Construction Noise Management Plan

High Noise Locomotive Paper

ETT
ALLIANCE

Epping to Thornleigh Third Track
High Noise Locomotive Paper

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Document Control

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Contents

1 Introduction

The Epping to Thornleigh Third Track Project (ETTT) involves the construction of six kilometres of new and upgraded track within the rail corridor between Epping and Thornleigh Stations on the western side of the existing tracks. The Conditions of Approval required the preparation of a detailed design stage Operational Noise and Vibration Review (ONVR) for the project, to identify noise and vibration impacts and mitigation measures. The ONVR[1] has been approved by the NSW Department of Planning and Environment.

The ONVR for the ETTT project includes the following commitment:

"Measures targeting high noise locomotives are outside the control of the project and would require regulatory changes. ETTT will however prepare a paper documenting the potential benefits of targeting high noise locomotives. This paper will be made publically available, to inform the community and government of the issue and possible benefits."

SLR Consulting Australia Pty Ltd (SLR) have been engaged by the ETTT Alliance to review existing available noise data, to quantify the potential benefit associated with improving the noise performance (or replacing) high noise locomotives. This review considers only diesel freight locomotives.

1.1. Objectives

In NSW, rail infrastructure projects require assessment of noise impacts in accordance with defined guidelines that provide a standardised approach to assessing impacts across all projects. These rail noise guidelines require calculation of the maximum (LAmax) and the energy average (L_{Aeq}) noise level parameters. However, it is recognised that these parameters do not provide a complete picture of the noise impacts which correspond to the public perception of noise. The LAmax and LAeq descriptors do not directly provide information on factors such as:

• The number of particularly noisy events and the times at which they occur

• The characteristics of the noise

• The duration of noisy events (and the duration of respite periods between noisy events)

• Noise that is perceived to be unnecessary

The variability in noise emissions between different classes of locomotives mean that some passby events are louder than others, and some have increased low-frequency content. In a situation where some of the locomotive fleet are noticeably quieter than others, there is a reasonable perception that some locomotives unnecessarily cause greater disturbance than others.

The objective of this study is to describe locomotive noise emissions from different locomotive classes, to identify potential mitigation measures for locomotive noise, and to identify the potential benefits of these measures in terms of both quantifiable and subjective parameters.

1.2. Locomotive Noise Data Sources

For this review, measured freight passby noise data is required that identifies the contribution of the locomotives in isolation from the wagons, and includes identification of the locomotive class and number of locomotives. TfNSW Freight and Regional Development (FRD) developed the Strategic Noise Action Plan to address the impact of noise from rail freight operations. Under SNAP, a key objective is to reduce the noise impact from freight locomotives. In support of this initiative, FRD engaged SLR Consulting to undertake a Freight Locomotive Wayside Noise Survey (FWNS, SLR Report 610.11872-R1 dated 2 September 2013).

The FWNS data collected by SLR in 2012-2013 forms the basis of this analysis. A total of 607 freight passby events were analysed, across five locations around the network. The measurement locations were all tangent (straight) track, and included three locations with steep grades and two relatively level locations. Curved track

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1   Available at http://www.transport.nsw.gov.au/projects-northern-sydney-freight-corridor-program/epping-thornleigh-third-track/current-works

locations were not selected, since curves introduce additional noise issues (particularly for wagons) and the study was focussed on locomotive noise emissions only.

The objective of the FWNS was to improve the understanding of the environmental noise impacts of freight locomotives, the statistical spread of locomotive noise, and the relative noise emissions of different locomotive classes. A further aim was to conduct a subjective noise assessment to distinguish between noise events with similar overall levels but different sound characteristics, in an attempt to identify locomotives that may be perceived to be particularly noisy or annoying.

This review adds to the findings of the FWNS, by examining the data in more detail to determine the numbers of locomotives of each class observed at each location, and to identify the effect of removing or modifying particularly noisy locomotives. It is noted that the 2012-2013 data may not represent current (2015) locomotive usage, as TfNSW works with operators to avoid the use of older locomotives in built-up areas. TfNSW continues to monitor noise from locomotives operating on steep gradients.

1.3. Terminology

Specific acoustic terminology is used within this assessment. An explanation of common acoustic terms is included as **Appendix A.**

The primary noise metrics used to describe rail noise emissions in this report are:

L_{Amax} The "Maximum Noise Level" occurring during a single train passby noise event.

L_{Aeq} The "Equivalent Continuous Noise Level". The L_{Aeq} may be likened to a "noise average" over the duration of an event or a particular time period.

SEL   The "Sound Exposure Level" or "SEL", used to indicate the total acoustic energy of an individual train passby, reflecting both the noise level and duration of the event. The SEL may be used to calculate the L_{Aeq} level, so that changes in the SEL parameter would also be seen in the corresponding L_{Aeq} level.

The subscript "A" in the above indicates that the noise levels are filtered to match normal human hearing characteristics (ie A-weighted). In addition to A-weighted noise levels required to be considered in NSW railway noise guidelines, this report includes C-weighted results. The FWNS found that the low frequency character of some locomotives mean that subjective annoyance to locomotive passbys may be better correlated to the C-weighted maximum noise level than the A-weighted maximum noise level. The A-weighting and C-weighting curves are shown in **Figure 1**.

Figure 1 A-Weighting and C-Weighting Curves
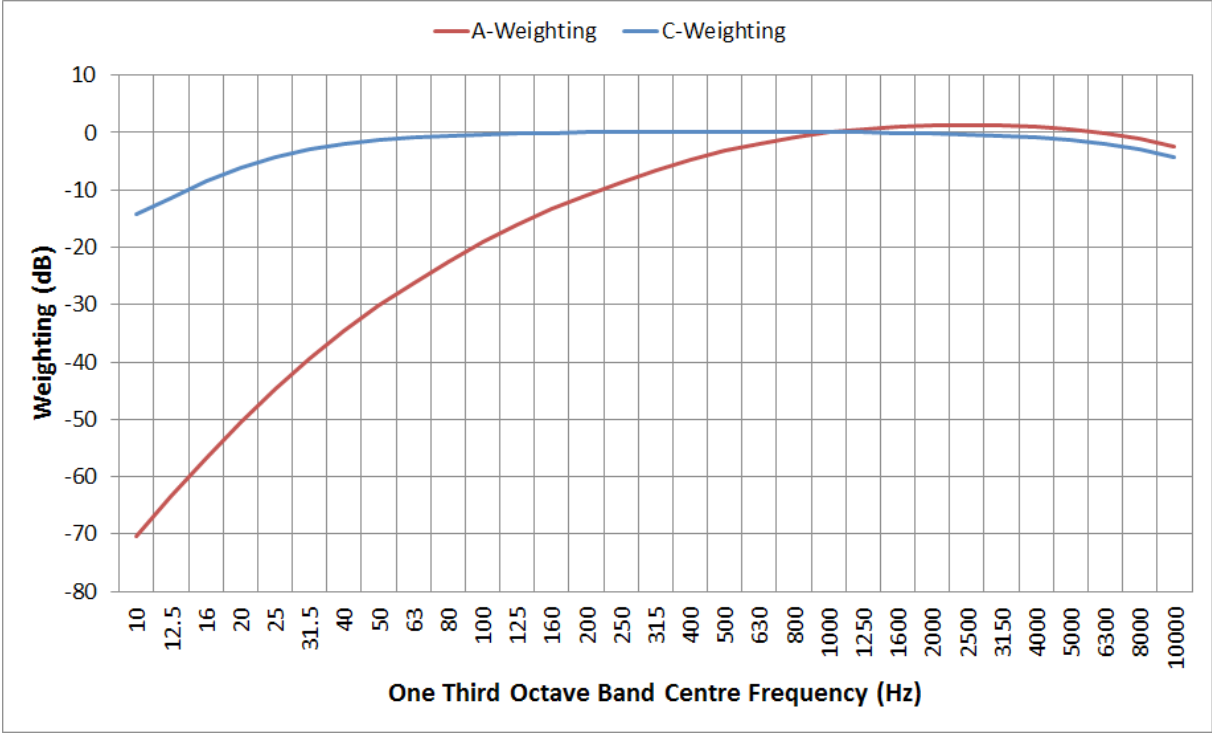
1.4.   Structure of this Study

The approach taken in this study is as follows:

1. Provide background on locomotive classes with approval to operate in NSW

2. Summarise the FWNS findings on noise emissions of individual locomotive classes

3. Identify locomotive classes with the greatest potential for noise mitigation benefits

4. Discuss potential mitigation options

5. Calculate the potential benefit of modifying or eliminating these locomotive classes.

2   Locomotives Approved for Operation in NSW

In NSW, Environment Protection Licences held by Sydney Trains and by the Australian Rail Track Corporation (ATRC) require Environment Protection Authority (EPA) approval, based on noise type tests of locomotives under defined conditions, prior to operation on the NSW rail network. The relevant Environment Protection Licences (EPLs) are:

• Sydney Trains - EPL12208

• Australian Rail Track Corporation Limited – EPL 3142

The locomotive noise limit conditions in the Environment Protection Licences in place at the time of the FWNS are summarised in **Table 1**. Type testing is carried out under controlled conditions (including stationary and defined pass-by speeds) for a single locomotive. In contrast, trackside monitoring involves several locomotives in combination, operating under various speeds and load conditions. For this reason, the EPL noise criteria are not directly applicable to trackside noise measurements. It is emphasised that, where measured levels in service exceed the EPL limits, this does not constitute a breach of an EPL.

Table 1   EPL Noise Criteria - Licence version date: 11 February 2015[2]

Overall Noise Limits	New and upgraded locomotives are required to comply with maximum noise levels of LA_{max} 87 dBA and L_{max} 95 dB, under all service conditions (moving and stationary) defined in AS2377:2002 (unless otherwise approved by the EPA), measured at 15 m from the track centreline and for a maximum speed of 80 km/h. When idling, the maximum noise limit is 70 dBA at 15 m.
Limits for Tonality	All external noise from locomotives must not be tonal. External noise is defined as not being tonal if the sound pressure level in each unweighted (linear) one-third octave band does not exceed the level of the adjacent bands on both sides by: • 5 dB if the centre frequency of the band containing the tone is above 400 Hz; and • 8 dB if the centre frequency of the band containing the tone is between 160 Hz and 400 Hz, inclusively; and • 15 dB if the centre frequency of the band containing the tone is below 160 Hz.
Limits for Low-Frequency Noise	All external noise from locomotives must not exhibit an undue low-frequency component. To comply with this requirement, the unweighted noise levels must not exceed the Aweighted noise levels by more than 15 dB.

The EPL noise criteria apply to new classes or types of locomotive (or locomotives that have been substantially modified since last used on the network). The limits are not applicable to locomotives that operated on the NSW rail network prior to the introduction of the rail systems EPLs.

EPL 12208 and EPL 3142 also identify which locomotive classes are approved to operate on the NSW rail network, the date and path of approval. **Table 2** summarises the approved freight classes by approval class and date.

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2   Note that EPL 3142 and DPL 12208 have both been recently revised. In the license version dated 11 June 2015, the ARTC EPL 3142 has been modified to remove the requirement for moving type tests as defined in AS2377:2002, so that only stationary type tests are required under this license. It also specifies that the 95 dB noise limit is a Z-weighted parameter, rather than unweighted as previously. The Sydney Trains EPL 12208 version dated 21 May 2015 retains the requirement for moving type tests and linear weighting of the 95 dB noise limit.

Table 2   NSW EPL Approved Freight Locomotive Classes – as of 11 February 2015

Approval Path	Date Range	Class
EPA Approved	2002-2012	BK, 1100, SCT, LDP, TT, TT1, WH, GWA, 92, 93, 6000, XRN, GWU, CEY, CF, 14, RL, VL, XR-2/XRB, 3200, BRM, CFCLA CM, 1200, FIE, 5000, 5020,6020, AC, ACA, SSR, CRL, CSR, MP33C, PB, CS, ACB, MRL
Approved Under Previous Legislation	1982-1996	90, NR, 82, 81, BL, G
Introduced prior to approval process	n/a	18, 22, 31, 35, 42,421, 423/1502, 43, 44, 44s, 442, 442s, 45, 45s, 47, 48, 48s, 422, 49, 73, 80, 80s, 600, 830, 900, 930, ALF, AN, B, C, CLF, CLP, D, DC, DL, EL, FL, GL, GM, HL, JL, KL, MM, PL LQ, LZ, S, L, K, T, X, N, Cs

3 Summary of Freight Wayside Noise Survey Results

3.1. FWNS Methodology

Measurements of freight train passby noise were taken at five locations around the Sydney rail network, as shown in **Table 3.** Audio data and sound pressure level time history data was recorded at each location for a minimum of a week. Freight train passby events were identified using an axle detector, supported by inspection of the audio time history. The extracted freight passby events were analysed and matched to particular locomotives.

In **Table 3**, train passbys in both directions at Minto and Kingswood were included in the analysis as passbys on level track. At Cheltenham, Jannali and Faulconbridge the direction of travel determined whether the train was travelling uphill or downhill.

All noise levels in this report are distance corrected to 15 m.

Table 3 FWNS Measurement Locations

Location	Line and Chainage (km)	Measurement Dates	Description
Cheltenham	Main North 26.083	16/11/2012 to 26/11/2012	1 in 50 grade, uphill in Down direction
Jannali	Illawarra 23.678	4/12/2012 to 10/12/2012	1 in 43 grade, uphill in Down Direction
Minto	Main South 48.750	30/1/2013 to 6/2/2013	Relatively level grade
Faulconbridge	Main West 81.578	15/2/2013 to 25/2/2013	1 in 33 grade, uphill in Down Direction
Kingswood	Main West 50.990	26/2/2013 to 5/3/2013	Relatively level grade

3.2. FWNS Parameters

The Ngara noise loggers used to record audio data for the FWNS log the fast response sound pressure level time history in both A-weighted and C-weighted formats (10 times per second), but do not log linear (unweighted) noise levels.

The L_{Cmax} noise levels can generally be considered almost identical to the unweighted L_{max} (linear) noise levels, for the majority of locomotives. Some locomotives may include significant low frequency components below 31.5 Hz. If these very low frequencies dominate the overall levels the use of L_{Cmax} noise levels to approximate the L_{max} (linear) levels has the potential to slightly underestimate the low-frequency impacts.

The EPL noise limits specify linear levels rather than C-weighted levels. With reference to **Section 2**, this parameter difference is an additional reason to note that the FWNS measurement data summarised in this report is not intended to be directly compared to the EPL noise criteria.

3.3. Summary of FWNS Results by Class

The measurement results across all locations were grouped for combined analysis by class in categories (uphill, downhill and level grade). Overall a total of 607 events were included in the analysis. Noise levels were attributed to a particular class of locomotive only when all the locomotives in the consist could be identified, and were

of the same class. 31% of all events were mixed-class locomotive consists, and were therefore not used to determine quantitative noise emissions of discrete locomotive classes.

Table 4 summarises the arithmetic average and maximum L_{Amax} and L_{Cmax} results for each category by class, sorted by the number of events of each class and category included in the analysis.

Classes where only a single passby event was recorded are not shown in Table 4. The most common three locomotive classes (after mixed consists) were the NR class, 82 class and 81 class. Less common locomotive classes often work in mixed consists, and therefore the quantitative noise levels reported here do not include many of the less common classes. It was not possible to obtain quantitative noise emissions for every individual class, due to the low number of passby events for these classes.

Figure 2 is a plot of the A-weighted vs C-weighted maximum noise levels for each event, for each scenario of locomotives travelling downhill, on level grades and travelling uphill. In these plots, events are separated into passbys where all locomotives in the consist are classes with EPA Approval (or approved under previous legislation), and passbys where at least one locomotive in the consist was introduced prior to EPA approval processes. Unidentified passby events are not included in Figure 2.

Table 4 Summary of Locomotive Noise Parameters By Class

Category	Class	Count[1]	Speed[2] (km/h)	LAmax (dBA)		LCmax (dBC)		SEL per Loco[2]	
				Av.[2]	Max.	Av.[2]	Max.	dBA	dBC
Downhill	Mixed	61	48	90	100	95	103	89	94
	NR	36	46	85	97	92	97	86	92
	82	21	47	86	97	92	98	85	91
	81	16	53	90	99	94	103	91	95
	CEY	11	56	88	93	93	98	88	93
	No ID	6	56	90	100	94	100	90	94
	LDP	5	40	84	89	90	95	86	92
	93	3	38	89	90	93	95	91	96
	1100	2	45	84	90	92	95	87	94
	XRN	2	74	90	94	93	95	92	96
	14	2	41	85	92	91	94	87	92

Category	Class	Count[1]	Speed[2] (km/h)	LAmax (dBA)		LCmax (dBC)		SEL per Loco[2]	
				Av.[2]	Max.	Av.[2]	Max.	dBA	dBC
Uphill	Mixed	55	43	93	100	101	111	95	103
	NR	33	41	90	101	98	100	93	100
	82	26	39	89	94	97	104	92	99
	81	11	45	92	95	97	99	96	101
	No ID	9	64	92	96	98	104	94	100
	CEY	9	54	90	96	99	100	93	101
	14	4	36	88	91	96	98	90	98
	LDP	4	39	92	93	97	98	94	99
	93	3	46	91	92	99	100	93	101
	48	3	15	91	91	103	104	95	106
	1100	3	45	90	92	96	99	92	97
	6000	2	71	91	92	98	98	94	101
Level	Unknown (SSFL)3	83	-	86	95	93	101	-	-
	Mixed	72	53	89	100	95	103	90	95
	82	28	73	84	89	89	93	82	87
	44	18	23	84	94	93	102	90	98
	81	10	52	87	97	92	98	89	93
	AN	9	64	90	93	97	105	91	98
	CEY	9	74	88	92	93	95	88	92
	No ID	9	54	88	92	94	99	90	96
	NR	8	50	87	91	94	98	86	92
	442	7	18	83	91	93	101	91	97
	47	7	14	86	91	93	102	90	99
	X	4	59	89	90	96	97	89	95
	14	3	79	89	91	93	95	89	93
Downhill Total	All	169	48	88	100	93	103	88	93
Uphill Total	All	167	43	91	101	99	111	94	101
Level Total	All	271	50	87	100	93	105	88	94
Combined	All	607	47	88	101	95	111	90	96

Note 1:   Events with a single passby per class in each category not shown
Note 2:   Arithmetic average
Note 3:   Locomotive class for passby events on the South Sydney Freight Line (SSFL) were not identified

Figure 2 Locomotive Maximum Noise Levels
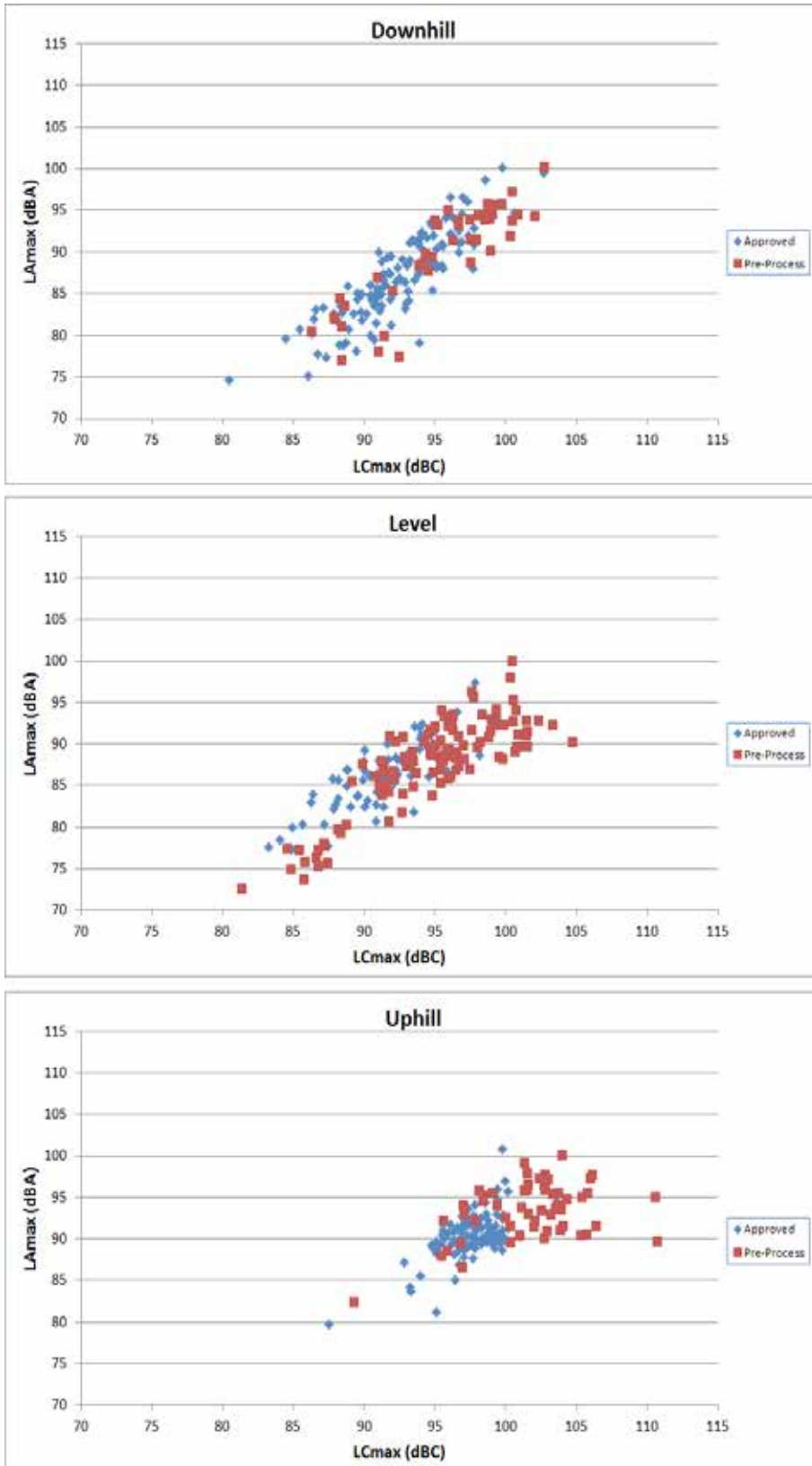
3.4. Discussion of Quantitative Noise Parameters

The overall quantitative data in **Table 4** confirms that locomotive noise impacts are highest when travelling up steep grades. Locomotive noise from trains on level track and travelling downhill were similar to each other. The difference between uphill and downhill/level track is greatest for low frequency noise emissions. C-weighted average noise parameters were 7 to 8 dB higher for uphill trains than downhill/level trains. In comparison, A-weighted average noise parameters were only 34 dB higher for uphill trains.

The following points are made with reference to the most numerous locomotive classes represented in **Table 4**:

- In the downhill direction, the 81 Class was observed to have higher A-weighted and C-weighted noise emissions than the 82 Class and NR class. The averaged L_{Amax} levels from the 81 Class were 4 to 5 dB higher than the NR Class and 82 Class, which had very similar average A-weighted noise levels. There was only 2 dB difference in the averaged L_{Cmax} levels between these three most common classes. Noise emissions from mixed passbys were similar to the noise from the 81 Class when operating downhill.

- At level measurement locations, the 81 Class and NR Class resulted in higher average L_{Amax} and L_{Cmax} noise emissions than the 82 Class, but none of these three common classes resulted in particularly high impacts relative to the other less numerous classes.

- In the uphill direction, the 81 Class was observed to have higher average L_{Amax} levels than the 82 Class and NR Class, with a range of 3 dB across these classes. The average L_{Cmax} levels of these three classes were very similar, with a range of only 1 dB. Mixed passbys uphill had slightly higher average L_{Amax} levels than any of the discrete classes. Average L_{Cmax} levels were highest for the 48 Class (although only a few discrete passbys were measured for this class), followed by mixed consists.

When travelling downhill, many locomotives are braking, and operating in low engine notch settings. In this operating scenario, there is little load placed on the locomotive engine, and exhaust noise emissions are generally lower. Noise from the wheel/rail interface and dynamic braking systems contribute more to the overall noise emissions than engine noise.

On level track, if a locomotive is travelling fast in a low or medium engine notch setting the L_{Amax} level increases with speed, whereas if a locomotive is travelling slower or in high notch settings the speed is less of a factor in the L_{Amax} level. Noise from the wheel/rail interface contributes more to the overall noise emissions than engine noise at higher speeds, and when the train is maintaining speed rather than accelerating or braking.

When travelling uphill, the load on the engine is greatest and locomotives operate in their highest notch settings. Depending on the load being pulled, speeds travelling uphill are often lower than at other locations. When travelling uphill, the maximum noise levels are likely to be generated by the locomotive engine and exhaust, rather than the wheel/rail interface.

The above factors mean that differences in locomotive engine and exhaust noise emissions are most apparent when travelling up steep grades.

Figure 2 is included in an attempt to differentiate the quantitative noise emissions of consists where all locomotives have EPA approval (or were approved under previous legislation) from the emissions of consists that include older locomotives. In **Figure 2**, the spread of L_{Amax} and L_{Cmax} noise emissions on downhill track is similar for both groups. On level track, the spread of L_{Amax} noise emissions is similar between both groups, but the passbys with the highest L_{Cmax} noise emissions include locomotives introduced prior to approval processes. When travelling uphill, the difference between the C-weighted maximum noise levels of these two groups is more marked. The greatest L_{Cmax} noise levels are generated by passbys including older locomotives.

3.5. FWNS High L_{Cmax} Events

It is thought that the low frequency character of some locomotives mean that subjective annoyance to locomotive passbys may be better correlated to the L_{Cmax} than the L_{Amax} parameter. The analysis of quantitative noise parameters from the FWNS indicates that the greatest L_{Cmax} noise levels are generated by passbys including older locomotives, travelling uphill.

Most events that were recorded involving older locomotives were mixed consists. This means it is difficult to identify which individual class or locomotive is responsible for the highest noise impacts except by examining each event in isolation. **Table 5** shows the uphill passby noise events with the highest locomotive LCmax noise levels, in ranked order with comments relating to the particular locomotives and classes in the consist. The passbys shown are all events with identified locomotives and LCmax noise levels of 101 dBC or higher, being representative of the upper 10 dB range of LCmax noise levels (the noisiest 36 of 158, or 23% of all identified uphill passby events).

Table 5 Noisiest Uphill LCmax Noise Level Locomotive Passbys

Date and Time	Location	Locomotives[1]	LCmax (dBC)	Comments on Individual Events and Locomotives
5/12/2012 13:32	Jannali	8216 8237 DL49 8223	111	DL49 appears in 3 uphill events with LCmax≥104 dBC. All locomotives in this consist were observed in other uphill events with LCmax≤97 dBC. It is likely that the high LCmax levels were generated by DL49.
16/2/2013 20:48	Faulconbridge	G513 G514 C503 BRM001	111	G class locomotives were observed in other passbys both with and without high LCmax levels. C class locomotives and the BRM class were not observed travelling uphill in other combinations. The BRM class was introduced in 2012 and has EPA approval. It is likely that the high LCmax levels were generated by C503.
18/2/2013 1:50	Faulconbridge	8139 DL45	106	Locomotive 8139 was not observed uphill except with DL45. DL45 appears in five events on this list and is a potential source of high LCmax levels.
19/2/2013 21:12	Faulconbridge	G513 S317 GM27 C503 G514	106	Variations of this consist appear several times in the data. The GM and S class are understood to be the same production model. G class locomotives were observed in other passbys both with and without high LCmax levels. It is likely that the high LCmax levels were generated by C503, S317 or GM27.
17/2/2013 20:26	Faulconbridge	G513 S317 GM27 C503 G514	106	As above. The following locomotives were observed to be worse than the leading locomotives.
15/2/2013 21:06	Faulconbridge	G513 G514 C503 BRM001	106	Same consist as observed on 16/2/2013. As above, it is likely that the high LCmax levels were generated by C503.
7/12/2012 14:47	Jannali	DL44 8101	106	DL44 appears in 3 uphill events with 8101 where LCmax≥102 dBC. 101 was observed in two other uphill events in other combinations with LCmax≤99 dBC. It is likely that the high LCmax levels were generated by DL44.

Date and Time	Location	Locomotives[1]	LCmax (dBC)	Comments on Individual Events and Locomotives
25/2/2013 3:30	Faulconbridge	8168 DL45 AN6	105	DL45 appears in 5 uphill events with LCmax≥103 dBC. 8168 and AN6 were not observed in other uphill events except with DL45.
20/2/2013 1:49	Faulconbridge	8165 AN6 DL45	105	As above. 8165 was also not observed in other uphill events.
9/12/2012 21:13	Jannali	8243 8217 8237 DL49	104	DL49 appears in 3 uphill events with LCmax≥104 dBC. All other locomotives in this consist were observed in other uphill events with LCmax≤100 dBC. It is likely that the high LCmax levels were generated by DL49.
22/11/2012 11:12	Cheltenham	48S33 48S34 473	104	48S33 and 48S35 appear in several uphill events with LCmax≥103 dBC. 473 was not observed in other uphill events. It is likely that high LCmax levels were generated by the 48S class.
20/2/2013 4:20	Faulconbridge	8133 8126 X47 8174	104	All the locomotives in this consist were observed in other uphill measurements without high LCmax levels. The source of the high LCmax level for this passby is not clear.
7/12/2012 23:06	Jannali	8126 8139 DL45 DL46	104	None of the locomotives in this consist were observed uphill except in passbys with high LCmax levels. Other passbys indicate that he DL class is likely to have high LCmax noise emissions.
11/20/2012 10:08	Cheltenham	48S33 48S34	104	48S33 and 48S35 appear in several uphill events with LCmax≥103 dBC. This is not a mixed consist so noise levels are attributable directly to the 48S class
8/12/2012 19:35	Jannali	8243 8217 8237 DL49	104	Same consist as observed on 9/12/2012. As above, it is likely that the high LCmax levels were generated by DL49.
7/12/2012 21:15	Jannali	8239 8222 8233 8218	104	All the 82 Class locomotives observed in this consist also appeared with lower LCmax noise levels in several other passbys. The reason for the high LCmax level for this passby is not clear.
6/12/2012 1:36	Jannali	8121 DL42	104	This pair of locomotives was observed in three uphill passbys, all with LCmax≥103 dBC. Other passbys indicate that he DL class is likely to have high LCmax noise emissions.

Date and Time	Location	Locomotives[1]	LCmax (dBC)	Comments on Individual Events and Locomotives
16/2/2013 1:49	Faulconbridge	VL360 UNK	103	This passby included one VL class and one unknown locomotive. The source of high LCmax noise levels is unclear
7/12/2012 1:36	Jannali	8121 DL42	103	This pair of locomotives was observed in three uphill passbys, all with LCmax≥103 dBC. Other passbys indicate that he DL class is likely to have high LCmax noise emissions.
20/2/2013 1:12	Faulconbridge	UNK 42203 1440	103	42203 was observed in one other high-noise passby at Cheltenham – there it was observed to have noticeably higher low frequency noise emissions that other locomotives in the consist. Locomotive 1440 was observed uphill on three other occasions without high LCmax noise levels. While the lead locomotive is unknown, it is likely that 42203 has high LCmax noise emissions.
24/11/2012 10:52	Cheltenham	48S33 48S34	103	As above, 48S33 and 48S35 appear in several noisy uphill events. This is not a mixed consist so noise levels are attributable directly to the 48S class
18/2/2013 3:33	Faulconbridge	8145 X50	103	8145 was observed travelling uphill in isolation (without other active locomotives) on two occasions, without high LCmax noise levels. It is therefore likely that X50 was responsible for the high LCmax noise levels for this event.
17/11/2012 13:29	Cheltenham	48S35 48S34	103	As above, 48S33 and 48S35 appear in several noisy uphill events. This is not a mixed consist so noise levels are attributable directly to the 48S class
6/12/2012 11:32	Jannali	DL42 8121	103	This pair of locomotives was observed in three uphill passbys, all with LCmax≥103 dBC. Other passbys indicate that he DL class is likely to have high LCmax noise emissions.
5/12/2012 23:31	Jannali	8126 DL45 8139 AN4	103	DL45 appears in 5 uphill events with LCmax≥103 dBC. The other locomotives were all observed in other events in mixed consists also with high LCmax levels.
18/2/2013 20:46	Faulconbridge	UNK 4911 KL82	102	The identified locomotives were not observed in any other uphill events. The source of high LCmax noise levels is unclear.

Date and Time	Location	Locomotives[1]	LCmax (dBC)	Comments on Individual Events and Locomotives
23/11/2012 22:10	Cheltenham	G540 BL31 48159	102	While G540 was observed in quieter uphill passbys, BL31 and 48159 were not observed in other events. The last locomotive (48159) was noticeably worse than the others in terms of low frequency noise emissions and is likely the source of the high LCmax noise levels.
4/12/2012 14:41	Jannali	DL44 8101	102	This pair shares 3 uphill events with LCmax≥102 dBC. 8101 was observed in two other uphill events in other combinations with lower LCmax levels. It is likely that the high LCmax levels were generated by DL44.
6/12/2012 14:45	Jannali	DL44 8101	102	As above.
20/2/2013 0:10	Faulconbridge	AN4 8151	102	A distinct change in noise character was observed between the two locomotives, with the low frequency attributed to the first locomotive AN4.
20/2/2013 3:03	Faulconbridge	X48 G540	102	While G540 was observed in quieter uphill passbys, X48 was not observed in other events and is likely the source of the high LCmax noise levels.
19/11/2012 11:32	Cheltenham	GM10 GM22 T385 T381	101	This passby was noted as having the greatest subjective noise impacts of any passby, due to the low frequency, throbbing character of the noise. These locomotives were not measured at any other uphill locations - they are understood to be a ballast train used in track construction and maintenance.
25/2/2013 4:25	Faulconbridge	8151 AN11	101	Low frequency noise was more noticeable for the second locomotive AN11. 8151 was observed in another uphill event without high LCmax levels.
17/11/2012 14:59	Cheltenham	1101 RL310 42203	101	42203 was observed to have noticeably higher low frequency noise emissions that other locomotives in the consist. Locomotive 1101 was observed uphill on other occasions without high LCmax noise levels. While RL310 was not observed elsewhere, it is likely that 42203 is the source of the high LCmax.

Date and Time	Location	Locomotives[1]	LCmax (dBC)	Comments on Individual Events and Locomotives
18/2/2013 20:51	Faulconbridge	G513 S317 GM27 C503 G514	101	Variations of this consist appear several times in the data. The GM and S class are understood to be the same production model. G class locomotives were observed in other passbys both with and without high LCmax levels. It is likely that the high LCmax levels were generated by C503, S317 or GM27.
5/12/2012 13:16	Jannali	8239 8211 8231 8258	101	All the 82 Class locomotives observed in this consist also appeared with lower LCmax noise levels in several other passbys.

Note 1: "UNK" refers to an unknown locomotive. Locomotives introduced prior to EPA approval processes are shaded.

3.6. Discussion of High LCmax Events and Subjective Noise Character

There are several locomotives and locomotive classes that appear repeatedly in the list of the noisiest LCmax events in **Table 5.** In some cases, this is because the same locomotives shuttled back and forth at a particular measurement location, and were recorded on multiple occasions. In other cases, the same locomotive was observed at different locations. The locomotive classes identified with potentially high LCmax noise levels are:

• DL Class – several locomotives of this class are thought to contribute high LCmax levels.

• S and GM Classes - the GM and S class are understood to be the same production model. Passbys involving these locomotive classes had some of the highest LCmax levels overall.

• C Class - only one individual example of the C class was observed travelling uphill, but passbys involving this locomotive had some of the highest LCmax levels overall.

• 48/48S Class – this class was observed with high LCmax levels in isolation, as well as in mixed consists.

• 422 Class – locomotive 42203 stood out from others in a mixed consist due to low frequency noise emissions.

• X Class – this class was involved in some passbys with high LCmax levels. The contribution of this class to these passbys was generally not conclusive.

• AN Class - this class was involved in some passbys with high LCmax levels. The contribution of this class to these passbys was generally not conclusive.

In addition to the locomotive classes identified above on the basis of quantitative high LCmax noise levels during passbys uphill, the FWNS also identified several locomotive classes and passby events with notable subjective noise impacts. These subjective impacts were based on the noise character noted while listening to the recordings of each passby. The classes identified in the FWNS as having potentially high subjective noise impacts were:

• 48 Class – this class stood out with a particularly recognisable low-frequency, throbbing noise character.

• 422 Class – potentially high subjective noise impacts, but a limited number of examples were captured in mixed consists.

• 47 Class – also stood out with a particular low-frequency, throbbing noise character

• 44 Class – exhibited high noise levels in isolation as well as in mixed consists

• 442 Class - potentially high noise impacts.

• Train consist GM10 GM22 T385 T381 was observed to have a particularly high subjective impact.

• The AN class locomotives were observed to have a low frequency character where they were observed, even on level tracks.

• DL Class – this class was not observed in isolation to permit an assessment of its individual noise character.

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All the locomotives identified as having notably high LCmax noise levels and subjective noise impacts were introduced to NSW prior to EPA approval processes.

3.7. Locomotive Classes in FWNS data

The FWNS examined passby noise from locomotives as entire consists, with up to five locomotives in each consist. This data has been broken down to identify the number of locomotives of each class that were measured. In this way, it is possible to identify how many times each individual locomotive was recorded at the measurement position, and to identify what proportion of locomotives recorded at each site were introduced prior to EPA approval processes. The breakdown of locomotives recorded is shown in **Table 6**.

Table 6 Locomotive Numbers Recorded in FWNS

Location and Line	Cheltenham Main North	Jannali Illawarra	Minto Main South[2]	Faulconbridge Main West	Kingswood Main West	Combined
Count of Train Passbys1	162	98	175	76	96	607
Count of Identified Locomotives1	432	283	152	246	299	1412
Number of Individual Classes	35	8	17	23	24	44
Number of Individual Locomotives	203	90	39	89	106	336
% Identified Loco Passbys EPA Approved	39%	0%	5%	11%	17%	18%
% Identified Loco Passbys Approved Previously	49%	88%	6%	64%	62%	58%
% Identified Loco Passbys Introduced Pre- Process	11%	12%	89%	21%	18%	23%

Note 1: The measurement duration was not the same at each site. Counts include unidentified consists and locomotives.

Note 2: At Minto, trains travelling on the newly opened SSFL were not identified. Results in *italics* for Minto are therefore not representative of all traffic at this location – only of freight traffic travelling on the non-SSFL tracks.

In total, 44 different locomotive classes and 336 individual locomotives were observed around the network during the survey. 84 of these individual locomotives (around 25%) were introduced to NSW prior to environmental noise approval processes, as shown in **Table 7**.

Table 7   FWNS Locomotives Introduced Prior to Environmental Noise Approval Processes

Class	Individual Locomotives	Count
22	2210	1
31	3101, 3104, 3122	3
44	4458, 4471, 4477, 4488	4
47	4701, 4703, 4716, 4717	4
48/48S	48128, 48139, 48159, 48162, 48203, 48S28, 48S30, 48S33, 48S34, 48S35, 48S33	11
49	4911	1
80	8012, 8049, 8050	3
421	473	1
422	42202, 42203	2
442	44202, 44204, 44206, 44208, 44251	5
600	D602	1
830	852, 869, 872	3
AN	AN1, AN3, AN4, AN6, AN7, AN8, AN9, AN11	8
B	B61, B65	2
C	C503, C510, C511, C513, C514	5
DL	DL38, DL39, DL42, DL44, DL45, DL46, DL49	7
EL	EL51, EL57, EL61, EL63	4
GL	GL102, GL106, GL107, GL109, GL112	5
GM	GM10, GM22, GM27	3
HL	HL203	1
KL	KL81, KL82	2
S	S317	1
T	T381, T385	2
X	X47, X48, X50, X53, X54	5
	Total	84

The locomotives identified in **Table 7** are the locomotives that were observed during the FWNS, rather than a complete list of all locomotives operating in NSW that were introduced to NSW prior to environmental noise approval processes. However, the sample collected gives an indication of the prevalence of the various locomotive classes in service at the time of the FWNS. With reference to the discussion in **Section 3.6**, approximately half of the individual observed pre-approval locomotives were members of classes that have been identified as potentially having high subjective or low-frequency noise emissions. Some of these locomotives have been operating since the 1950s.

4 Potential Benefits of Mitigating High Noise Locomotives

The FWNS provided a summary of overall locomotive noise levels for each of the measurement locations, reproduced in Table 8. In order to identify the potential benefits of targeting high noise locomotives, this data has been re-examined to assess what the change in noise levels would be if passbys containing older locomotives were excluded at all locations.

Table 8 Summary of Locomotive Noise Levels by Location

Location	Direction	Count	Average Speed km/h	50th Percentile Maximum[1]		95th Percentile Maximum[1]		Logarithmic Average SEL per Locomotive[1]	
				L_{Amax}	L_{Cmax}	L_{Amax}	L_{Cmax}	A	C
Cheltenham	Downhill	85	47	85	91	93	97	89	93
	Uphill	77	40	90	98	93	102	94	101
	Overall	162	44	89	95	93	100	92	98
Jannali	Downhill	50	61	90	95	97	100	91	95
	Uphill	48	38	91	99	96	104	96	104
	Overall	98	50	91	98	96	104	94	101
Minto2	Level (Up)	43	45	89	96	94	101	93	99
	Level (Down)	49	32	86	93	92	102	92	100
	SSFL	83	-	86	93	93	98	-	-
	Overall	175	38	87	94	93	101	93	100
Faulconbridge	Downhill	34	32	91	96	98	101	92	97
	Uphill	42	53	92	99	98	106	95	102
	Overall	76	44	92	98	98	106	94	100
Kingswood	Level (Up)	45	74	86	91	94	98	88	92
	Level (Down)	51	64	88	94	93	99	89	94
	Overall	96	68	87	93	94	98	88	93

Note 1: All levels corrected to 15 m from track centreline.
Note 2: Speed information, number of locomotives and locomotive identification not available for SSFL events at Minto.

For the purpose of this exercise, the summary parameters have been re-calculated, considering only train passby events with all locomotives approved to operate in NSW through a noise approval process. This analysis excludes the following:

- All events with one or more locomotives from the list of locomotives introduced to NSW prior to a noise approval process (see Table 2). This means mixed events have been excluded only if one or more the locomotives was introduced prior to the noise approval process.

- All events with one or more unidentified locomotives

While all the locomotive classes identified in the FWNS as having notably high subjective noise impacts were introduced to NSW prior to EPA approval processes, this does not necessarily mean that all locomotives in this group have high noise emissions. However, after removing all pre-approval locomotives and all unidentified locomotives from the data, the remaining set of train passbys are all known to have "approved" noise emissions. It is therefore assumed that the resulting overall noise levels are representative of a situation with only approved locomotives.

Table 9 shows the resulting revised summary of locomotive noise levels by location, along with the difference in noise levels from the case including all locomotive events. Results for Minto have not been calculated, since almost all of the identified events at this location were pre-approval locomotives (in the absence of identified locomotives for train passbys on the SSFL).

Table 9 Summary of Locomotive Noise Levels – Approved Locomotives Only

Location	Direction	50th Percentile Maximum[1]		95th Percentile Maximum[1]		Logarithmic Average SEL per Locomotive[1]	
		L_{Amax}	L_{Cmax}	L_{Amax}	L_{Cmax}	A	C
Cheltenham	Downhill	86 (+1)	91 (0)	92 (-1)	96 (-1)	89 (0)	93 (0)
	Uphill	90 (0)	98 (0)	93 (0)	100 (-2)	93 (-1)	100 (-1)
	Overall	89 (0)	95 (0)	93 (0)	100 (0)	91 (-1)	98 (0)
Jannali	Downhill	88 (-2)	93 (-2)	97 (0)	98 (-2)	91 (0)	94 (-1)
	Uphill	90 (-1)	98 (-1)	96 (0)	101 (-3)	96 (0)	102 (-2)
	Overall	90 (-1)	97 (-1)	97 (+1)	100 (-4)	94 (0)	100 (-1)
Faulcon-bridge	Downhill	88 (-3)	95 (-1)	97 (-1)	98 (-3)	90 (-2)	95 (-2)
	Uphill	90 (-2)	96 (-3)	95 (-3)	99 (-7)	92 (-3)	98 (-4)
	Overall	90 (-2)	96 (-2)	96 (-2)	99 (-7)	91 (-3)	97 (-3)
Kingswood	Level (Up)	86 (0)	90 (-1)	92 (-2)	95 (-3)	86 (-2)	90 (-2)
	Level (Down)	87 (-1)	92 (-2)	92 (-1)	96 (-3)	88 (-1)	92 (-2)
	Overall	86 (-1)	91 (-2)	92 (-2)	95 (-3)	87 (-1)	91 (-2)

Note 1: All levels corrected to 15 m from track centreline. Brackets indicate change with only approved locomotives.

Table 9 gives an indication of the potential benefits of targeting pre-approval locomotives, in terms of overall locomotive noise emissions. The FWNS data has been collected trackside, with several locomotives in combination, operating under various speeds and load conditions, with corrections applied for measurement distance. As discussed in Sections 2 and 3.2, these noise levels therefore cannot be directly compared with the EPL noise criteria which apply to a controlled type test of a single locomotive. However, in a general sense, the summary of noise levels from approved locomotives indicates that it is likely that the noise emissions of some approved locomotives are in excess of the EPL noise criteria. This issue is discussed further in Section 5.

In practice, the overall rail noise at any individual location is the sum of locomotive noise, wagon noise and often passenger train noise. At locations where locomotive noise dominates the overall levels for a particular parameter, then the benefits shown in Table 9 might be achieved if all locomotives are replaced or upgraded to EPA standards. However, at locations where wagon noise or passenger noise dominates, the benefit might be less than shown in Table 9.

At locations where A-weighted maximum noise levels are dominated by locomotives, a reduction of between 0 dB and 3 dB might be achieved in the 95th percentile LAmax parameter by targeting high noise locomotives. This situation is most likely to occur at locations where trains travel at relatively low speeds, so noise from the wheel rail interface is quieter than locomotive engine/exhaust noise.

At locations where A-weighted average noise levels are dominated by locomotives, a reduction of between 0 dB and 3 dB might be achieved in the L_{Aeq} parameter by targeting high noise locomotives. However, in most situations noise from wagons (or from passenger trains) also contributes to the L_{Aeq} noise levels, so a reduction in overall L_{Aeq} noise levels would only be realised at low speed locations.

The low frequency content of locomotive noise means that the benefits of targeting high noise locomotives can be more readily seen in the C-weighted noise parameters. At Faulconbridge, a reduction of 7 dB would be expected in the 95th percentile L_{Cmax} parameter by targeting high noise locomotives. The largest benefits would be seen at locations with steep uphill grades.

Targeting high noise locomotives would also have subjective benefits, by reducing the number of particularly noisy events and by reducing noise that is perceived as unnecessary, particularly at night.

5   Potential Mitigation Measures

The FWNS has confirmed that locomotives subjectively rated as noisy include older locomotives. The low frequency character of some locomotives mean that subjective annoyance to locomotive passbys may be better correlated to the LC_{max} than the LA_{max} parameter. This means that as additional locomotives are added to the fleet over time, the proportion of locomotives subjectively rated as noisy will decrease through dilution. This section describes additional mitigation measures and regulatory factors with the potential to reduce the locomotive fleet noise emissions over time.

5.1.   EPA Review of Regulation of Railway Systems Activities

The NSW EPA acknowledges in their 2014 position paper *Review of regulation of 'railway systems activities' under the Protection of the Environment Operations Act 1997* (2014), the current regulatory framework has limitations:

"*It was presumed that locomotives would require a major overhaul every 8–10 years, and therefore every locomotive operating in NSW would have been substantially modified and assessed against specified noise criteria within a decade. However, this has not been the case, either because many locomotives have not been 'substantially modified' (as defined in the EPLs) when overhauled or the EPA/railway system operator has not been notified when rolling stock operators have substantially modified locomotives.*"

The EPA position paper notes that the current approach to licensing places primary responsibility for environmental performance on network operators, and does not make rolling stock operators directly responsible for rolling stock noise emissions. To address this issue, the EPA is proposing that current regulations be amended so that both railway systems operators and rolling stock operators require an EPL. This change would enable a mechanism for specific noise issues relating to rolling stock to be addressed through EPLs, for example by introducing individual conditions or Pollution Reduction Programs (PRPs) to a rolling stock operator's license.

5.2.   Controlled Locomotive Noise Testing

The FWNS identified 24 classes of locomotives that were operational in NSW during the survey and that have not been required to undergo noise testing or to meet any particular noise standard. Several of these classes were identified as having potentially annoying low frequency noise characteristics.

The FWNS utilised measurements of trackside noise during normal operations. While this approach was required for the purposes of the FWNS, it is noted that trackside monitoring does not take place under controlled conditions. Train passbys involve several locomotives in combination (often of different classes), followed by wagons, and operating under various speeds and load conditions. In comparison, noise type testing under controlled conditions provides information on locomotive noise emissions in isolation, under specific operational conditions. Test results for different locomotives or classes can be directly compared, as each has been measured under comparable conditions.

Noise type testing under controlled conditions of locomotives that were introduced to NSW prior to the introduction of EPA noise approval processes would quantify the noise emissions of each class or individual locomotive, identify conclusively which locomotives have the highest noise emissions, and may identify options for additional mitigation measures such as modifications to exhaust systems. Controlled noise type testing would enable ranking of locomotive noise emissions, and hence prioritisation of the mitigation measures described in the following sections.

In addition to controlled noise type testing of pre-approval locomotives, a program of controlled type tests of approved locomotives would identify whether noise emissions are maintained within approved levels. At present, after a locomotive is approved to operate in NSW there is no requirement for regular noise emission testing or to maintain locomotive noise emissions at the approved levels.

Procedures for undertaking locomotive noise type testing are contained in the existing rail systems EPLs, and in Australian Standard AS2377-2002 *Acoustics - Methods for the measurement of railbound vehicle noise.*

5.3.   Modifications to Reduce Noise Emissions

Each class of locomotive is different, and there is no single solution or modification that can be implemented to reduce noise emissions from all locomotives. However, there may be opportunities to reduce the noise emissions from some of the older locomotive classes. As an example, modifications to the exhaust system to reduce low frequency noise were successfully implemented for the 3200 class locomotive (rebadged from the 2800 class).[4]

The potential for modifications to provide a noise benefit depend on the specific design of each locomotive. The existing muffler size, design, and tuning are factors that determine whether noise emissions can feasibly be reduced.

5.4.   Replacement of Noisy Locomotives

Since freight services are supplied by different operators, ownership and availability of quieter locomotives to enable replacement of noisier locomotives is likely to be an issue for some operators. If this option cannot be achieved from within the existing fleet of locomotives, quieter locomotives could be achieved by upgrading or replacing part of the locomotive fleet over time.

5.5.   Operational Restrictions

The introduction of operational restrictions would provide incentives for locomotive operators to modify or upgrade their fleet. Examples of operational restrictions include differential track charge incentives (with higher track access charges for noisier locomotives), or limiting track access times (for example to prevent noisy locomotives operating in metropolitan areas at night).

Both of these options would likely result in a reduction in the number of high noise events, and would provide benefits in terms of a reduction in both quantitative noise levels and subjective noise levels.

Operational restrictions need careful consideration to ensure that they do not result in a modal shift to more freight being transported by trucks on roads. Transporting freight by truck could have greater noise impacts on the community than transporting freight by rail.

5.6.   Implementation of Mitigation Measures

Once regulatory amendments are in place to require rolling stock operators to hold EPLs, the mitigation options described above could be implemented through EPL PRPs, specific to each rolling stock operator. The EPA position paper notes that rolling stock operators include state-owned and private corporations, and range from small operators controlling less than ten locomotives, to large corporations with several hundred locomotives.

Implementation of any of these mitigation measures would need to take place in stages, over a period of time. Rolling stock operators would need to be able to plan and manage the costs of implementation of mitigation over several years.

6 Summary

A review of existing available locomotive noise data has been undertaken, with the objective of quantifying the potential noise benefit associated with improving the noise performance (or replacing) high noise locomotives. The data reviewed was collected during a 2012-2013 survey of freight wayside noise, instigated by TfNSW Freight and Regional Development as part of their Strategic Noise Action Plan to address the impact of noise from rail freight operations.

The freight wayside noise survey involved noise measurements for a minimum of a week at five locations distributed around the network. In total, 44 different locomotive classes and 337 individual locomotives were observed around the network during the survey. The survey identified a number of locomotive classes with notable subjective noise impacts, and locomotives with noise characteristics such as low frequency components that have the potential to be more annoying to residents near freight lines than other locomotives.

All the locomotives identified as having notably high LC_{max} levels or subjective noise impacts were introduced to NSW prior to EPA approval processes. Some have been operating since the 1950s.

While not all locomotives operating in NSW would have been observed during the survey, the sample collected gives an indication of the prevalence of the various locomotive classes in service at the time. Around 25% of the individual locomotives observed during the survey were introduced to NSW prior to environmental noise approval processes. Of these, approximately half were members of classes that were identified as potentially having high subjective or low-frequency noise emissions.

6.1. Potential Noise Benefits

At locations where A-weighted maximum noise levels are dominated by locomotives, a reduction of between 0 dB and 3 dB might be achieved in the 95th percentile LA_{max} parameter by targeting high noise locomotives. This situation is most likely to occur at locations where trains travel at relatively low speeds, for example up or down steep grades, so noise from the wheel rail interface is quieter than locomotive engine/exhaust noise.

At locations where A-weighted average noise levels are dominated by locomotives, a reduction of between 0 dB and 3 dB might be achieved in the LA_{eq} parameter by targeting high noise locomotives. However, in most situations noise from wagons (or from passenger trains) also contributes to the LA_{eq} noise levels, so a reduction in overall LA_{eq} noise levels would only be realised at low speed locations.

The low frequency content of locomotive noise means that the benefits of targeting high noise locomotives can be more readily seen in the C-weighted noise parameters than in A-weighted parameters. For locomotives, C-weighted maximum noise levels are thought to correlated better with annoyance than A-weighted parameters. At locations with steep uphill grades, a reduction of up to 7 dB might be expected in the 95th percentile LC_{max} parameter by targeting high noise locomotives.

Targeting high noise locomotives would also have subjective benefits, by reducing the number of particularly noisy events (particularly at night-time) and by reducing noise that is perceived as unnecessary, since quieter alternatives to high noise locomotives are available.

6.2. Mitigation Measures

The EPA is proposing to amend existing regulations to enable a mechanism for specific noise issues relating to rolling stock to be addressed through EPLs. Once regulatory amendments are in place, mitigation options such as locomotive noise testing, modifications, operational restrictions or phasing out of noisy locomotives could be implemented. Implementation of any of these mitigation measures would need to take place in stages, over a period of time.

Appendix A - ACOUSTIC TERMINOLOGY

1. Sound Level or Noise Level

The terms "sound" and "noise" are almost interchangeable, except that in common usage "noise" is often used to refer to unwanted sound.

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

The symbols SPL, L or 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 2×10^{-5} Pa.

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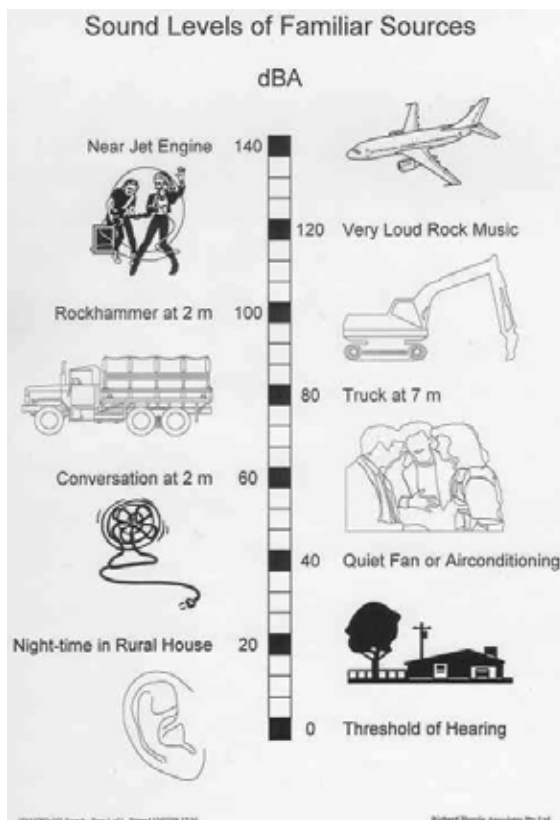
The overall level of a sound is usually expressed in terms of dBA, which is measured using a sound level meter with an "A-weighting" filter. This is an electronic filter having a frequency response corresponding approximately to that of human hearing.

People's hearing is most sensitive to sounds at mid frequencies (500 Hz to 4000 Hz), and less sensitive at lower and higher frequencies. Thus, the level of a sound in dBA is a good measure of the loudness of that sound. Different sources having the same dBA level generally sound about equally loud.

A change of 1 dBA or 2 dBA in the level of a sound is difficult for most people to detect, whilst a 3 dBA to 5 dBA change corresponds to a small but noticeable change in loudness. A 10 dBA change corresponds to an approximate doubling or halving in loudness. The figure below lists examples of typical noise levels

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 dBZ.

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 may be likened to 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, LA[10] 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.
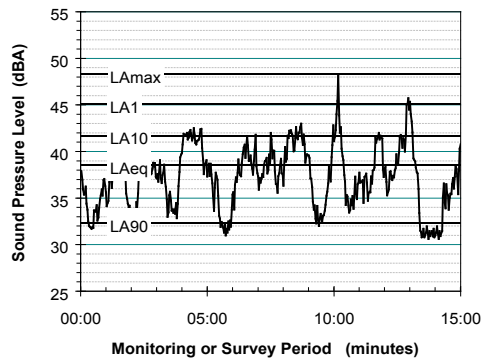
Of particular relevance, are:

$L_{Amax \; (Max \; LpA)}$ The maximum noise level during the 15 minute interval

L_{A1} The noise level exceeded for 1% of the 15 minute interval.

L_{A10} The noise level exceed for 10% of the 15 minute interval. This is commonly referred to as the average maximum noise level.

L_{A90} 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.

L_{Aeq} 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.

When dealing with numerous days of statistical noise data, it is sometimes necessary to define the typical noise levels at a given monitoring location for a particular time of day. A standardised method is available for determining these representative levels.

This method produces a level representing the "repeatable minimum" L_{A90} noise level over the daytime and night-time measurement periods, as required by the EPA. In addition the method produces mean or "average" levels representative of the other descriptors (L_{Aeq}, L_{A10}, etc).

5.   Tonality

Tonal noise contains one or more prominent tones (ie distinct frequency components), and is normally regarded as more offensive than "broad band" noise.

6.   Impulsiveness

An impulsive noise is characterised by one or more short sharp peaks in the time domain, such as occurs during hammering.

7.   Frequency Analysis

Frequency analysis is the process used to examine the tones (or frequency components) which make up the overall noise or vibration signal. This analysis was traditionally carried out using analogue electronic filters, but is now normally carried out using Fast Fourier Transform (FFT) analysers.

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 (3 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.
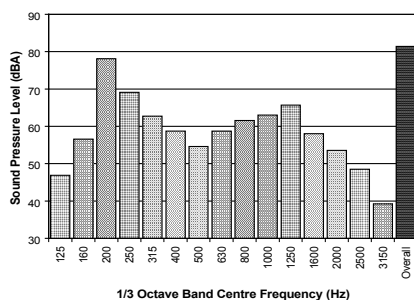
8.   Vibration

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. Where triaxial measurements are used, the axes are commonly designated vertical, longitudinal (aligned toward the source) and transverse.

The common units for velocity are millimetres per second (mm/s). As with noise, decibel units can also be used, in which case the reference level should always be stated. 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 by some organizations.

9. 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.

10. Over-Pressure

The term "over-pressure" is used to describe the air pressure pulse emitted during blasting or similar events. The peak level of an event is normally measured using a microphone in the same manner as linear noise (ie unweighted), at frequencies both in and below the audible range.

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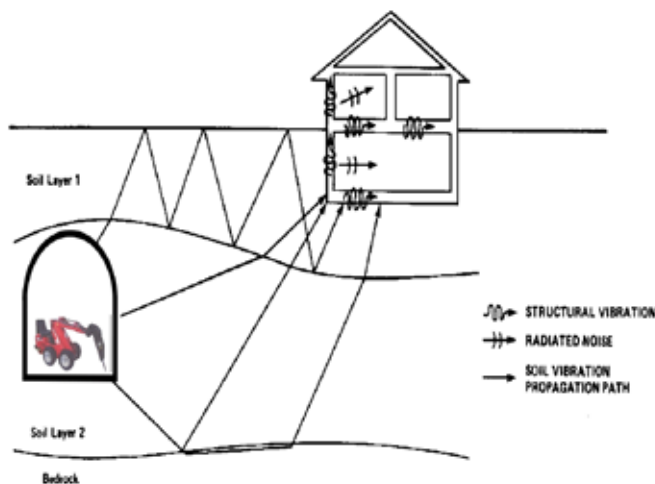
The term "regenerated noise" is also used in other instances where energy is converted to noise away from the primary source. One example would be a fan blowing air through a discharge grill. The fan is the energy source and primary noise source. Additional noise may be created by the aerodynamic effect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