APPENDIX D ACOUSTIC ASSESSMENT

4/7 HONEYBEE PARADE, BANKSIA GROVE

Container Collection Depot (CCD)

Noise Impact Assessment

Prepared for:

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with TOMRA Collection Solutions (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
675.30081.0000	25 October 2021	Ying Liu	Luke Zoontjens	Luke Zoontjens

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APPENDICES

1 Introduction

SLR Consulting Australia Pty Ltd (SLR) has been commissioned by TOMRA Collection Solutions Australia Pty Ltd (TOMRA) to undertake a noise impact assessment of the proposed Container Collection Depot (CCD) located at 4/7 Honeybee Parade, Banksia Grove, WA.

In support of the development permit application, this report provides an assessment of noise associated with the CCD. The assessment is to ascertain whether there would be potential noise issue(s) regarding the installations and, if so, options to ensure compliance with Environmental Protection (Noise) Regulations 1997 and relevant environmental legislation for noise.

This report details the prediction of potential noise emissions and the assessment of noise impacts from the proposed development on surrounding noise sensitive premise. A description of acoustic terminology is provided in **Appendix A**.

1.1 Project description and site location

This proposed CCD is located at 4/7 Honeybee Parade Banksia Grove. The proposed works include retrofitting the internal layout of the existing building, with vehicular access off Jewel Way. **Figure 1** shows the site location in the context of surrounding area as well as the indoor design of CCD.

TOMRA are proposing the retrofit the existing building to incorporate three (3) banks of two (2) Reverse Vending Machines that handles all materials. In total, all 6 machines could operate simultaneously, sorting a mixture of glass and lightweight materials. The depots are proposed to operate as per the following:

- Opening hours Monday to Friday 7:00 am to 7:00 pm; Saturday and Sunday 7:00 am to 5 pm and Public Holiday 9:00 am to 5:00 pm.
- Heavy Vehicles including Medium Rigid Vehicle (MRV) and Reverse Collection Vehicle (RCV) to operate Monday to Sunday during the above-mentioned operating hours.
- The use is conducted wholly indoors, with the loading of containers onto the collection truck to occur within the building with roller door shut.
- MRV or similar industrial standard collections expected 4 times a day (Monday to Sunday). RCV rubbish removal trucks expected four times a week (Monday to Sunday). In summary a total of 32 heavy vehicle movements are expected per week.

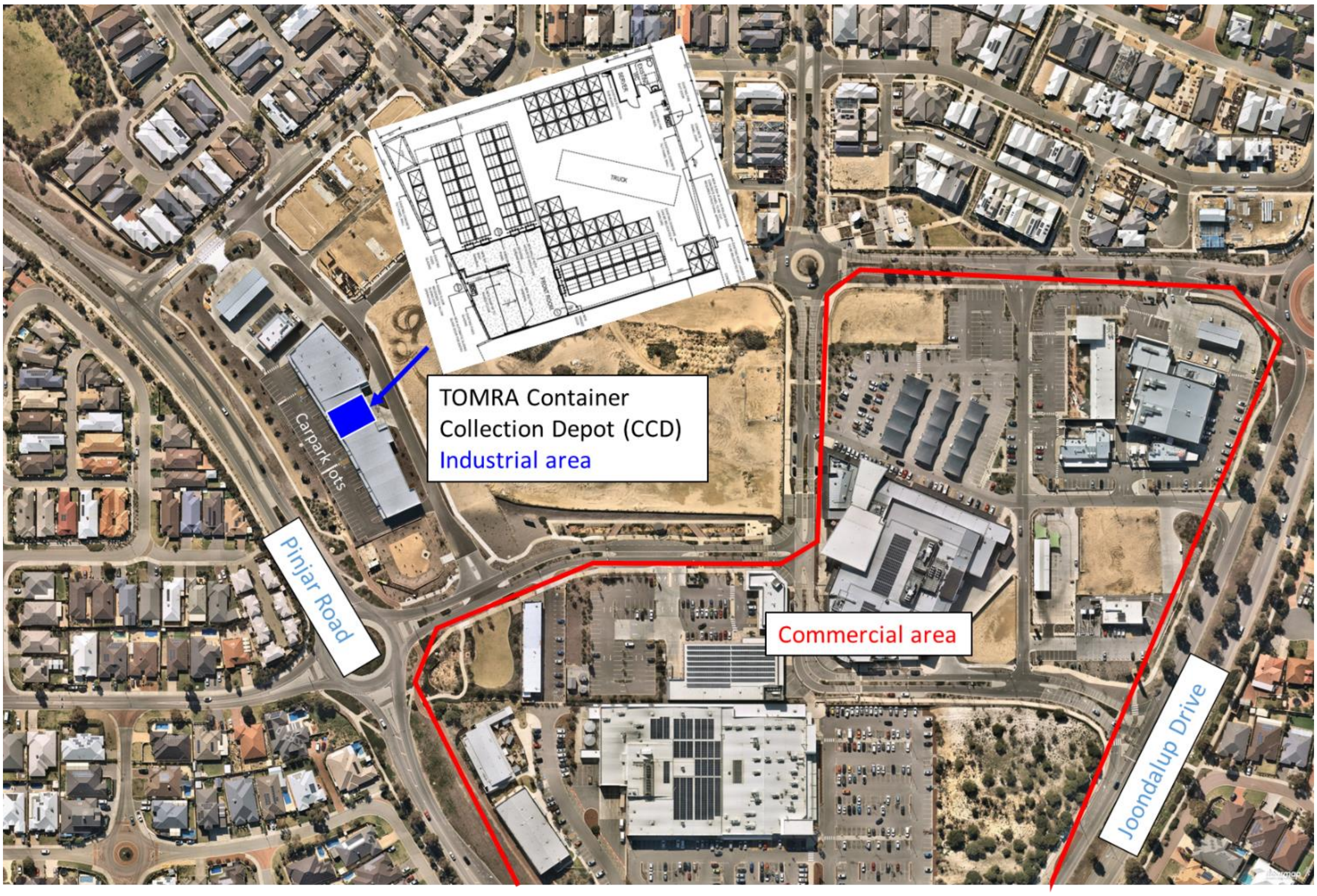


Figure 1 Annotated aerial image indicating location of Container Collection Depot (CCD) at Banksia Grove

1.2 Scope

The following acoustics scope has been determined based on our prior knowledge of similar TOMRA developments and our review of the four subject sites:

- Review specific site location and estimate background noise levels using methods listed in AS1055.
- Determination of appropriate operational noise limits to suit local and state authority requirements.
- Using noise source data previously gathered, model noise emissions from the proposed site/s considering specifics such as the proposed number of machines, surrounding building structure, orientation of building openings and distance to any noise sensitive receivers.
- Identification of in-principle noise mitigation measures needed to achieve relevant criteria.

2 Noise criteria

2.1 Western Australia Environmental Protection (Noise) Regulations 1997

Project noise emissions are addressed by state noise policy in the form of the *Western Australia Environmental Protection (Noise) Regulations 1997* (“EPNR”, “the Regulations”). To achieve compliance with this policy, noise levels at nearby residential areas are not to exceed defined limits referred to as Assigned Noise Levels. These limits are determined from consideration of prevailing background noise levels and ‘influencing factors’ that considers the level of commercial and industrial zoning in the locality.

The influencing factor considers zoning and road traffic around the nearest sensitive receiver of interest, within a 100 m and 450 m radius. A summary of the applicable noise limits is provided in **Table 1**. The specific assigned levels for each receiver are included in the sections of this report which detail the specific noise assessment for each site.

Table 1 Summary of assigned noise levels

Part of premises receiving noise	Time of day	Assigned level, dB		
		L_{A10}	L_{A1}	L_{Amax}
Noise Sensitive premises at locations within 15 metres of a building directly associated with a noise sensitive use	0700 to 1900 hours Monday to Saturday *('Day')*	45 + IF	55 + IF	65 + IF
	0900 to 1900 hours Sunday and public holidays *('Sundays')*	40 + IF	50 + IF	65 + IF
	1900 to 2200 hours all days *('Evening')*	40 + IF	50 + IF	55 + IF
	2200 hours on any day to 0700 Monday to Saturday and 0900 hours Sunday and public holidays *('Night')*	35 + IF	45 + IF	55 + IF
Noise Sensitive premises at locations further than 15 metres from a building directly associated with a noise sensitive use.	All hours	60	75	80
Commercial premises	All hours	60	75	80
Industrial and utility premises	All hours	65	80	90

If noise emitted from any premises when received at any other premises cannot reasonably be free of intrusive characteristics of tonality, modulation and impulsiveness, then a series of adjustments must be added to the emitted levels (measured or calculated) and the adjusted level must comply with the assigned level.

The adjustments are detailed in **Table 2** and are further defined in Regulation 9(1) of the Environmental Protection (Noise) Regulations 1997.

Table 2 Adjustments to the emitted levels

Noise characteristic	Definition	Adjustment if present (Note[1])
Tones	Where the difference between the A weighted sound pressure level in any one third octave ban and the arithmetic average of the A weighted sound pressure levels in the two adjacent one third octave bands is greater than 3 dB in terms of L_{Aeq},T where the time period T is greater than 10% of the representative assessment period, or greater than 8 dB at any time when the sound pressure levels are determined as L_{ASlow} levels.	+5 dB
Modulation	A variation in the emission of noise that – • Is more than 3 dB L_{AFast} or is more than 3 dB L_{AFast} in any one third octave band; • Is present for at least 10% of the representative assessment period; and, • Is regular, cyclic and audible.	+5 dB
Impulsiveness	Present where the difference between the L_{APeak} and L_{Amax} is more than 15 dB when determined for single representative event.	+10 dB

Note 1 where noise emission is not music, these adjustments are cumulative to a maximum of 15 dB.

2.2 Front room noise criteria

TOMRA has requested an assessment of likely internal noise levels within the front room and offices. Whilst not specific to state noise policy assessment requirements, this report has accordingly considered internal noise levels within the front room and offices.

Table 3 nominates the criteria for separate commercial tenancies within the same building drawn from guideline levels contained in Australian Standard AS 2107:2016 *Acoustics – Recommended design sound levels and reverberation times for building interiors*. The type of occupancy/activity is based on general office activities.

Table 3 Office based noise criteria

Area	Design sound level range, L_{Aeq}
General office areas (office buildings)	40 – 45 dB

3 Assessment Methodology

3.1 Overview

A noise prediction model was established to estimate the noise levels at nearby noise sensitive receivers surrounding the CCD. The predicted noise levels were assessed against the Assigned Noise Levels to determine the potential compliance with the Regulations.

3.2 Noise prediction model

The noise emissions from the operation of CCD were modelled using ISO 17534[1] compliant software (iNoise). and standardised equations and functions for outdoor noise propagation. The noise prediction algorithms account for the octave band sound power level and the heights of the sources, the distances to receptors, and building construction materials (including the ceiling/roof and windows/walls).

The site scenario and the principal sources of noise included in the model are detailed below.

3.2.1 Site scenario

Available terrain data was implemented to construct a 3D spatial environment in the noise prediction model. The container collection depot as well as the surrounding constructions were modelled to account for reflections and screening form building facades. The large empty area to the east of the CCD (see **Figure 1**) has been included as ground region, where the attenuation effect of the ground was included in the calculation. The 3D view of the site scenario is displayed in **Figure 2**.

[1] ISO 17534-1:2015 Acoustics — Software for the calculation of sound outdoors — Part 1: Quality requirements and quality assurance

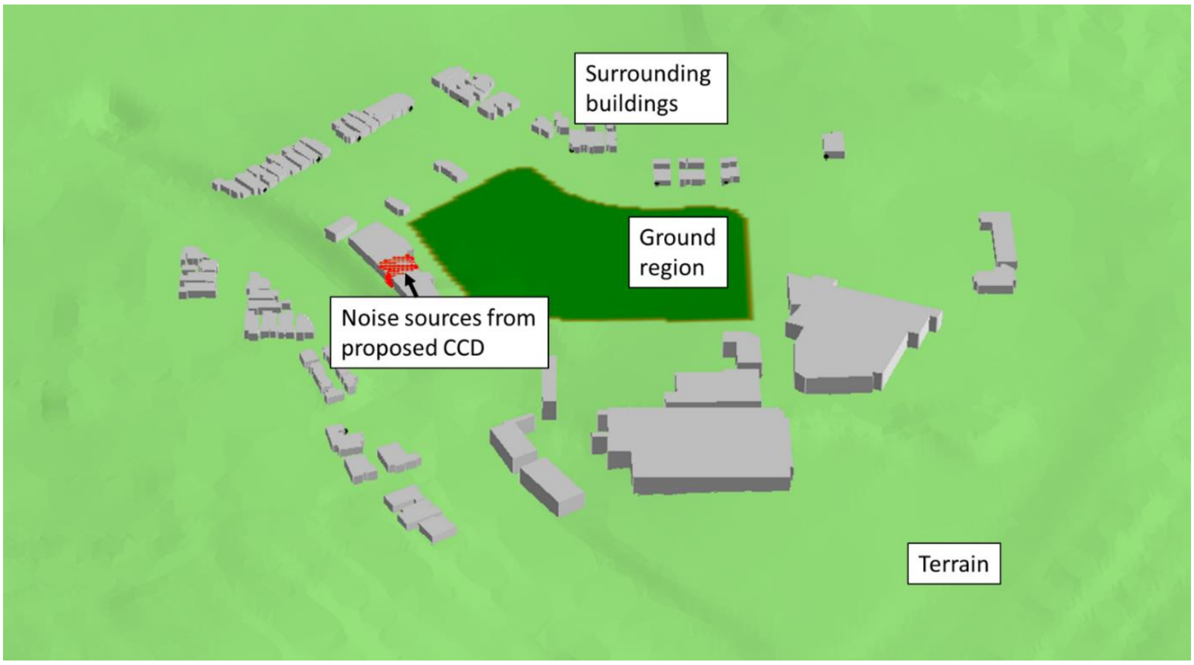


Figure 2 3D view of site scenario in the prediction model

A total of 21 receivers are identified as noise sensitive receptors as described in **Table 4**.

Table 4 Assessed nearby existing noise sensitive receivers

TOMRA container collection depot	Noise sensitive premises located near the proposed site
Unit 4/7 Honeybee Parade, Banksia Grove, 6031 WA	Existing Representative Detached dwellings within 200m to the North (R1-R2) Existing Representative Detached dwellings within 300m to the Northeast (R3-R5) Existing Representative Detached dwellings within 300m to the East (R6-R9) Existing Representative Detached dwellings within 300m to the West (R10-R14) Future Representative Detached dwellings under construction to the Northeast (R15-R16) Existing commercial sites within 200m to the South (R17-20) Existing adjacent tenant within the same building (R21, indoor)

The approximate locations of each noise sensitive receiver (R1-R21) to the proposed CCD are shown in **Figure 3**.

Figure 3 Approximate locations of assessed receivers

3.2.2 Noise emission levels of sources

The advised opening hours are Monday to Friday 7:00 am to 7:00 pm, Saturday and Sunday 7:00 am to 5 pm and Public Holiday 9:00 am to 5:00 pm. During the operation hours, the principal sources of noise associated with the proposed development are:

- Vehicle movements and parking activities,
- Loading bay including truck reversing and material handling noise,
- Depot operational noise, and
- Mechanical plant.

CCD back of house will close 30 minutes later than opening hours for (cleaning etc), during which the principle sources of noise are unlikely to be at operation.

3.2.2.1 Light vehicle movements

Carpark lots adjacent to western façade of the CCD building will be used by customers on site, with access via an entry point off Jewel Way.

Short-term noise events from onsite vehicles and car park activities can potentially affect nearby noise sensitive receptors. Staff and customer vehicles modelled during opening hours are considered to be a mixture of passenger vehicles and light commercial vehicles such as utilities and 4WDs. Typical car parking noise events that may affect neighbouring properties include:

- Vehicle movement (tyre scuff, braking, etc); and
- Door slamming.

Light vehicle movements noise emission levels based on the range referenced in the Association of Australian Acoustical Consultants (AAAC) typical sound power levels for car park vehicle movements (i.e. $L_{Aeq,30sec}$ 88 dB per vehicle movement). The spectrum of noise emission levels related to light vehicle movements are presented in **Table 5**.

Table 5 Noise emission level – Light vehicle movements

Source	Sound power level in dBZ (unweighted), L_w re 1 pW									Overall level
	31.5Hz	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz	dBA
Light vehicle movements	-	101	96	90	87	80	70	64	55	88

3.2.2.2 Heavy vehicle loading bay and delivery noise

The loading area activities and delivery vehicle movements are expected during opening hours. Deliveries are expected to be made in the proposed internal loading zone highlighted in **Figure 4.**

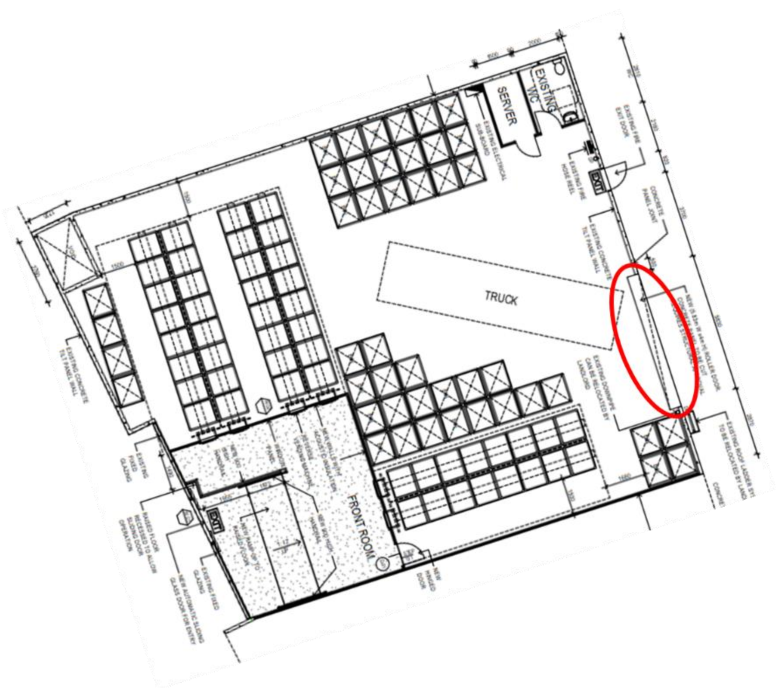


Figure 4 Proposed loading zone for CCD

TOMRA has advised that there will be approximately four (4) truck loadings per day. The loading zone is indoors with truck loading processes to be completed with the roller door closed. Therefore, the loading-zone itself is expected to be acoustically shielded from nearest noise sensitive receivers due to the building geometry. Given the loading activity emissions are considered quieter than other activities within that space, further assessment is not considered necessary. The noise emission levels related to truck movements are presented in **Table 6**.

Table 6 Noise emission level – Truck movements

Source	Sound power level in dBZ (unweighted), L_w re 1 pW									Overall level
	31.5Hz	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz	dBA
Truck movements	0	87	92	95	90	88	85	79	73	93

3.2.2.3 Operational noise

Based on concept plans we understand the reverse vending machines will be installed as identified in **Figure 5**.

Figure 5 Proposed CCD machine layout

A description of the expected reverse vending machines acoustic signature are as follows:

- In the Front room, patrons place empty containers into front end of each machine.
- Containers are either glass, plastic or aluminium, a separate line exists for each.
- Conveyors are then activated by sensor and carry the containers into the Back Room.
- At the end of conveyor, the containers drop into 1100L plastic wheelie bins.
- Once a bin is full, TOMRA staff wheel the bin away and replace it with another.

SLR have conducted sound level measurements of RVM machines for glass, plastic or aluminium, in TOMRA's head office in Sydney. Equipment sound levels are shown in **Table 7** with the overall calculated noise level.

Table 7 Noise source levels and calculated operating noise level, continuous operation

Material	Number of machines	Estimated Noise Level per machine, L_{Aeq} dB
Glass	2	87

Material	Number of machines	Estimated Noise Level per machine, L_{Aeq} dB
Plastic	2	69
Aluminium	2	68
Sum of estimated noise levels	**6**	**91**

The corresponding spectrum of the overall noise level is shown in **Table 8**.

Table 8 Estimated noise emission level –Operation

Source	Sound power level in dBZ (unweighted), L_w re 1 pW									Overall level
	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz	dBA
Operation	-	68	77	76	77	78	79	88	85	91

Conservatively, this operational noise assessment models 6 machines running at 100% capacity continuously. Lower noise levels will result in practice where the actual utilisation rate is less.

3.2.2.4 Mechanical plant

At this stage of the design, the location of external mechanical plant has not been finalised, however SLR understands that a packaged HVAC unit will likely be installed to provide air conditioning for the Front Room. SLR have conducted an assessment based on an external equipment sound power of L_{WA} 80 dB placed on the roof of the building. The noise emission level of the mechanical plant is shown in **Table 9**.

Table 9 Noise emission level –Mechanical plant

Source	Sound power level in dBZ (unweighted), L_w re 1 pW									Overall level
	31.5Hz	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz	dBA
Mechanical plant	-	83	86	80	78	74	70	66	61	80

3.2.3 Environmental propagation

The model applied the International Standard ISO 9613-2[2] method for calculating the outdoor noise propagation given the relative short distances involved. The ISO method calculates noise levels with default meteorological conditions favourable for downwind propagation of noise (wind speeds between approximately 1 m/s and 5 m/s) or under a moderate ground-based temperature inversion. This approach is widely applied in Australia for the prediction of noise from industrial premises at these distances.

3.3 Assigned Levels

The assigned noise levels for nearby sensitive receivers surrounding the container collection depot are detailed in **Table 10** on basis of the influencing factor (IF) determined from the proximity of the receivers to Pinjar Road, Joondalup Drive, the industrial area including the proposed depot and nearby Banksia Grove commercial area.

[2] International Standards Organization, 1996. ISO 9613-2:1996, Acoustics – attenuation of sound during propagation outdoors – Part 2: General method of calculation.

Table 10 Assigned Levels – Nearby Existing Receivers

Sensitive receivers (Figure 3)	Notes	Influencing Factor, dB	Assigned Levels, L_{A10} dB		
			Day	Evening	Night
Existing Residential Building North Side (R1-2)	Within 100 m of Pinjar Road and commercial area	8	53	48	43
Existing Residential Building Northeast Side (R3-5)	Within 450 m of Pinjar Road, industrial and commercial area	3	48	43	38
Existing Residential Building East Side (R6-9)	Within 450 m of Pinjar Road and Joondalup Drive, industrial and commercial area	5	50	45	40
Existing Residential Building West Side (R10-14)	Within 100 m of Pinjar Road Within 100m of commercial area R11 and R12 are located within 100m of industrial area	8	53	48	43
Future Residential Building East Side (R15)	Within 100 m of Pinjar Road and industrial and commercial area	9	54	49	44
Future Residential Building East Side (R16)	Within 450 m of Pinjar Road and Joondalup Drive, industrial and commercial area	5	50	45	40
Existing commercial building (R17-20)	Commercial area	-	60	60	60
Existing adjacent tenants (R21)	Commercial area, indoor	-	60	60	60

As some operations are forecast to occur during night-time periods (Sunday mornings), the night-time assigned levels are considered to be the most stringent assessment criteria.

4 Results and Discussion

4.1 Predicted noise levels due to light vehicle movements

The noise impact contributed by light vehicle movements has been predicted for the nearest receiver to the car parking lots (R12, refer **Figure 3**). Assuming 30 off 30 seconds movements per hour, a reduction of 6 dB is applied to determine the corresponding pseudo-continuous sound power level.

Based on the above, car park related noise emission levels predicted at the nearest commercial receptors are presented in **Table 11**.

Table 11 Predicted car park related noise emission levels

Assessed noise source	Car Park related noise to nearest receiver R12
Light vehicle sound power level (L_{WA}), dB	88
Time correction	-6 dB
Distance attenuation	-42 dB (50 m)
Predicted noise level at the nearest receptor, L_{A10}	40 dB
Complies with EPNR L_{A10} Criteria?	Yes, complies with criteria (refer **Table 1**)

Since the nearest receptor R12 complies with the criteria, other existing receptors were assumed to comply with the criteria as well considering the more attenuation from further distance. Therefore, noise impact from light vehicle movements is expected to be compliant during the operating periods.

4.2 Predicted noise levels due to truck movements in the external driveway

The noise impact contributed by truck movements has been predicted using Strutt, where the nearest receiver to the truck pass-by area (R15, refer **Figure 3**) was assessed. Given the relatively short duration of truck movements in the external driveway, the noise generated is best described by the L_{A1} parameter. Based on the above, the results are displayed in Table 12.

Table 12 Predicted delivery truck noise emission levels

Assessed noise source	Truck movement related noise to nearest receiver R15
Sound power level (L_{WA}), dB	93
Distance attenuation	-45 dB (70m)
Predicted noise level at the nearest receptor, L_{A1}	48 dB
Complies with criteria?	Yes, complies with L_{A1} criteria of 54 dB (refer **Table 1**)

Based on Table 12, truck-based deliveries and loading bay noise is expected to be compliant during the nominated operating periods.

4.3 Predicted noise levels due to operation and mechanical plant noise

Predicted noise levels due to operation and mechanical plant are presented in **Table 13**.

Table 13 Predicted Noise Levels from operation and mechanical plant noise

Location / Receiver	Criteria $L_{A10, night}$(dB)	Predicted L_{A10} (dB)	Comments
Residential Building (R1)	43	26	Complies with criteria
Residential Building (R2)	43	28	
Residential Building (R3)	38	27	
Residential Building (R4)	38	29	
Residential Building (R5)	38	26	
Residential Building (R6)	40	29	
Residential Building (R7)	40	28	
Residential Building (R8)	40	27	
Residential Building (R9)	40	24	
Residential Building (R10)	43	28	
Residential Building (R11)	43	31	
Residential Building (R12)	43	33	
Residential Building (R13)	43	30	
Residential Building (R14)	43	28	
Residential Building (R15)	44	34	

Location / Receiver	Criteria $L_{A10, night}$(dB)	Predicted L_{A10} (dB)	Comments
Residential Building (R16)	40	30	
Commercial Building (R17)	60	27	
Commercial Building (R18)	60	28	
Commercial Building (R19)	60	27	
Commercial Building (R20)	60	25	

The grid contour map of predicted noise level is displayed in **Figure 6.** Based on these predictions, the noise impact due to CCD operation and mechanical plant is expected to be compliant during the operating periods.

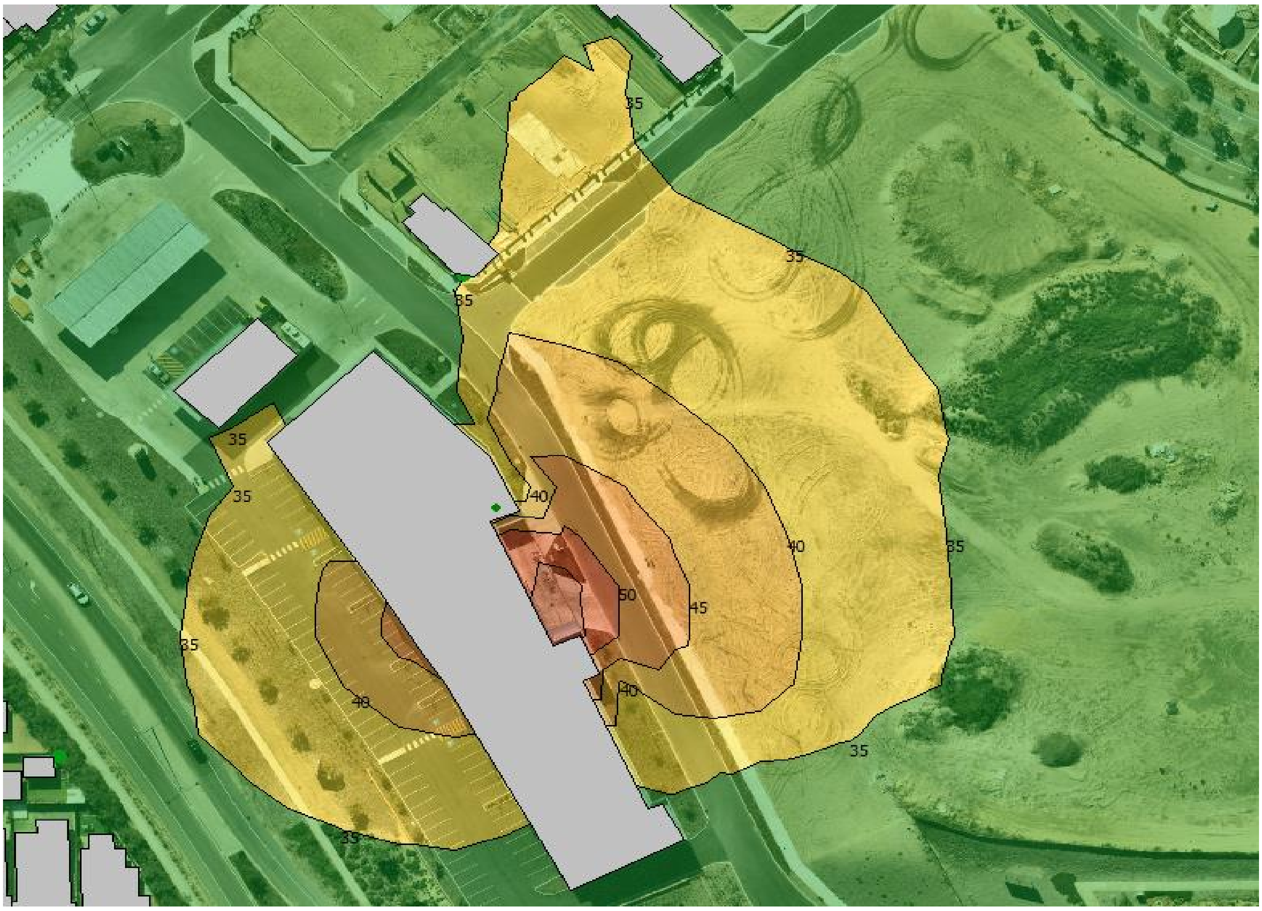


Figure 6 Grid contour of predicted noise level from operation and mechanical plant

4.4 Predicted noise levels of adjacent indoor receiver R21

The noise sensitive receptor at R21 represents an adjacent tenancy next to the CCD within the same building. The potential for noise impact is detailed in **Table 14**.

Table 14 Predicted noise levels at adjacent tenancy

Assessed noise source	Adjacent tenancy R21
Sound power level (L_{WA}), dB	91 dB
Estimated wall D_W	50 to 55 dB (based on **Table 8**)
Indoor measurement adjustment	15 dB
Predicted noise level at the nearest receptor, L_{A10}	51 to 56 dB
Complies with criteria?	Complies with criteria (refer **Table 1**)

4.5 Combined predicted noise levels

The combined predicted noise levels of assessed noise sensitive receptors are displayed in **Table 15**.

Table 15 Predicted overall noise levels of assessed receivers

Location / Receiver	Criteria $L_{A10, night}$(dB)	Predicted noise level (dB)			Predicted noise level L_{A10} (dB) at Adjacent tenant	Comments
		Car parking, L_{A10}	**Truck pass by' L_{A1}**	**Operation and mechanical plant, L_{A10}**		
Residential Building (R1)	43	<40	<38	26	-	Complies with criteria
Residential Building (R2)	43	<40	<38	28	-	
Residential Building (R3)	38	<40	<38	27	-	
Residential Building (R4)	38	<40	<38	29	-	
Residential Building (R5)	38	<40	<38	26	-	
Residential Building (R6)	40	<40	<38	29	-	
Residential Building (R7)	40	<40	<38	28	-	
Residential Building (R8)	40	<40	<38	27	-	
Residential Building (R9)	40	<40	<38	24	-	
Residential Building (R10)	43	<40	<38	28	-	
Residential Building (R11)	43	<40	<38	31	-	
Residential Building (R12)	43	40	<38	33	-	
Residential Building (R13)	43	<40	<38	30	-	
Residential Building (R14)	43	<40	<38	28	-	
Residential Building (R15)	44	<40	38	34	-	
Residential Building (R16)	40	<40	<38	30	-	
Commercial Building (R17)	60	<40	<38	27	-	
Commercial Building (R18)	60	<40	<38	28	-	
Commercial Building (R19)	60	<40	<38	27	-	
Commercial Building (R20)	60	<40	<38	25	-	
Industrial Building (R21)	60	-	-	-	51-56	

The noise criteria are based on the EPNR1997 Night period criteria. The operational noise level tabled above is based the scenario with the roller door being closed.

Based on SLR's predictions, the noise impact of CCD is expected to be compliant during the operating periods.

4.6 Emissions to On-Site Sensitive Receivers – Internal Office Space

This section was included on behalf of TOMRA and isn't to be conditioned by COB. The TOMRA supplied architectural drawings form the basis of the noise reducing treatments with walls being built at the locations shown in **Figure 7.**

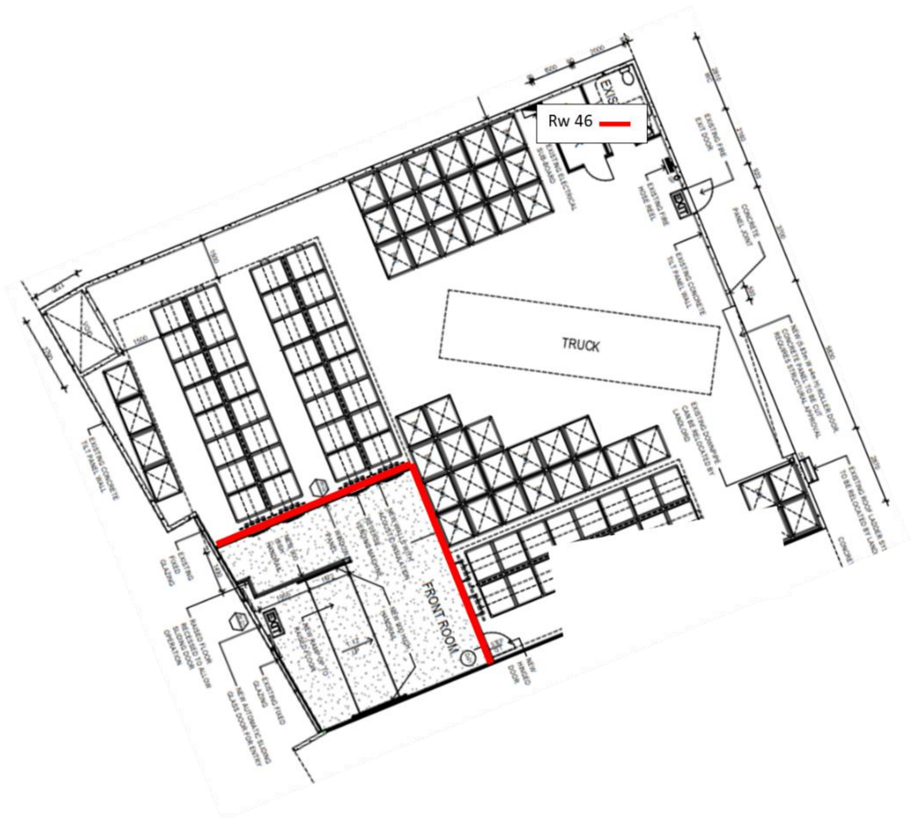


Figure 7 Proposed noise attenuation wall design

As stated in **Table 3**, noise reducing treatment of the front and office rooms will be based on an office-based criteria of L_{Aeq} 40 to 45 dB. The office-based treatment includes the construction of a new acoustically insulated walls for the front room for the customers feeding the reverse vending machines.

The office-based treatment includes the construction of new acoustically insulated walls and ceiling for the Front Room used by customers feeding the RVMs.

Suggested noise reducing treatment options for both the walls and ceiling include:

- Transmission Loss Double Leaf: (1x16mm Plasterboard (Fire)) - 120mm Steel Stud + 100mm Fibreglass 18 kg/m³ - (1x16mm Plasterboard (Fire)).
- Transmission Loss Double Leaf: (1x22mm HDF (yellow-tongue) office-side) - 120mm Steel Stud + 100mm Fibreglass 18 kg/m³ - (1x12.5mm Echostop 6mm square – warehouse side).

5 Conclusion

SLR has been commissioned to undertake an acoustic assessment of the proposed Container Collection Depot (CCD) located at 4/7 Honeybee Parade, Banksia Grove. Noise generated by the proposed development has been considered with regard to *Western Australia Environmental Protection (Noise) Regulations 1997* requirements. The predictions show that the proposed development as currently documented is expected to comply with the relevant criteria at the existing noise sensitive receptors, thus confirming the suitability of the site for such development.

6 Recommendations

The following recommendations are proposed to ensure ongoing compliance with relevant noise criteria during the operation of the CCD as part of a management plan:

1. Staff training includes awareness of the need to control noisy activities, such as equipment and vehicle loading / unloading to maintain compliance with the applicable noise limits.
2. Scheduled truck loading/unloading conducted in the internal loading zone with the roller door in the closed position.
3. Roller door generally to be in the closed position when recycling machinery is operational, preferably via an automatic door system.
4. The operator commits to investigating and responding to any noise complaints received in writing investigated, and if the cause of the complaint is identified the issue should be rectified and then appropriately communicated back to the complainant.

APPENDIX A

Glossary of Acoustic Terminology

1. Sound Level or Noise Level

The terms 'sound' and 'noise' are almost interchangeable, except that 'noise' often refers to unwanted sound.

Sound (or noise) consists of minute fluctuations in atmospheric pressure. The human ear responds to changes in sound pressure over a very wide range with the loudest sound pressure to which the human ear can respond being ten million times greater than the softest. The decibel (abbreviated as dB) scale reduces this ratio to a more manageable size by the use of logarithms.

The symbols SPL, L or LP are commonly used to represent Sound Pressure Level. The symbol LA represents A-weighted Sound Pressure Level. The standard reference unit for Sound Pressure Levels expressed in decibels is 2 x 10^{-5} Pa.

2. 'A' Weighted Sound Pressure Level

The overall level of a sound is usually expressed in terms of dBA, which is measured using a sound level meter with an 'A-weighting' filter. This is an electronic filter having a frequency response corresponding approximately to that of human hearing.

People's hearing is most sensitive to sounds at mid frequencies (500 Hz to 4,000 Hz), and less sensitive at lower and higher frequencies. Different sources having the same dBA level generally sound about equally loud.

A change of 1 dB or 2 dB in the level of a sound is difficult for most people to detect, whilst 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. The table below lists examples of typical noise levels.

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

Other weightings (eg B, C and D) are less commonly used than A-weighting. Sound Levels measured without any weighting are referred to as 'linear', and the units are expressed as dB(lin) or dB.

3. Sound Power Level

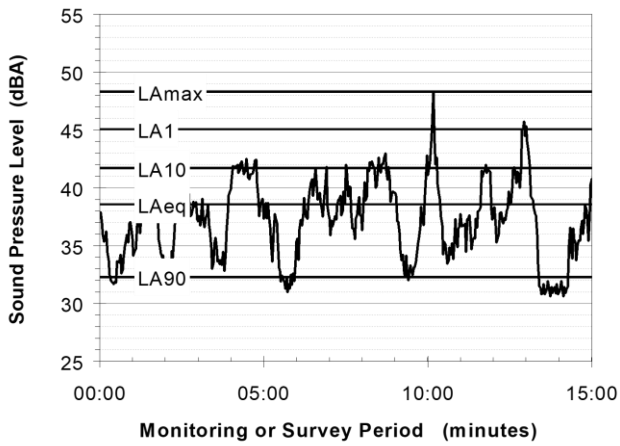
The Sound Power of a source is the rate at which it emits acoustic energy. As with Sound Pressure Levels, Sound Power Levels are expressed in decibel units (dB or dBA), but may be identified by the symbols SWL or LW, or by the reference unit 10^{-12} W.

The relationship between Sound Power and Sound Pressure is similar to the effect of an electric radiator, which is characterised by a power rating but has an effect on the surrounding environment that can be measured in terms of a different parameter, temperature.

4. Statistical Noise Levels

Sounds that vary in level over time, such as road traffic noise and most community noise, are commonly described in terms of the statistical exceedance levels LAN, where LAN is the A-weighted sound pressure level exceeded for N% of a given measurement period. For example, the LA1 is the noise level exceeded for 1% of the time, LA10 the noise exceeded for 10% of the time, and so on.

The following figure presents a hypothetical 15 minute noise survey, illustrating various common statistical indices of interest.



Of particular relevance, are:

LA1 The noise level exceeded for 1% of the 15 minute interval.

LA10 The noise level exceeded for 10% of the 15 minute interval. This is commonly referred to as the average maximum noise level.

LA90 The noise level exceeded for 90% of the sample period. This noise level is described as the average minimum background sound level (in the absence of the source under consideration), or simply the background level.

LAeq The A-weighted equivalent noise level (basically, the average noise level). It is defined as the steady sound level that contains the same amount of acoustical energy as the corresponding time-varying sound.

5. Frequency Analysis

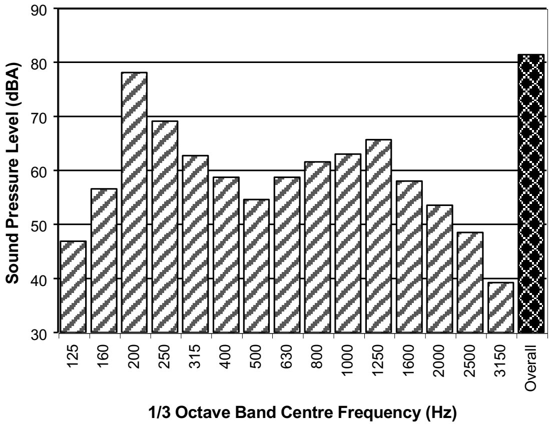
Frequency analysis is the process used to examine the tones (or frequency components) which make up the overall noise or vibration signal.

The units for frequency are Hertz (Hz), which represent the number of cycles per second.

Frequency analysis can be in:

- Octave bands (where the centre frequency and width of each band is double the previous band)
- 1/3 octave bands (three bands in each octave band)
- Narrow band (where the spectrum is divided into 400 or more bands of equal width)

The following figure shows a 1/3 octave band frequency analysis where the noise is dominated by the 200 Hz band. Note that the indicated level of each individual band is less than the overall level, which is the logarithmic sum of the bands.



6. Annoying Noise (Special Audible Characteristics)

A louder noise will generally be more annoying to nearby receivers than a quieter one. However, noise is often also found to be more annoying and result in larger impacts where the following characteristics are apparent:

- **Tonality** - tonal noise contains one or more prominent tones (ie differences in distinct frequency components between adjoining octave or 1/3 octave bands), and is normally regarded as more annoying than 'broad band' noise.
- **Impulsiveness** - an impulsive noise is characterised by one or more short sharp peaks in the time domain, such as occurs during hammering.
- **Intermittency** - intermittent noise varies in level with the change in level being clearly audible. An example would include mechanical plant cycling on and off.
- **Low Frequency Noise** - low frequency noise contains significant energy in the lower frequency bands, which are typically taken to be in the 10 to 160 Hz region.

7. Vibration

Vibration may be defined as cyclic or transient motion. This motion can be measured in terms of its displacement, velocity or acceleration. Most assessments of human response to vibration or the risk of damage to buildings use measurements of vibration velocity. These may be expressed in terms of 'peak' velocity or 'rms' velocity.

The former is the maximum instantaneous velocity, without any averaging, and is sometimes referred to as 'peak particle velocity', or PPV. The latter incorporates 'root mean squared' averaging over some defined time period.

Vibration measurements may be carried out in a single axis or alternatively as triaxial measurements (ie vertical, longitudinal and transverse).

The common units for velocity are millimetres per second (mm/s). As with noise, decibel units can also be used, in which case the reference level should always be stated. A vibration level V, expressed in mm/s can be converted to decibels by the formula 20 log (V/Vo), where Vo is the reference level (10^{-9} m/s). Care is required in this regard, as other reference levels may be used.

8. Human Perception of Vibration

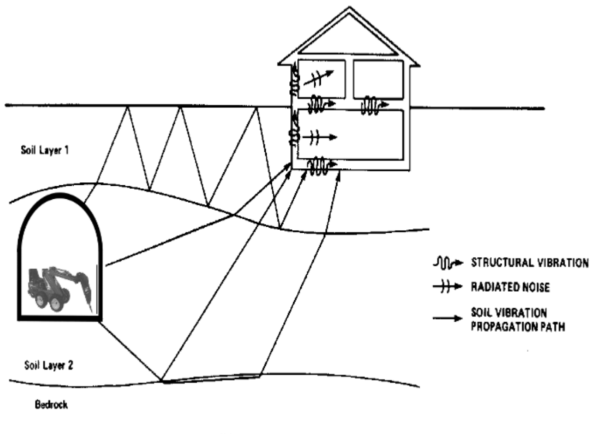
People are able to 'feel' vibration at levels lower than those required to cause even superficial damage to the most susceptible classes of building (even though they may not be disturbed by the motion). An individual's perception of motion or response to vibration depends very strongly on previous experience and expectations, and on other connotations associated with the perceived source of the vibration. For example, the vibration that a person responds to as 'normal' in a car, bus or train is considerably higher than what is perceived as 'normal' in a shop, office or dwelling.

9. Ground-borne Noise, Structure-borne Noise and Regenerated Noise

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

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

The following figure presents an example of the various paths by which vibration and ground-borne noise may be transmitted between a source and receiver for construction activities occurring within a tunnel.



The term 'regenerated noise' is also used in other instances where energy is converted to noise away from the primary source. One example would be a fan blowing air through a discharge grill. The fan is the energy source and primary noise source. Additional noise may be created by the aerodynamic effect of the discharge grill in the airstream. This secondary noise is referred to as regenerated noise.

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