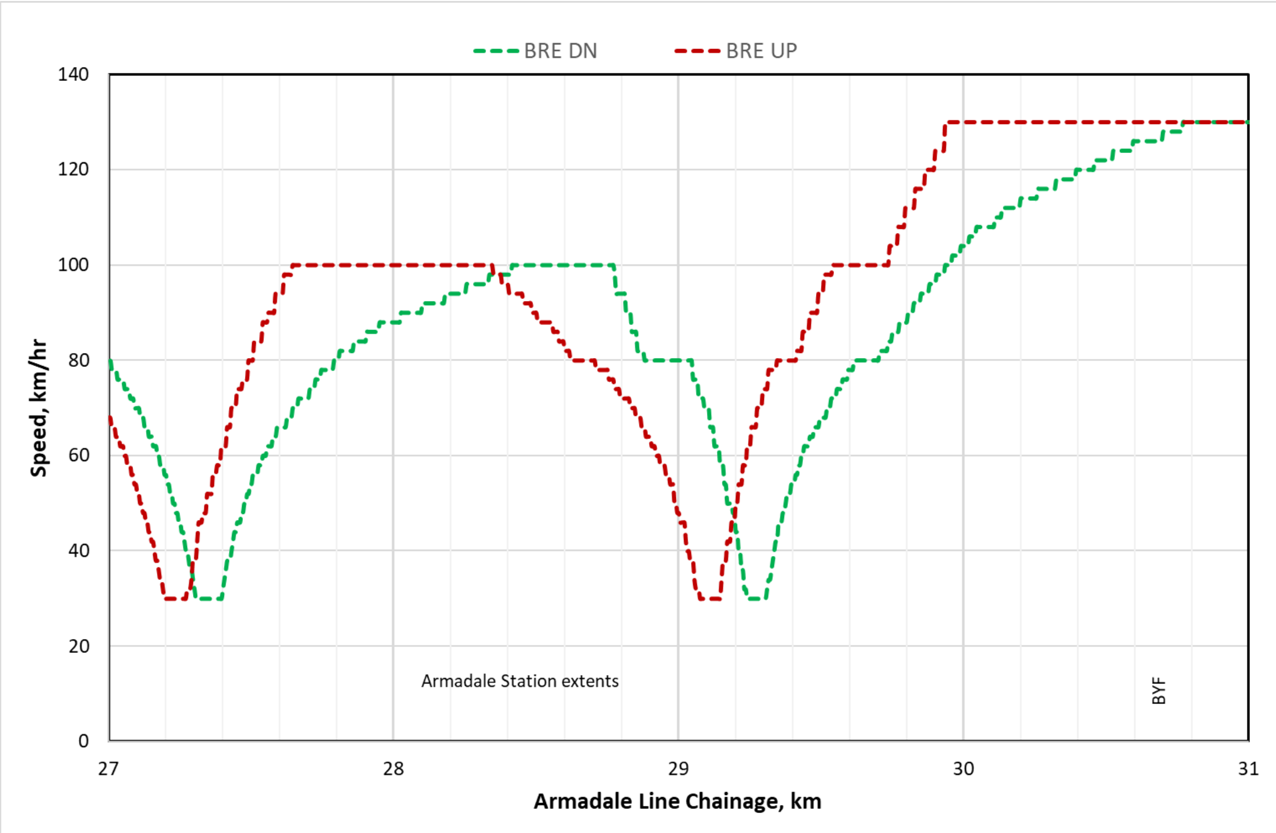

Figure 5: Modelled speeds in the vicinity of the station

Note that the Australind service to Bunbury, along with the first and last trains (referred to as positioning runs) with a non-stop pattern are considered to constitute less than 5% of all traffic. This means that the maximum noise level objectives adopted (which are based on the 5th highest percentile event or averaged over significant time periods) are not sensitive to those events.

Note that the signal speed limit at certain locations may be lower than 30 km/hr at certain sections of the project, however, they have still been considered at a minimum of 30 km/hr for noise modelling purposes overcome the limitations of the modelling algorithm at such low speeds.

4.3 Track form Types

The permanent way is modelled with two types of track form, referred to here as simply ballasted and slab track. Table 6 lists out key details for these modelled track types.

Table 6: Track types and conditions

Parameter	Ballasted track	Slab track, direct fix
Locations	Generally	As per **Table 7**
Track structure	Ballasted on grade track, typ. 200-250 mm depth. Concrete monobloc sleepers, 700 mm centres.	Direct slab fix, 700 mm centres
Rail	AS50kg	AS60kg
Rail fastener systems	Rail clip with cast-in shoulder, 8-8.5mm rubber pad (Pandrol RP65221)	Delkor ALT.1 (25 MN/m) Pandrol VIPA Cat C/D (25 MN/m)
Rail surface condition	The assessment relies on the track to be continuously welded and ground smooth to the same specification as existing network average (or better), taken to be ISO 3095, maintained to be free of defects.	

Note 1 These are dynamic stiffness values for the key frequencies of interest, allowing for ageing and in-service. These are likely to be slightly higher than advertised static or dynamic stiffness values.

Noise levels from slab track sections are likely to be higher than typical ballasted track, due to the use of relatively softer rail supports and no ballast to provide sound absorption.

It has been assumed that the running surface of the rail head is free of audible defects, and tracks being constructed with welded rail joints which does not cause any increase in train passby noise levels.

4.4 Viaduct

Viaduct structures are modelled for the Armadale section track slab locations defined in **Table 7**. Viaducts are modelled with the same cross-sectional geometry as that defined in the Civil Permanent Way Typical Cross Sections. 'DN' refers the Down main line, and 'UP' is the Up main line.

Table 7: Slab track sections modelled

Location	Line	Chainage, m		Length, m	Details, Notes	Structure
		Start	End			
Armadale Precinct	BRE DN	28020	29805	1785	Starts on tangent track on approach to viaduct and ends at the end of viaduct.	Viaduct is from chainage of 28240 to 29770.
	BRE UP	28020	29805	1785		

5. Railway airborne noise predictions

5.1 Overview and modelling process

There are many factors influencing rolling noise and vibration levels in practice, including:

- **Number of trains per period**. This is as described in **Section 4.1**.
- **Rail roughness and track condition.** Local noise emissions are particularly sensitive to rail roughness conditions and driver behaviour (e.g. abrupt acceleration/deceleration while exiting/approaching rail curve sections / stations). Track roughness conditions are here assumed to be similar to that during historical measurements.

- **Speed**. The speed at each chainage is modelled as per **Section 4.2**.
- **Trackform and supports**. Trackform and support structure has been modelled throughout as either ballasted or slab track. Where direct fix slab track is introduced over ballasted track, noise levels increase as a result of generally softer rail supports (which tends to increase noise emitted by the rails) and less sound absorption (ballast provides sound absorptive benefits).
- **Local features** such as turnouts can introduce discontinuities or sudden changes which increase noise emissions.
- **Local curving noise gain**. There is potential for flange/wheel squeal noise in areas of short radius turns and turnouts assuming similar wheel and track conditions to existing infrastructure. Such noise if presented could be a key source of annoyance (e.g. exceeding set L_{Amax} trigger levels).
- **Rolling stock**, e.g. wheel defects. The baseline measurements have been undertaken over a significant number of days at each location to reduce the influence of individual trains and represent the existing fleet.

In accordance with SPP5.4 Guidelines, an industry standard noise prediction model was developed to estimate the relative differences due to these factors. The model has been validated against historical measurements of Perth Series B trains on similar track form and speeds along the Mandurah line, and also of Perth Series A trains operating north of Armadale station. The viaduct is also considered in terms of structural noise (radiated by the structure itself) and vibration emissions via its supports (**Section 6**).

City of Armadale and DevelopmentWA have proposed Armadale City Centre Activity Centre Plan and City Centre West of Railway Precinct Plan (refer Figure 12) for future development, which includes multi-storeyed (more than 3) buildings. In accordance with the requirement of planning horizon of SPP5.4, additional grid contour maps at 9 meters above ground has been calculated to suit future development of 3 storey buildings.

Full details of the noise prediction model (source emission levels, adjustments applied, validation with field data etc.) are provided in the project Operational Noise and Vibration Design Report (R30-SLR-RPT-NV-540-00007).

5.2 Results and Discussion

5.2.1 Airborne Noise Prediction at 2m Above Ground

Predictions of airborne noise from rail operations (including proposed rail damper and noise walls as scheduled in Appendix B) at 2 meters above ground are provided in Figure 6 to Figure 11. From these plots, it can be seen that railway noise levels:

- are not predicted to exceed the day-time period targets (60 dB) at any of the sensitive receivers;
- are not predicted to exceed the night-time period targets (55 dB) at any of the sensitive receivers;
- are not predicted to exceed the maximum passby targets (80 dB) at any of the sensitive receivers.

The predicted noise and vibration exceedances are based on 95% certainty of outcome and will be further investigated during detailed design.

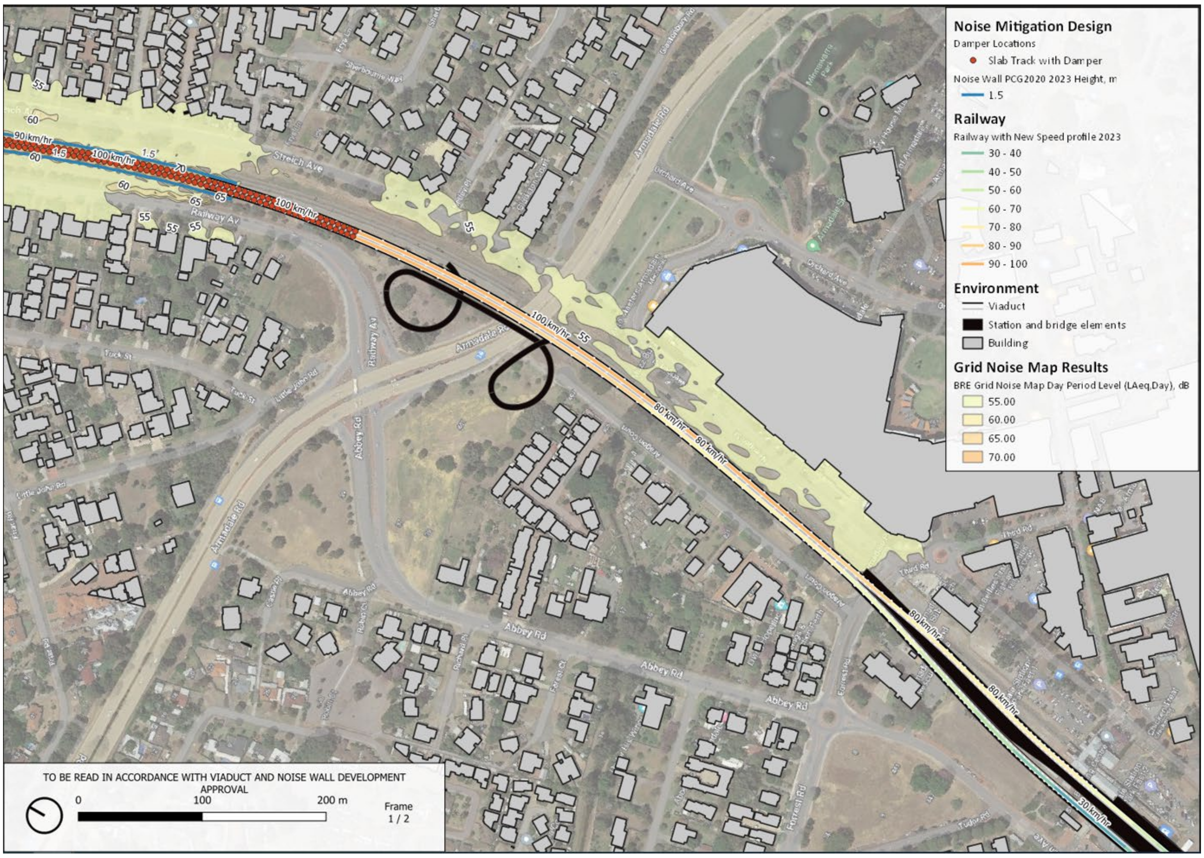

Figure 6: Predicted distribution in day period ($L_{Aeq,day}$) noise levels at 2m above ground, northern end of study area

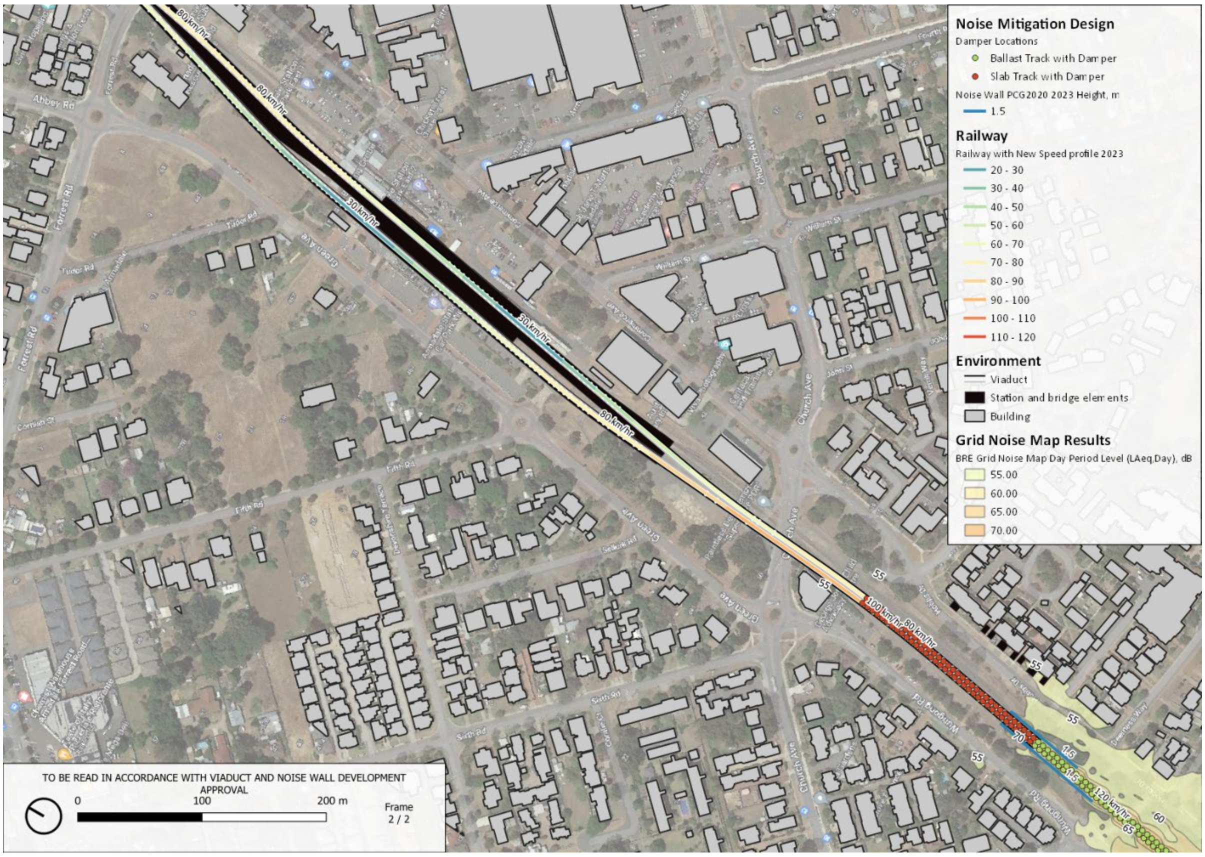

Figure 7: Predicted distribution in day period ($L_{Aeq,day}$) noise levels at 2m above ground, southern end of study area

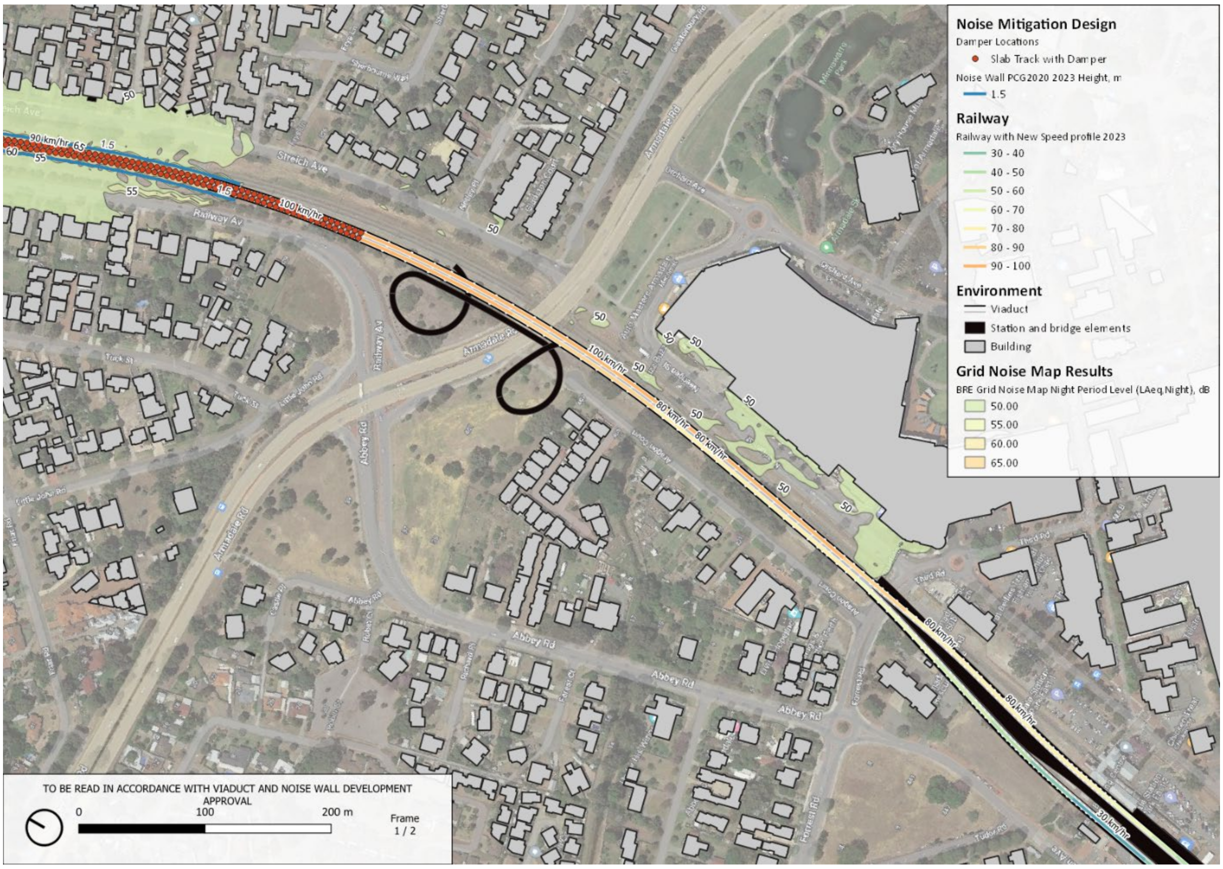

Figure 8: Predicted distribution in night period ($L_{Aeq,night}$) noise levels at 2m above ground, northern end of study area

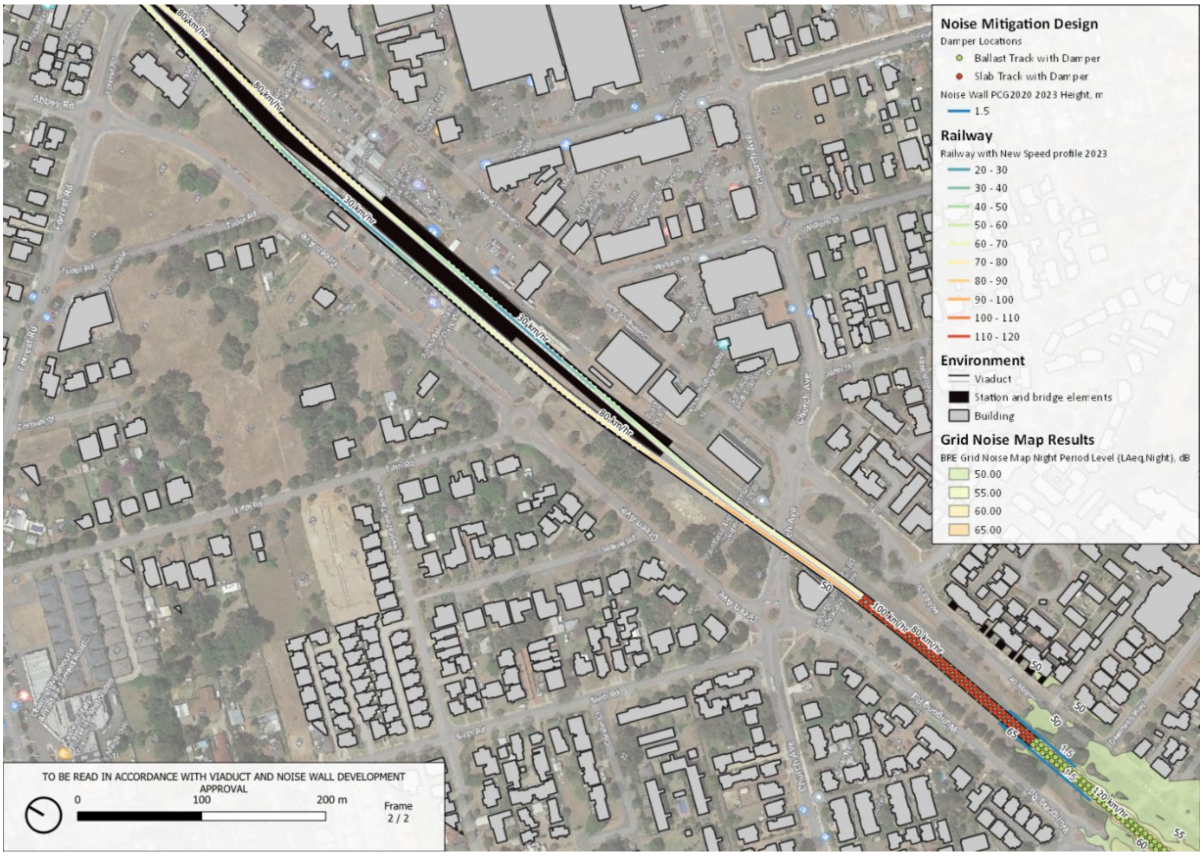

Figure 9: Predicted distribution in night period ($L_{Aeq,night}$) noise levels at 2m above ground, southern end of study area

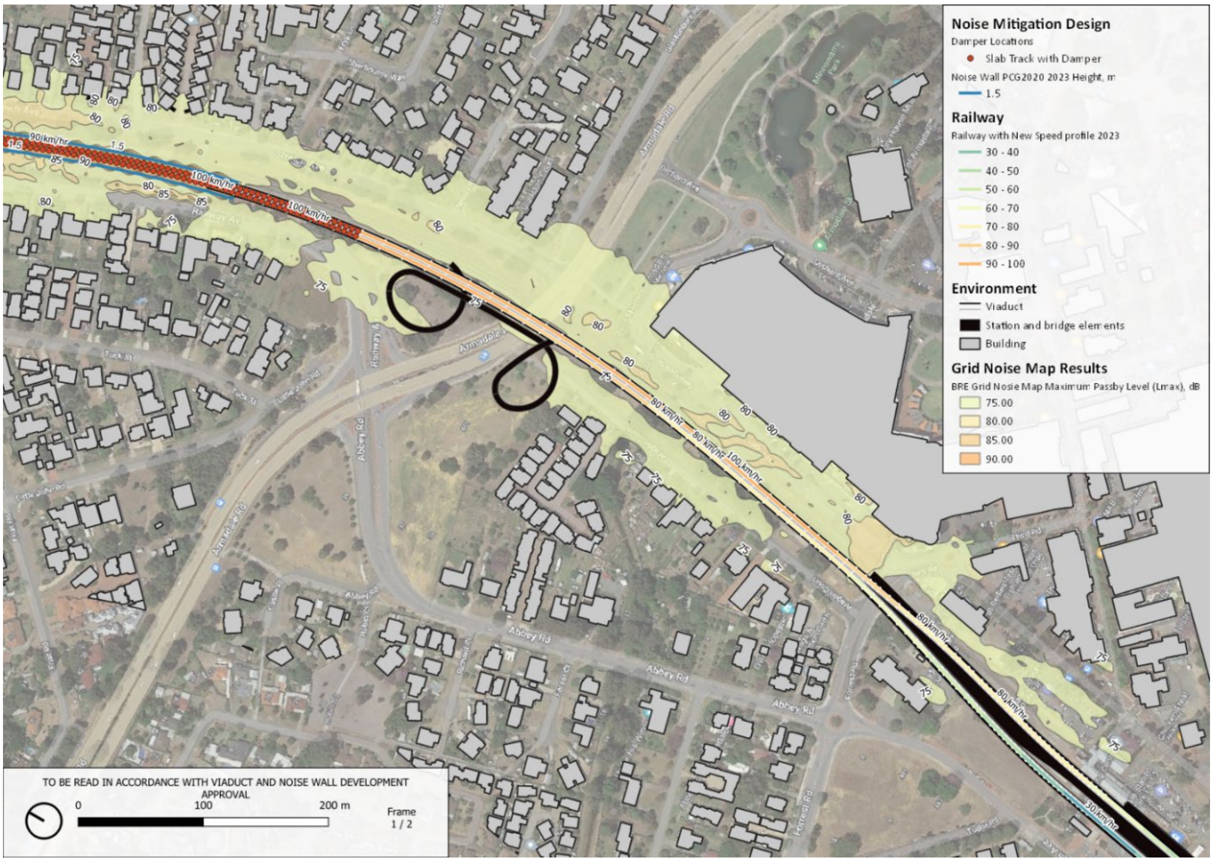

Figure 10: Predicted distribution in maximum passby (L_{Amax}) noise levels at 2m above ground, northern end of study area

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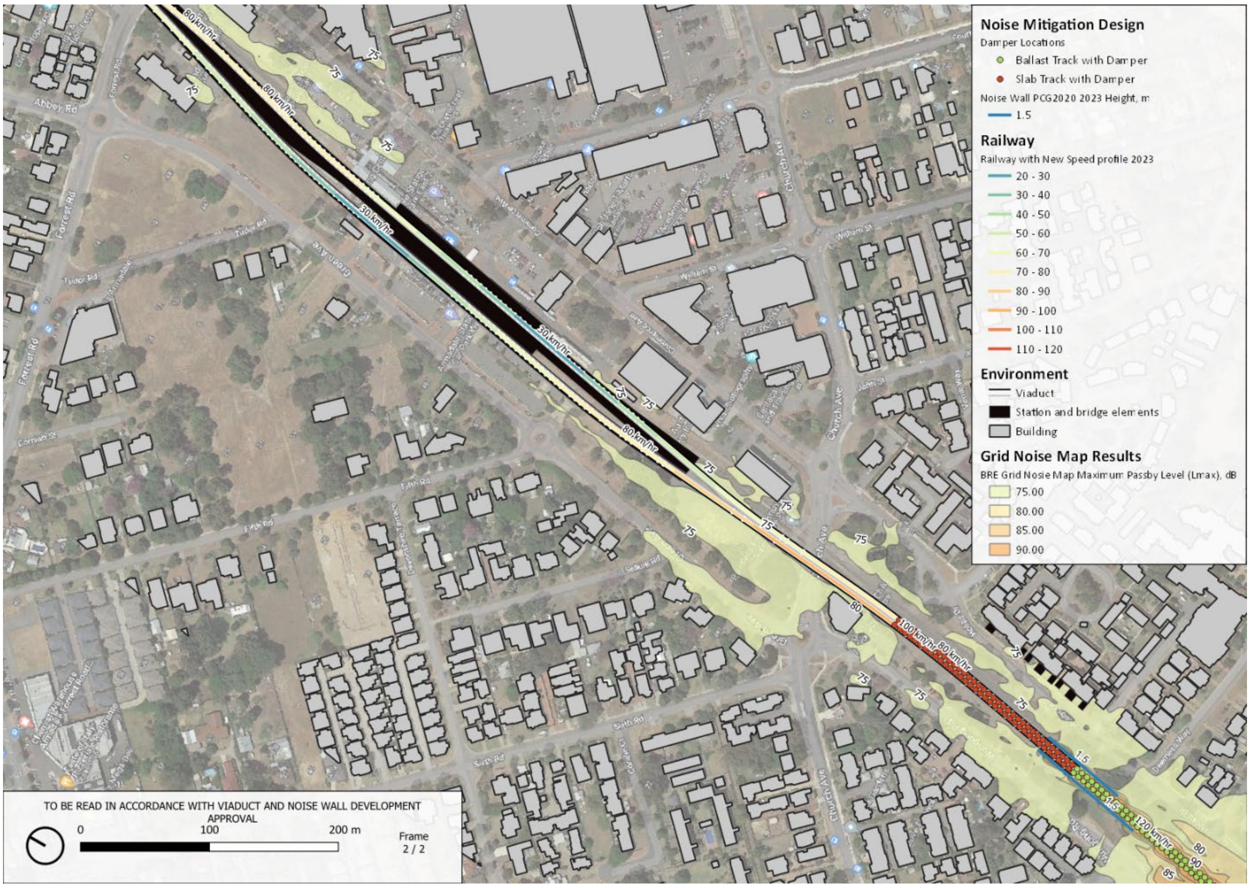

Figure 11: Predicted distribution in maximum passby (L_{Amax}) noise levels at 2m above ground, southern end of study area

5.2.2 Airborne noise prediction at 9m above ground

Figure 12 presents the Armadale City Centre Activity Centre Plan and City Centre West of Railway Precinct Plan, where multi-storeyed buildings will be constructed in the precinct close to the railway. Predictions of airborne noise from rail operations at 9 meters above ground are calculated to assess the noise impact on the multi-storeyed buildings in the future development. The results are provided in Figure 13 to Figure 18. From these plots, it can be seen that railway noise levels at 9 meters above ground:

- Gateway North Precinct and the edges of precincts for future development are the mostly affected area by airborne noise from the rail operation through viaduct. The noise levels regarding $L_{Aeq,\ Day}$ and $L_{Aeq,\ Night}$ are predicted to be complaint with the target. The noise levels regarding L_{max} marginally exceed (within prediction error) the target.
- The noise levels at current Armadale Shopping Centre area are predicted to be compliant with the day period and night period targets, except L_{max} levels marginally exceed (within prediction error) the maximum passby targets.

Noise received at sensitive precincts that are considered excessive will be reviewed during detailed design which may lead to more effective treatments on the viaduct. However, it is important to note that compliance with the L_{Amax} target is beyond that required by applicable state noise policy and is not considered practicable under all circumstances.

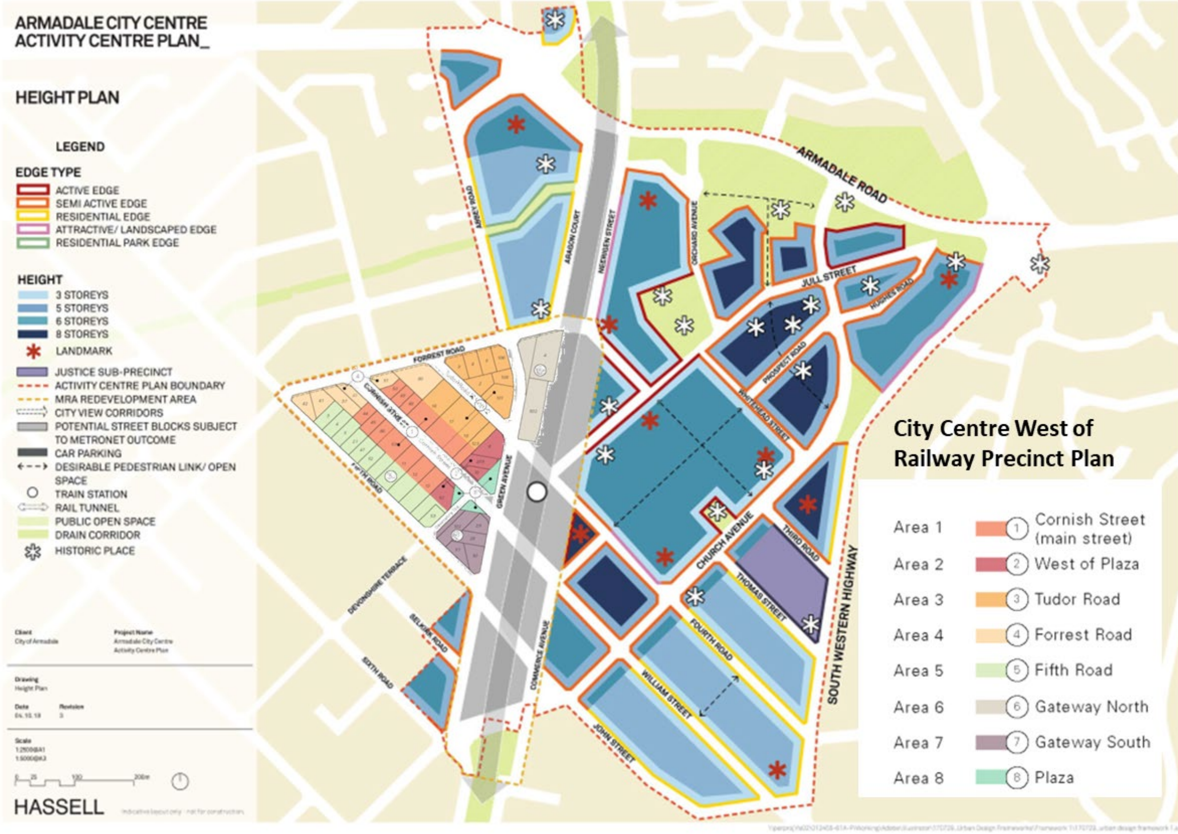

Figure 12: Armadale City Centre Activity Centre Plan and City Centre West of Railway Precinct Plan

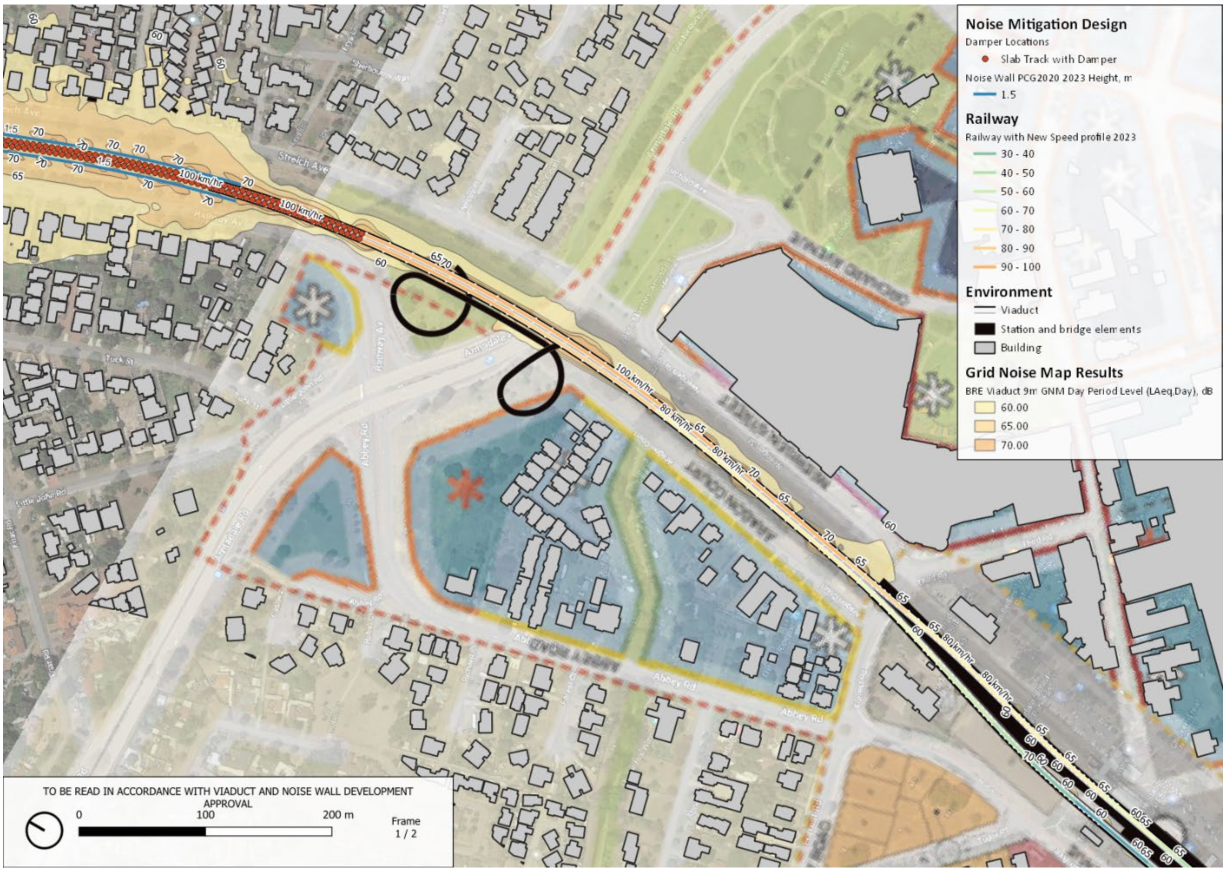

Figure 13: Predicted distribution in day period ($L_{Aeq,day}$) noise levels at 9m above ground, northern end of study area

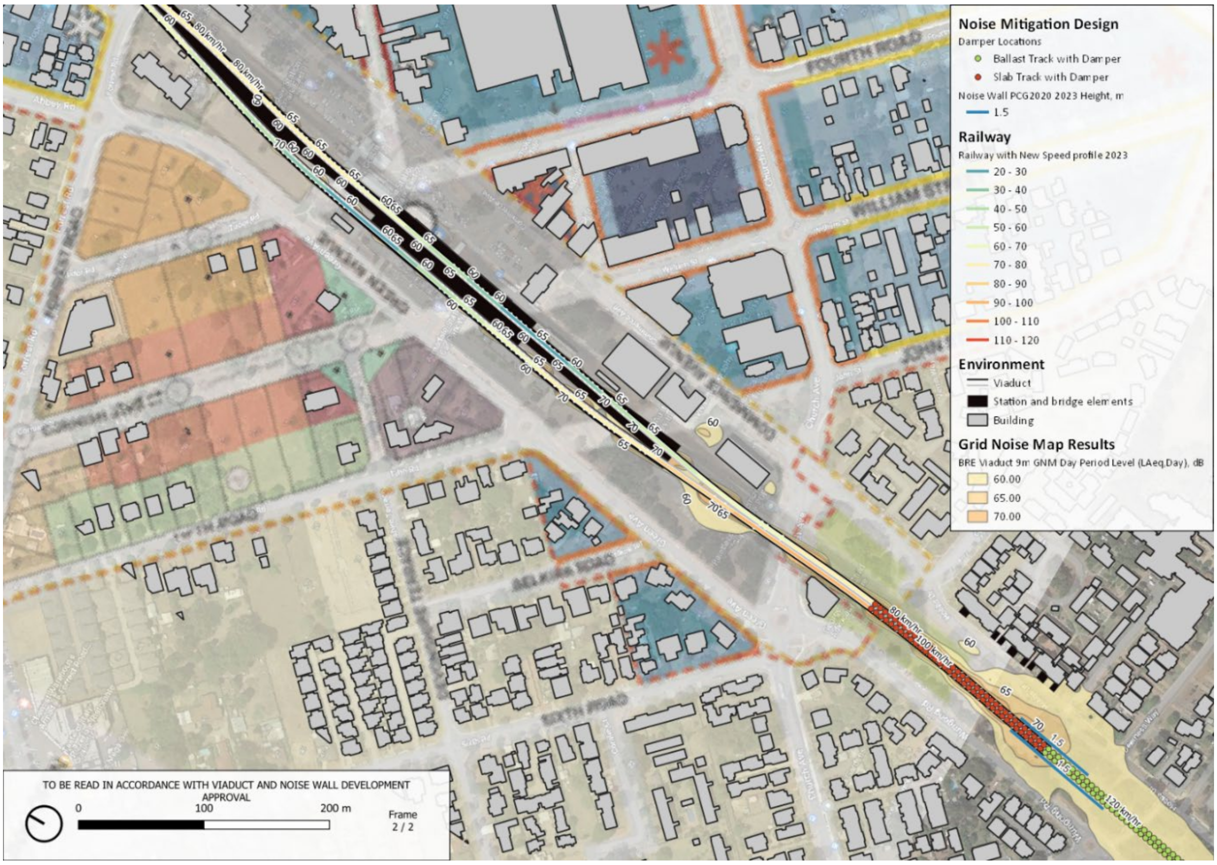

Figure 14: Predicted distribution in day period (LAeq,day) noise levels at 9m above ground, southern end of study area

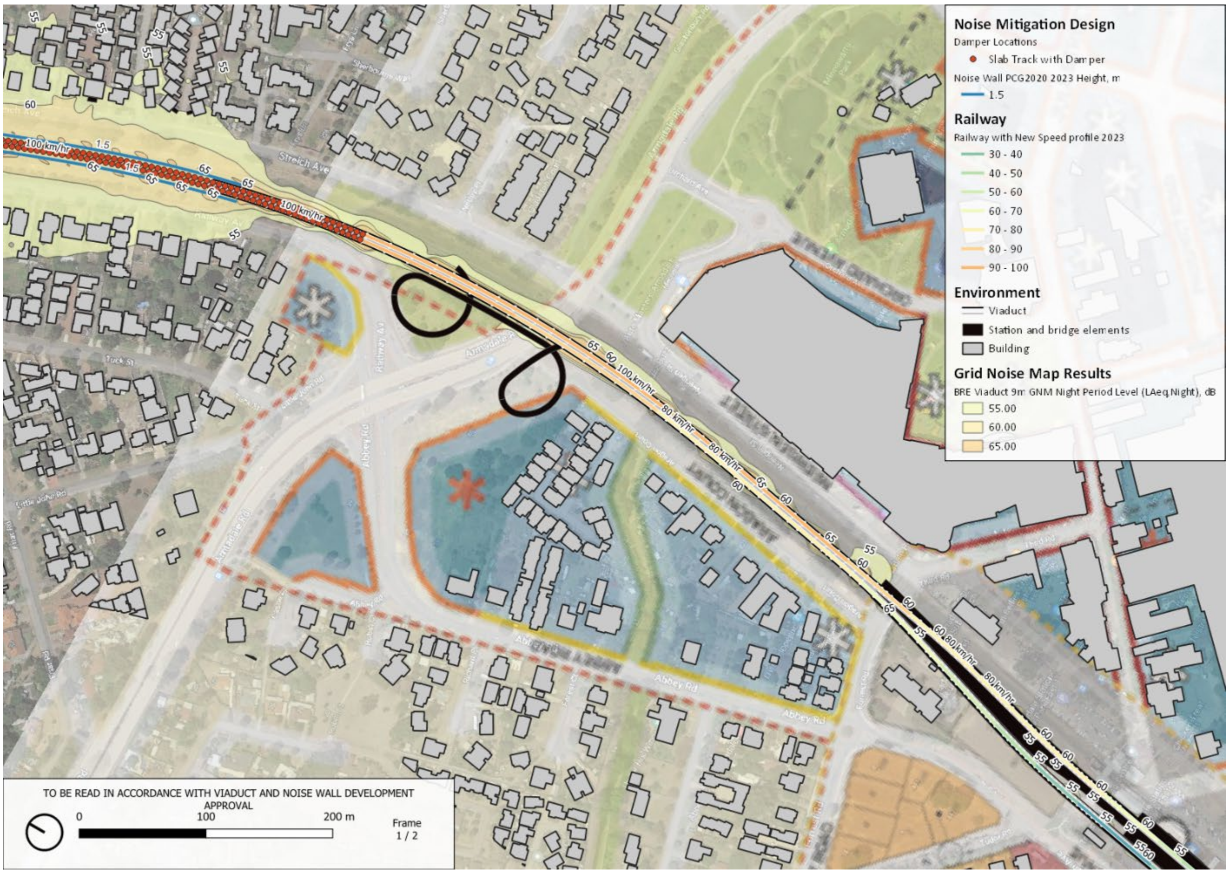

Figure 15: Predicted distribution in night period ($L_{Aeq,night}$) noise levels at 9m above ground, northern end of study area

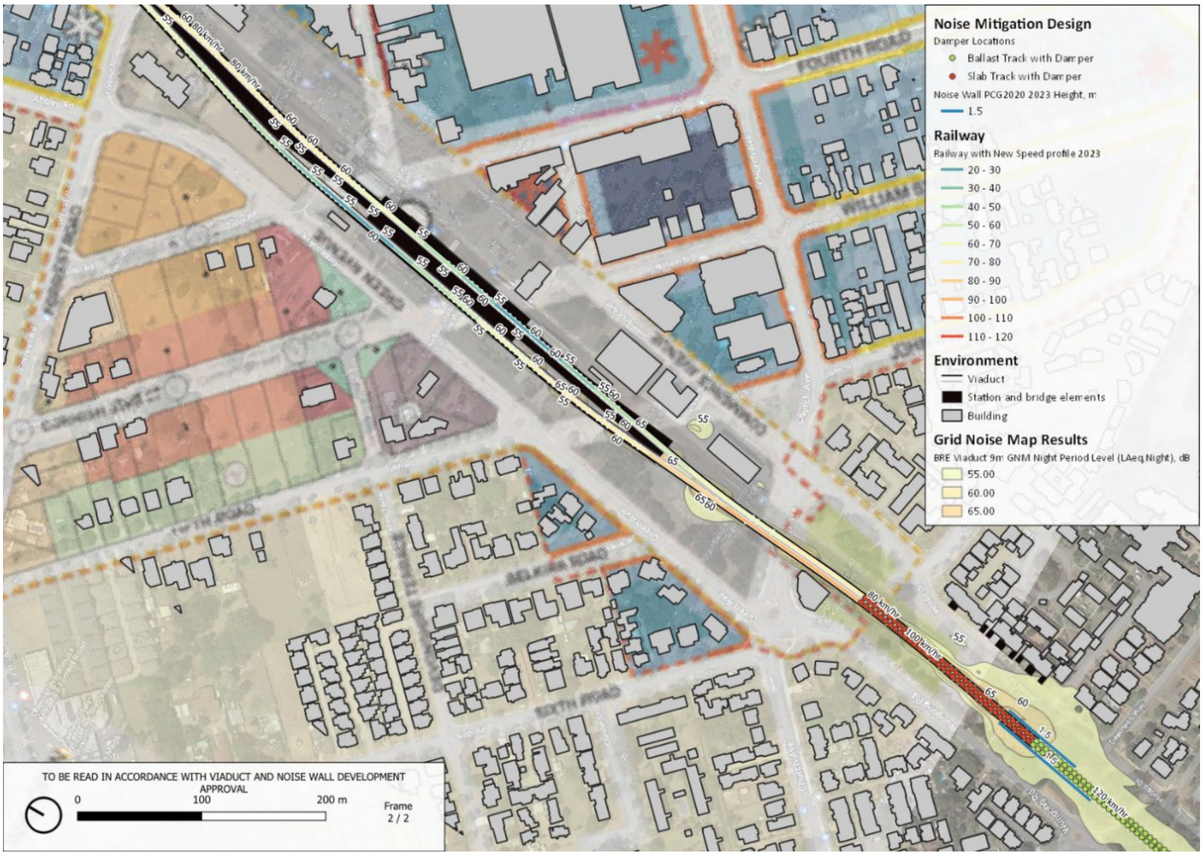

Figure 16: Predicted distribution in night period ($L_{Aeq,night}$) noise levels at 9m above ground, southern end of study area

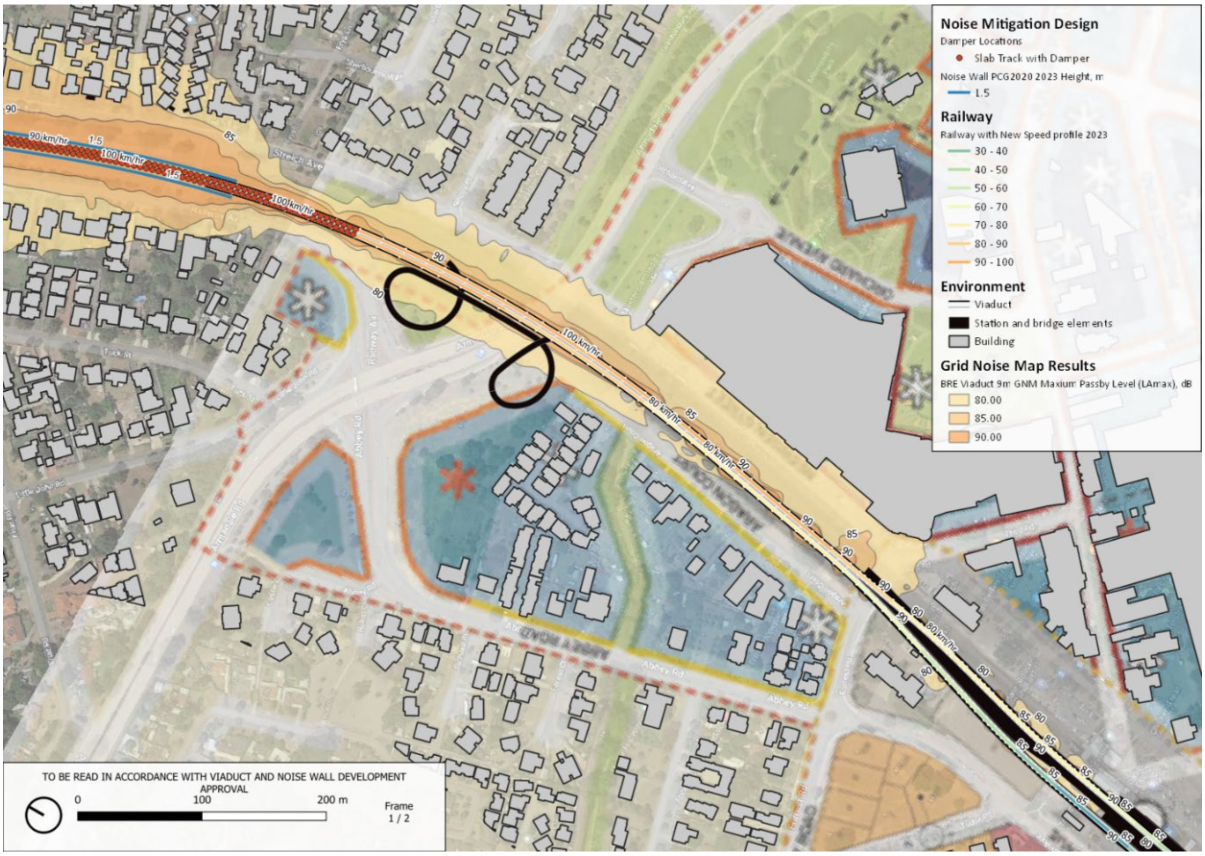

Figure 17: Predicted distribution in maximum passby (L_{Amax}) noise levels at 9m above ground, northern end of study area

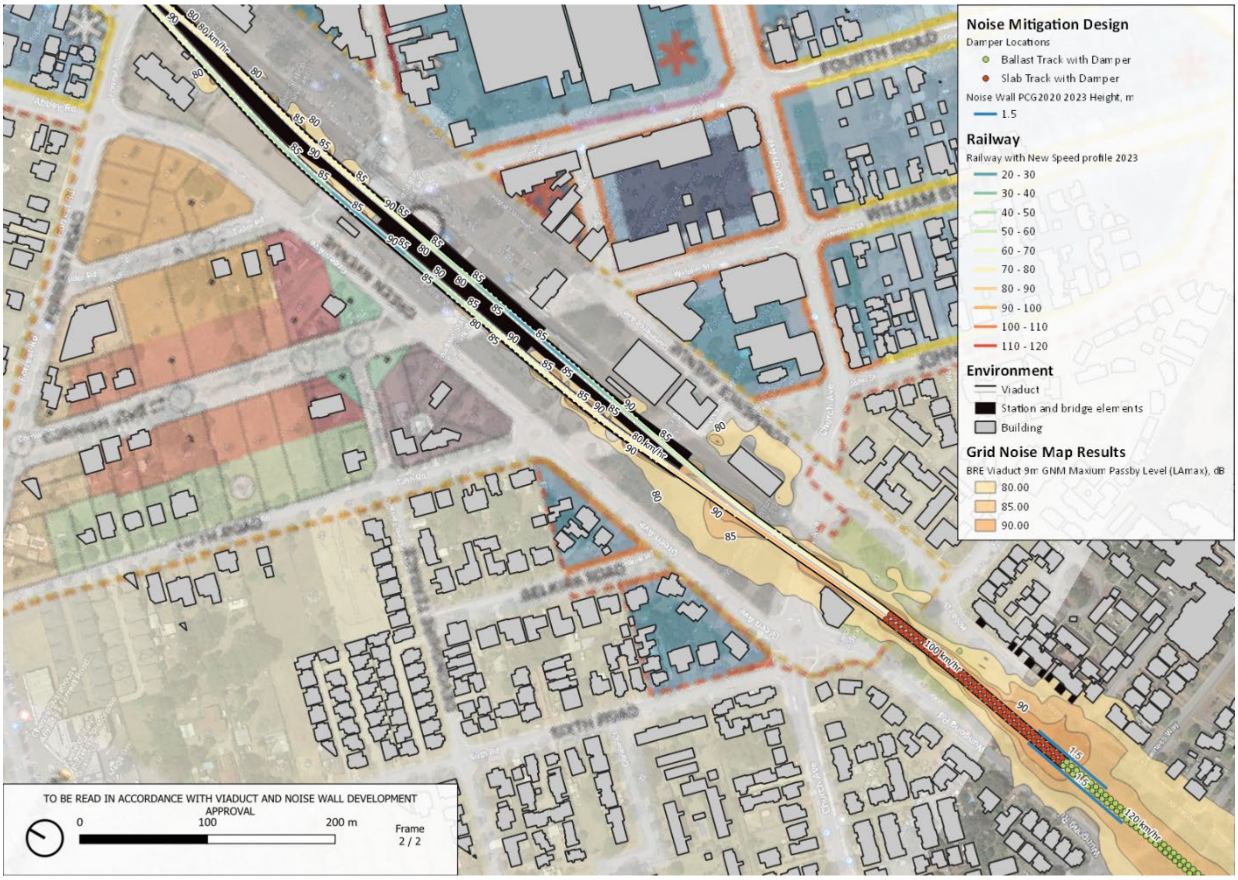

Figure 18: Predicted distribution in maximum passby (L_{Amax}) noise levels at 9m above ground, southern end of study area

6. Railway Vibration Predictions

6.1 Overview and Modelling Process

The prediction of ground-borne noise (GBN) and vibration (GBV) from rail systems is a complex and constantly developing technical field. Whilst much research has been undertaken into various aspects associated with forecasting GBN and GBV from underground rail systems, there is currently no universally accepted modelling approach, and several different modelling approaches are currently in use (including empirical methods, finite element methods, boundary element methods and combinations of these).

In accordance with the International Standard ISO 14837-1 2005 “Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General guidance”, modelling for this project was conducted using SLR-developed code for estimating propagation losses between the railway and nearby sensitive receivers. Vibration emissions are estimated for four types of track form:

- **Ballasted:** as measured on the Perth network and described in **Table 6**.
- **Ballasted with under sleeper pad (USP):** Under Sleeper Pads (USPs) similar to that shown in **Figure 19** are seen as a lower cost option to under ballast matting (UBM), however they have other declared benefits in regards to extending track service life and reducing costs of maintenance.

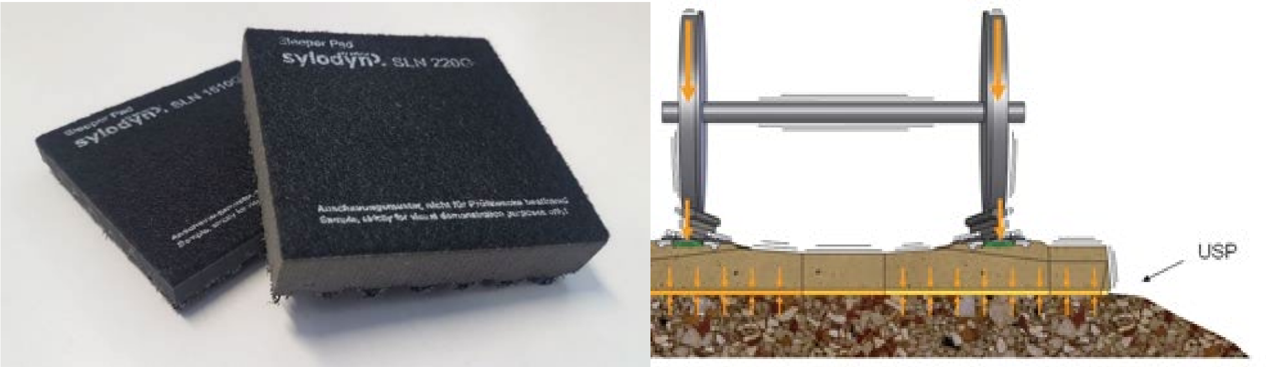

Figure 19: Example under sleeper pad (USP) products, Sylodyn 220G and 1510G; (right) location of USP relative to wheel, sleeper and ballast[17]

- **Ballasted with under ballast matting (UBM):** The detailed design and selection of under ballast matting must be undertaken in conjunction with civil and geotechnical studies and may require stiffening of sub-base / capping ground layers.
- **Slab track:** as described in **Table 6** and estimated based on past measurements near slab track sections on the Perth network.

Full details of the vibration prediction model (source emission levels, adjustments applied, validation with field data etc.) are provided in the project Operational Noise and Vibration Design Report (R30-SLR-RPT-NV-540-00007).

6.2 Results and Discussion

The following figures present the forecasted ground-borne noise and vibration at the nearest residential receivers along the railway with the vibration mitigation extent detailed in Appendix B. From these figures it can be seen that with the proposed mitigation,

- Compliance with a ground borne vibration (GBV) target of L_{vRMS} 106 dB is expected throughout the area.
- Compliance with a ground borne vibration (GBN) target of L_{Amax} 35 dB is expected throughout the area.

The mitigation measure will be further investigated as part of detailed design.

[17] Loy, H. 2008, 'Under Sleeper Pads: improving track quality while reducing operational costs', Global Railway Review, Issue 4, https://www.globalrailwayreview.com/article/671/under-sleeper-pads-improving-track-quality-while-reducing-operational-costs/

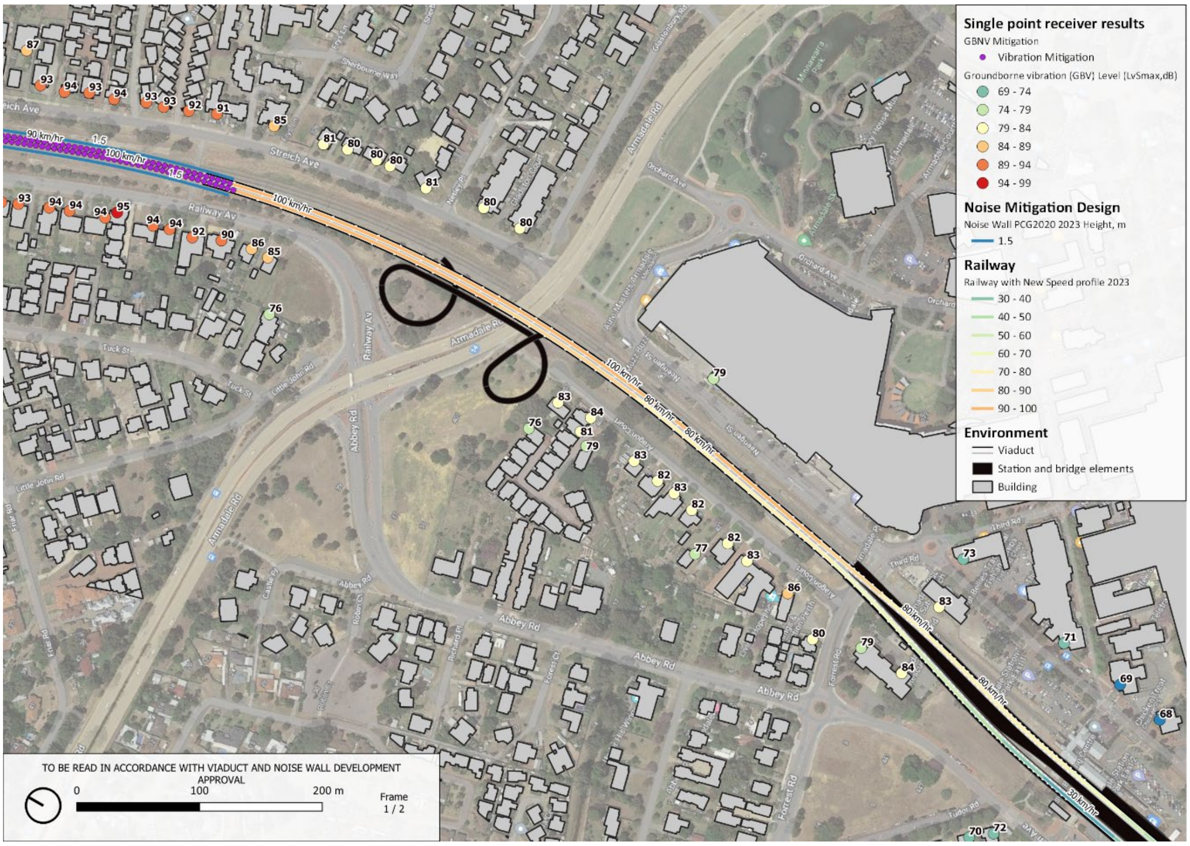

Figure 20: Forecasted ground-borne vibration level (GBV) LvSmax values at nearest residential receivers along the track, northern section

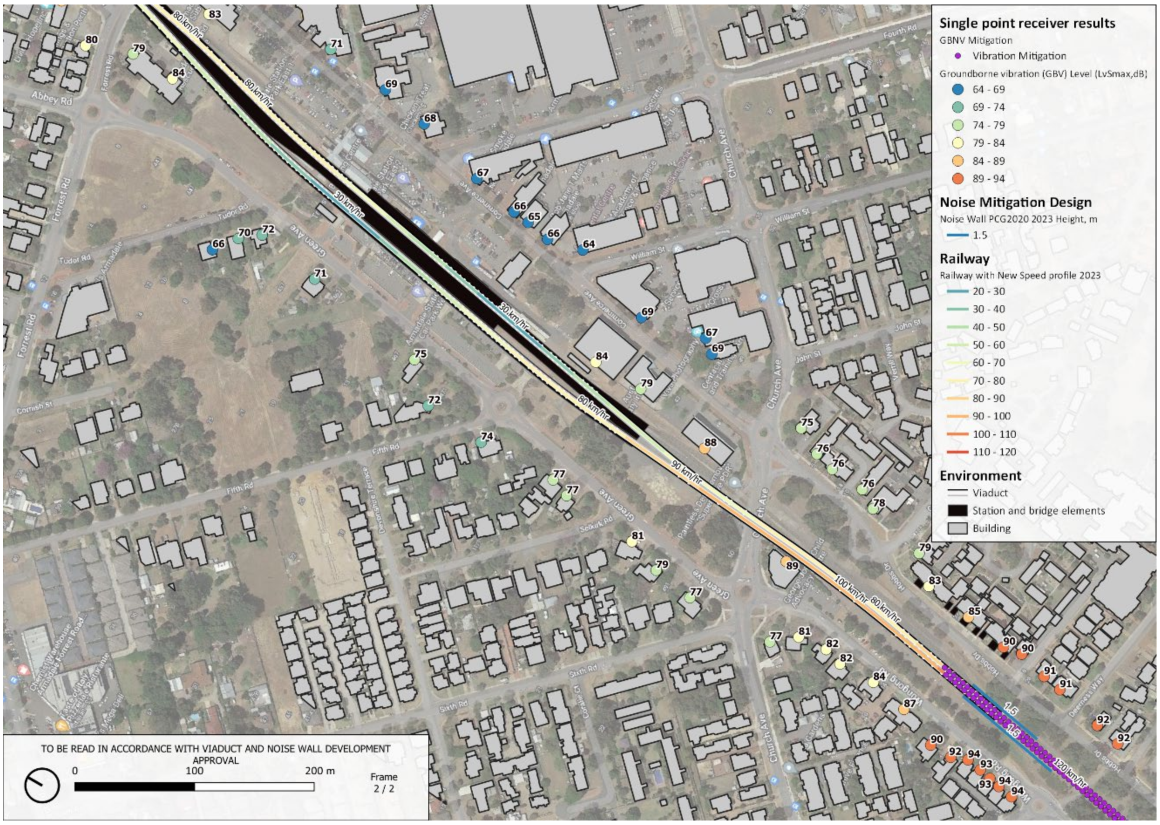

Figure 21: Forecasted ground-borne vibration level (GBV) LvSmax values at nearest residential receivers along the track, southern section

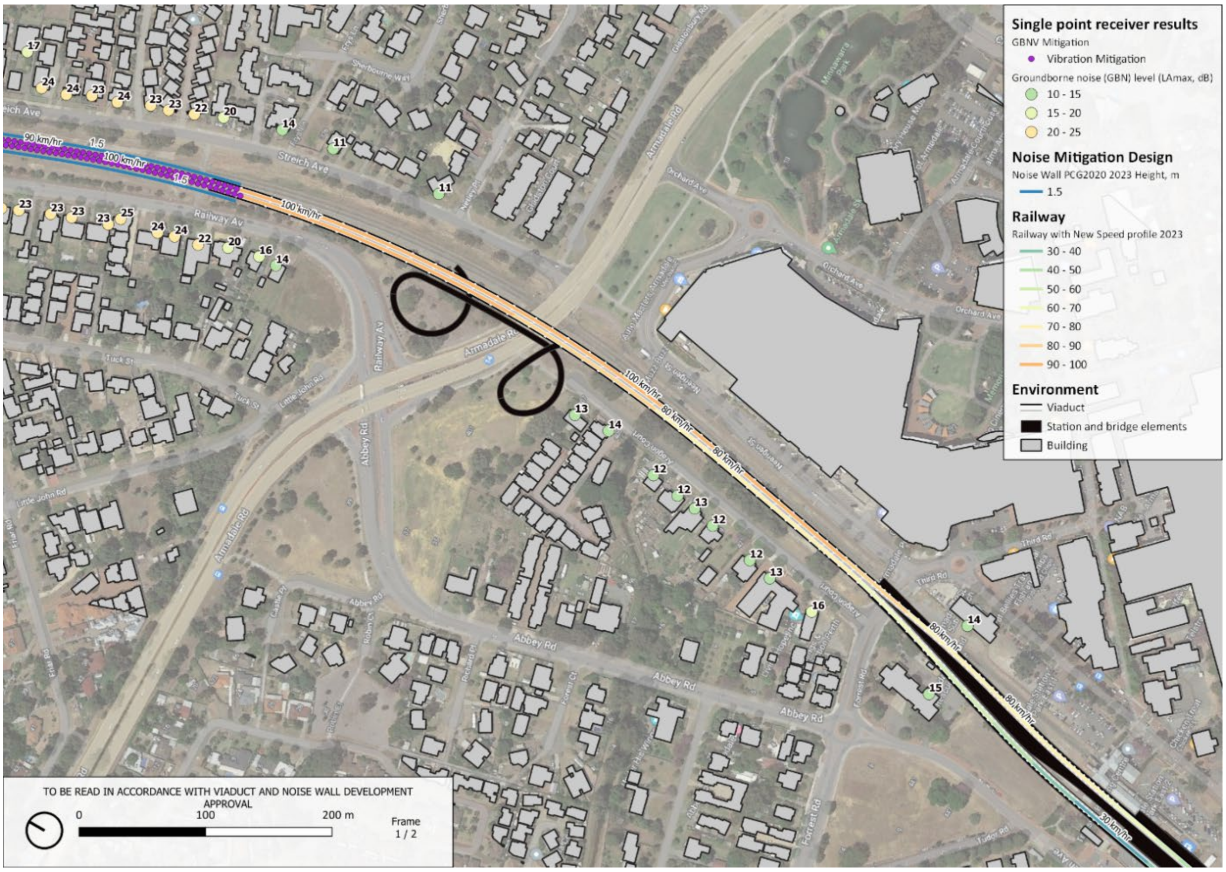

Figure 22: Forecasted ground-borne noise (GBN) level LAmax values at nearest residential receivers along the track, northern section

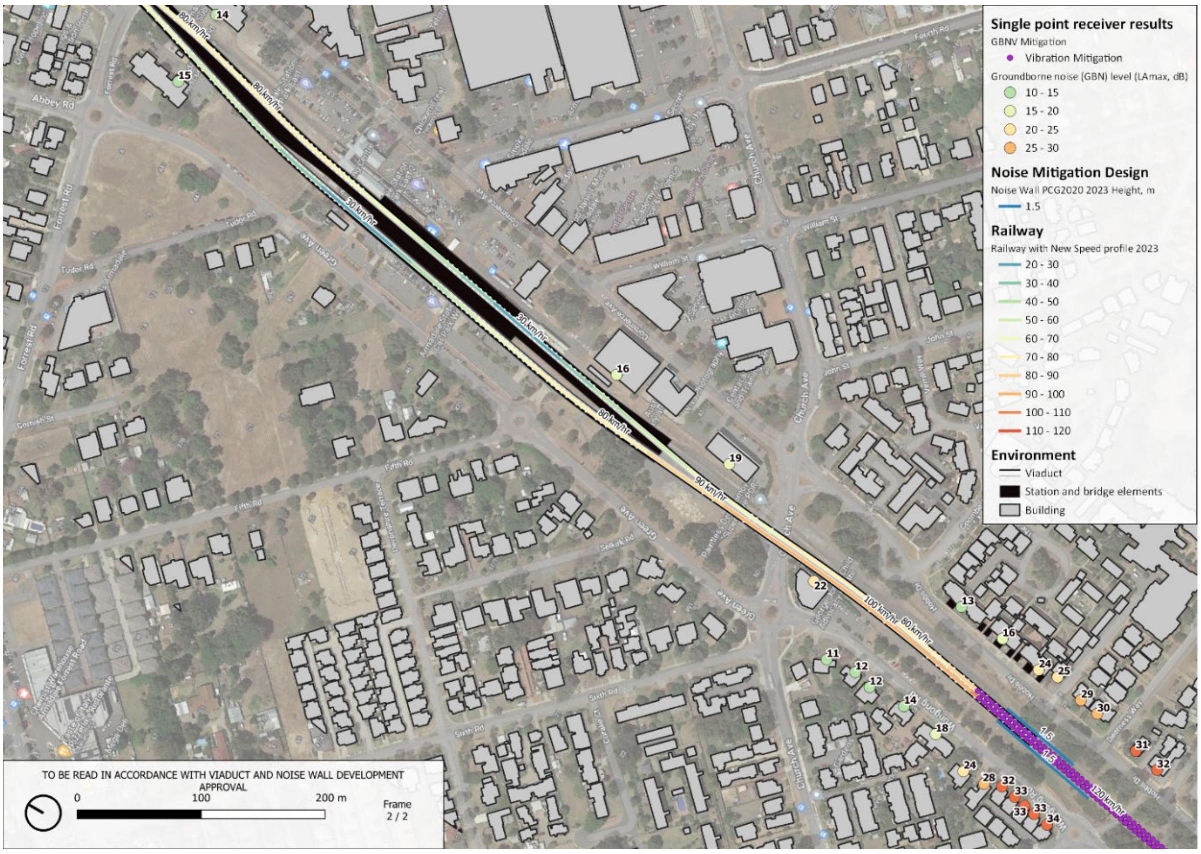

Figure 23: Forecasted ground-borne noise (GBN) level LAmax values at nearest residential receivers along the track, southern section

7. Summary

An assessment of environmental noise and vibration has been undertaken to support development approval of viaducts and noise walls at Armadale Station.

Predicted noise and vibration emissions from the railway have been compared with targets derived from a review of relevant state noise policies and guidelines.

The predicted results indicate that, with the mitigation extent indicated in **Appendix B**,

- Noise levels at 2 meters above the ground are forecasted to comply with set targets at all location;
- Noise levels at 9 meters above the ground are forecasted to marginally exceed (within prediction error) the maximum passby target L_{max} mainly at the edges of Gateway North Precinct and current Armadale Shopping Centre for future development of multi-storeyed buildings; and
- Ground borne vibration and ground borne noise levels are forecast to comply with set targets at all sensitive receivers within the study area.

On this basis, noise and vibration from railway operations associated with the viaducts at Armadale Station can be practicably managed to comply with applicable criteria.

The extents and type of mitigation indicated are subject to refinement as detail in the design develops. Further effective treatments within the viaduct are available to suit development at the locations and heights indicated in the Armadale City Centre Activity Centre Plan and City Centre West of Railway Precinct Plan

Appendix A: Key terms

A.1 Terms used

The following table describes key terms used in this report.

Table 8: Terms used

Parameter	Comment
dB	Decibel, a unit of sound or vibration which is described as a ratio of the result to a fixed reference value. All sound pressure levels (LpA, LA, LAeq etc.) quoted in this report are referenced to 20 micro Pascals (dB re 20µPa).
	Vibration velocity levels (Lv) quoted in this report are referenced to 1 nanometre per second (dB re 10-9 m/s), noting that some US criteria use dB re 10-6 in/s.
Guidelines	Implementation Guidelines for State Planning Policy 5.4 Road and Rail Transport Noise
LAmax	The maximum A-weighted noise level associated with a sampling period.
LAmax,95%	The "typical maximum noise level" for a train pass-by event. For operational rail noise, LAmax refers to the maximum noise level not exceeded for 95% of rail pass-by events measured using the 'slow' (sometimes denoted by subscript 'S') response setting on a sound level meter.
LA1	The A-weighted noise level exceeded for 1% of a given measurement period. This parameter is often used to represent the typical maximum noise level in a given period.
LA10	The A-weighted noise level exceeded for 10% of a given measurement period and is utilised normally to characterise average maximum noise levels.
LAeq	The A-weighted average noise level. It is defined as the steady noise level that contains the same amount of acoustical energy as a given time-varying noise over the same measurement period.
LA90	The A-weighted noise level exceeded for 90% of a given measurement period and is representative of the average minimum background noise level (in the absence of the source under consideration), or simply the "background" level.
Lv	Unweighted vibration velocity level, see dB.
Lv,RMS,1s	Maximum unweighted RMS vibration velocity level over a 1 second period.
Policy	State Planning Policy 5.4 – Road and Rail Transport Noise (2019)
RMS	Root Mean Square, a parameter used to estimate the average energy level of a continuous signal.

A.2 Noise

The terms "sound" and "noise" are almost interchangeable, except that in common usage "noise" is often used to refer to unwanted sound. Sound (or noise) consists of minute fluctuations in atmospheric pressure capable of evoking the sense of hearing. The human ear responds to changes in sound pressure over a very wide range. The following table presents examples of typical noise levels.

The loudest sound pressure to which the human ear responds is ten million times greater than the softest. The decibel (abbreviated as dB) scale reduces this ratio to a more manageable size by the use of logarithms. The symbol 'A' represents A-weighted sound pressure level (SPL): the weighting is designed to better represent the hearing ability of the average listener at each frequency.

L_{Aeq} values represent an energy average of sound over time and are basic indicators of loudness. However there other ways to statistically represent sound and common noise level descriptors that may be used are illustrated in the following figure and are described below.

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Table 9: Guide to sound pressure level ranges for selected environments (dB re 20µPa)

Subjective Evaluation	L_{Aeq}	Comments / Examples
Intolerable. Onset of pain. Exceeds daily exposure limit in under a second.	140	Military jet engine at 30 metres
	130	2kW disaster warning siren at 1 metre
Very loud. Risk of exceeding daily noise exposure limit in under a minute.	120	Jet aircraft take-off at runway edge
	110	Rock concert; freight train main horn at 25 metres
Loud. Onset of risk to exceeding daily recommended noise exposure limit.	100	225mm angle grinder at 1 metre, car horn at 3 metres
	90	Heavy industrial factory interior
Noisy	80	Shouting at 1 metre, kerb side of busy street
	70	Freeway at 20 metres
Moderate	60	Normal conversation at 1 metre, department stores
	50	General office areas
Quiet	40	Office air conditioning background level
Very quiet	30	Bedroom in quiet suburban area
Almost silent	20	Whisper, rural bedroom at night
	10	Human breathing at 3 metres
	0	Threshold of typical hearing

For example, the L_{Amax} parameter is used to describe the highest noise level over a relatively short period (typically 1 second), and the L_{A90} (90th percentile A-weighted result) indicates ambient or background noise levels.

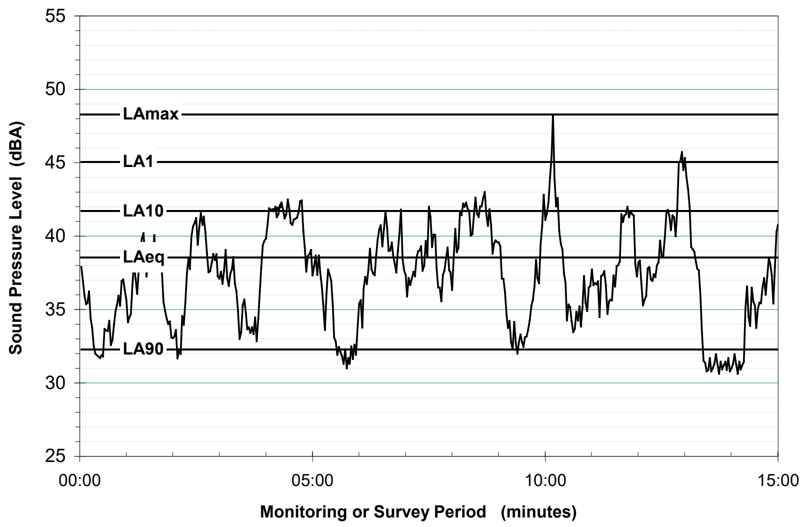

Figure 17: Example of typical noise indices (1 second logging)

The ability to discern a change in noise level varies between individual listeners, however it is reasonable to suggest that a change of up to 3 dB in the level of a sound is difficult for most people to detect, and a 3 dB to 5 dB change corresponds to a small but noticeable change in loudness. A 10 dB change corresponds to an approximate doubling or halving in loudness and is readily noticeable.

A.3 Vibration

Vibration is the term used to describe the oscillating or transient motions in physical bodies. Reference is here in terms of velocity, however this motion can also be described in terms of displacement or acceleration. Most ground borne vibration (GBV) assessments are of human response / comfort first, as the risk of cosmetic and structural damage to buildings occurs at vibration levels that are orders of magnitude higher.

Vibration and sound are intimately related. Vibrating objects can generate (radiate) sound and, conversely, sound waves (particularly at lower frequencies) can also cause objects to vibrate. Noise that propagates through a structure as vibration and is radiated by vibrating wall, ceiling and floor surfaces is termed “ground-borne noise” (GBN), “regenerated noise”, or sometimes “structure borne noise”.

The primary noise metrics used to describe railway induced GBN emissions in the modelling and assessments are:

- LvSmax: The “typical maximum vibration level” for a train passby event, being the highest 1 second maximum root-mean square (RMS) value in dB re 1 nm/s. For operational rail GBV, this similarly refers to the 5th highest percentile of LvSmax results.
- LAsmax: The “typical maximum noise level” for a train passby event, in dB re 20 µPa. For operational rail GBN, LASmax refers to the maximum noise level not exceeded for 95% of rail passby events measured using the sound level meter ‘slow’ (1 second) response setting. Statistically this is the 5th highest percentile of LASmax results. The subscript “A” indicates that the noise levels are filtered to match normal human hearing characteristics (i.e. A-weighted).

On the basis of guidance in International Standard ISO 14837-1 2005 Mechanical vibration - Ground-borne noise and vibration arising from rail systems – Part 1: General guidance, ground-borne noise levels are evaluated over the 20 Hz to 315 Hz frequency range.

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

Table 10: Guide to one-second maximum RMS floor vibration level ranges for selected environments

Typical response	mm/s	dB re 1nm/s	Comments / Examples
Visible response in building items, structural damage risk	16	144	High impact events such as blasting or dynamic compaction in close proximity to structures.
	10	140	
	8.0	138	
Cosmetic damage to some buildings possible over extended periods	5.0	134	
	3.0	130	Impact pile driving, 15 metres.
Noticeable. Minor cosmetic damage is feasible to buildings that are in fragile condition / an existing state of disrepair	2.0	126	Freight trains at 80 km/h, ~10 metres.
	1.0	120	Rock breaking at 15 metres. Vibratory roller at 10 metres.
	0.8	118	Typical target for workshops.
	0.4	112	Freight trains at 80 km/h, ~40 metres. Regenerated noise highly likely in typical residential buildings.
Barely noticeable	0.3	110	
	0.2	106	Typical residential daytime target for continuous vibration.
Threshold of human perception to vibration	0.15	104	Passenger trains at 80 km/h, ~30 metres.
Not felt	0.10	100	Operating rooms, surgeries.

Appendix B: Schedules

B.1 Rail Damper Extent

Table 11 indicates the extent of rail damper modelled, which applies to all main line tracks at each chainage.

Table 11: Modelled rail damper extent

ID	Chainage From (km)	Chainage To (km)	Distance (m)	Track form
TBC	27.47	28.02	550	Ballast track with damper
TBC	28.02	28.35	330	Slab track with damper
TBC	29.625	29.805	180	Slab track with damper
TBC	29.805	30.405	600	Ballast track with damper
TBC	30.85	31.435	585	Ballast track with damper
TBC	32.455	35.63	3175	Ballast track with damper

B.2 Noise walls

Table 12 indicates the extent of noise walls modelled.

Table 12: Modelled noise walls

ID	Chainage(km)		Distance (m)	Height	Distance from nearest CL	Side of Track	Comment
	Start	End					
1	27.52	28.245	725	1.5	5m (as request between chainage 27.5-27.78)	Western	Formation to be widened by 1m to accommodate (especially the chainage between 27.780-28.245, or further mitigation may need). Height measured from 0.6 m below TOR - ballasted track (north end of viaduct)
2	27.555	28.025	470	1.5-2.4	17m (as request between chainage 27.5-28)	Eastern	On boundary - due to equipment, MCR, drainage Height measured from the elevation level of updated civil input
3	28.02	28.245	225	1.5	5m	Eastern	Formation needs to be widened by 1m to accommodate, or further mitigation may need. Height measured from 0.6 m below TOR - ballasted track (north end of viaduct)
4	29.78	29.88	100	1.5	4.1m	Western	Civil to widen formation if required Height measured from 0.6 m below TOR - ballasted track (south end of viaduct)
5	29.78	29.85	70	1.5	4.4m	Eastern	Civil to widen formation if required Height measured from 0.6 m below TOR - ballasted track (south end of viaduct)
6	32.47	32.59	120	1.5	4m	Eastern	Civil to widen formation if required Height measured from 0.6 m below TOR - ballasted track
7	32.83	32.98	150	1.8	12m (as request between chainage 32.83-33)	Eastern	Moved to be clear of drain up to Culvert 8 Height measured from the elevation level of updated civil input
8	32.975	33.32	345	1.5-1.8	18m at boundary (as request between chainage 33-33.45)	Eastern	Due to proposed drain diverting TSER and LGA drain Height measured from the elevation level of updated civil input
9	34.72	34.84	120	1.5	around 7m (follow the updated civil input)	Eastern	Height measured from the elevation level of updated civil input
10	34.9	35.06	160	1.5	Around 6-16m (follow the updated civil input)	Western	Height measured from the elevation level of updated civil input
11	35.33	35.6	270	1.5	Around 6m (follow the updated civil input)	Western	Two pieces to follow the civil Height measured from the elevation level of updated civil input

ID	Chainage(km)		Distance (m)	Height	Distance from nearest CL	Side of Track	Comment
	Start	End					
12	34.92	35.6	680	1.5-1.8	Around 6m (follow the updated civil input)	Eastern	Height measured from the elevation level of updated civil input

B.3 Under ballast matting / Under sleeper pads (UBMs / USPs)

The modelled extent of UBM/USP is detailed in Table 13, applying to both the UP and DOWN tracks.

Table 13: Vibration mitigation extent

ID	Chainage (km)		Distance (m)
	Start	End	
TBC	27.5	28.25	750
TBC	29.75	31.35	1600
TBC	32.5	34.4	1900
TBC	34.75	35.65	900

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