THE GENERATION AND PROPAGATION OF NOISE FROM LARGE COAL MINES, AND HOW IT IS MANAGED IN NSW

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Abstract

Regulating noise impacts from large coal mines is difficult, particularly given the potential topographical and meteorological variations that can occur over setbacks of up to 5 km between mine sites and potentially impacted receivers. In NSW, the *Industrial Noise Guideline* is used to determine noise criteria for sensitive noise receivers that may be impacted by mine noise (such as residences). In many instances, this results in noise criteria being established at levels as low as $L_{eq(15\ minute)}$ = 35 dB(A). Exceedance of this criterion may be negotiated by agreement, but exceedances of more than 5 dB may require the mine to offer property acquisition.

Despite having some of the most stringent noise criteria in the world, regulators still receive a high number of complaints from residents surrounding mine sites. This paper examines the generation and propagation of mine noise, methods used to manage to project noise objectives (including reactive and predictive measures), and the regulatory regime that underpins these objectives.

1. Background to the Mining Industry

NSW is home to 56 coal mines [1] including some of the largest open-cut coal mines in the world. Production from these mines varies from around 2 Mtpa up to 30 Mtpa. In 2012-13, NSW produced 196 Mt of coal, 136 Mt of which was exported, accounting for 31% of all merchandise leaving NSW. During this period Australia exported 335 Mt of coal, which is 30% of the world's exports [1], [2]. Mining development includes not only new mines but is also represented by the expansion of existing mines. In some circumstances, the development and expansion of villages and towns over time has resulted in residences encroaching on existing mines (some of which are over 120 years old). In other circumstances, new mines have been or are proposed to be established in 'greenfield areas', rural land that has traditionally been home to agricultural practices with little or no heavy industry.

Because of the way coal seams often outcrop, it is common for multiple mines to operate in close proximity to one another, sometimes within a single mine lease. By their nature, underground mining methods cause less noise disturbance than do open cut mines as most noise sources are contained underground. However, underground mining is not always economic.

The aim of this paper is to identify the challenges faced in the management of mine noise in NSW and to describe the approaches taken in the management and demonstration of compliance.

2. Regulatory Environment in NSW

In NSW there are two authorities which have a regulatory role over noise generated on mine sites. The first is the Environment Protection Authority (EPA), which regulates 'scheduled activities' specified in Schedule 1 of the *Protection of the Environment Operations Act 1997* (POEO Act). Under the POEO Act, large scale extractive industries are required to hold an Environment Protection Licence (EPL) which usually contains noise criteria that the mine is expected to adhere to. Current legislation requires the noise criteria in an EPL to be consistent with development consents or approvals issued by the Minister for Planning (or delegate). In practice, criteria are jointly developed by the NSW Department of Planning and Environment (DPE) and the EPA, before being recommended to the Minister for Planning. However, the EPA may alter the criteria following the first review date of the EPL (usually after 3 years) or impose a Pollution Reduction Program (PRP) on the mine.

The second authority is the DPE who regulates development consents or approvals (for the purposes of this paper, collectively referred to as 'development approvals') granted by the Minister for Planning. DPE administers the *Environmental Planning and Assessment Act 1979* (EP&A Act). Conditions attached to development approvals can only be changed by way of a modification, which in turn can only be instigated by the owner of the development approval. In practice, this only occurs when the mine requests changes to its conditions of approval such as when seeking to install major new facilities or changes to operational hours or approved throughput.

As a consequence, DPE must exercise caution in establishing noise criteria in development approval conditions due to the inability to subsequently alter them easily. Therefore, where it is likely that there will be technological or procedural changes over time, DPE will often recommend that these requirements are detailed in a Noise Management Plan (NMP). Unlike conditions of approval, NMPs can be changed more easily over time to reflect evolving best practice.

2.1 Considerations when Developing Criteria

While certain noise-generating activities on a mine site may be covered by guidelines with specific noise criteria (such as construction or rail), operational activities are generally assessed with regard to the *NSW Industrial Noise Guideline* (ING) [3]. The ING is a revision of the previous *NSW Industrial Noise Policy* which has recently been released in a draft form for public comment. For the purposes of this paper, any references to the ING include any successor document and the Government's objectives for noise which are to set, where possible, noise levels that will protect a nominated percentage (generally 90%) of the population from being 'highly annoyed' for most of the time (i.e. 90%). Under the ING, industrial noise is managed by using the more stringent of the following two approaches:

- Amenity Criteria – establishes acceptable noise levels for particular land uses; and
- Intrusive Criteria – developed to contain the level of noise relative to the background.

Table 1 identifies the acceptable and recommended noise levels that have been established for particular land uses. This table is a reproduction of Table 2.1 in the ING. Amenity criteria are generally consistent with results found in dose/response studies such as those undertaken by Mediema and Vos [4] and Janssen et al [5].

Table 1. Amenity noise criteria (reproduced from the draft *Industrial Noise Guideline*, 2015)

Noise Amenity Area	Time of Day	Recommended L_{eq}. Noise Level dB(A)	
		Acceptable	Recommended Maximum
Rural	Day	50	55
	Evening	45	50
	Night	40	45
Suburban	Day	55	60
	Evening	45	50
	Night	40	45
Urban	Day	60	65
	Evening	50	55
	Night	45	50
Industrial Interface – for existing situations only – all periods		+ 5	+ 5

To control the emergence of new noise sources in otherwise quiet environments, the ING also seeks to restrict individual industrial premises from either generating an L_{eq} level of more than 5 dB above the existing L_{90} level, or exceeding the minimum intrusiveness criterion of $L_{eq(15\ minute)}$ 35 dB(A) (whichever is the greater).

In practice, most mines in NSW are controlled by noise objectives based on the intrusive noise criteria (due to the low background noise levels in these areas). In general, the noise criteria for these mines are around 35 – 38 dB(A) during the night, and 35 – 40 dB(A) during the day.

2.2 Meteorological Conditions under which Noise Criteria Applies

In most development approvals, noise criteria only apply during typical meteorological conditions which are generally wind speeds of up to 3 m/s, Pasquill Stability Class A to E, or Pasquill Stability Class F (strong temperature inversions) with or without source-to-receiver drainage flows of up to 2 m/s. Under non-typical conditions that result in extreme noise enhancement such as G Class inversions, an exemption for noise limits may apply.

3. Mine Noise Generation and Impact Zone

To understand the methodologies used in managing mine noise impacts, there needs to be some understanding of the key aspects of how this noise is generated and experienced.

3.1 The Noise Receivers

Sensitive receivers within the noise catchment of an open-cut mine may range from a few isolated homesteads on large acreages, to one or more villages with anywhere between 10 to 100 dwellings located on smaller allotments.

3.2 The Noise Generators

Large open cut coal mines may consist of one or more pits accommodating a range of activities operating at the same time. The range of plant and equipment used on these sites are generally consistent across most mines and vary only by way of quantity. A typical mine site will have scrapers to remove topsoil, excavators or drag lines to remove coal and overburden, trucks for haulage, a coal preparation plant with associated conveyor systems and rail infrastructure including a rail spur coming from a main line, and train loading facilities. As with everything in mining, this equipment is big and in standard form, loud.

Tables 2 and 3 give some general indication of the sound power levels (L_W) of equipment used on open-cut mine sites.

Table 2. Typical Fixed Plant Sound Power Levels.

Description	No, length or Area	L_W L_{eq} dB(A)	Controlling Frequency Bands
Coal Washery	1 x 2000m^2	114 - 125	16 - 63
Crushing Plant	1 x 600m^2	104 - 118	16 - 125
Transfer Conveyors	Up to 3 km	102/100m	63 - 500
Total Typical Fixed Plant		**127 - 130**	

Table 3. Typical Mobile Plant and Equipment Sound Power Levels.

Description	No, length or Area	L_W L_{eq} dB(A)	Controlling Frequency Bands
Tracked Dozers	3 - 10	114 - 125	63 - 1000
Front End Loader	2 - 4	110 - 125	63 - 1000
Reject/Product truck uphill	Up to 40	116 - 125	63 - 500
Excavator/Shovel	2 - 6	116 - 125	63 - 500
Total Typical Mobile Plant		**130 - 138**	

In basic terms, open-cut mines are big industrial juggernauts with footprints that can cover 5 km^2 or more. From a distance, these sites and the activities undertaken there collectively appear as a single large noise source with a L_W of around 125 – 140 dB(A).

4. Factors that Affect the Level and Character of Noise Experienced at Receivers

Besides the usual factors that attenuate noise propagating from source to receiver (such as hemispherical spreading, ground absorption, topographical shielding and barriers etc), there are other factors which affect the level and duration of mine noise once the separation between mines and receivers exceeds a distance of around 2 km. By far the most important of these is meteorology.

4.1 Meteorology

While mines generally operate the same way 24h/7 days a week, noise levels at remote sensitive receivers can vary considerably as a consequence of changing meteorological conditions. Although meteorology cannot alter the amount of acoustic energy being generated on a mine site, it can focus or concentrate acoustic energy in a particular direction. As a consequence, enhancement of noise in one direction results in an equivalent reduction in another direction. On this basis, the critical issue for the management of mine noise is how it is addressed during periods of noise enhancing meteorology. Certain meteorological conditions may increase noise levels by focusing sound-wave propagation paths at a single point. These include conditions where there is a positive wind speed gradient in the source-to-receiver direction, as well as when there are temperature inversions. These meteorological effects typically increase noise levels by 3 to 10 dB at receivers. However, extreme conditions have been known to increase noise levels by much more, resulting in significant noise impacts on residents living in areas prone to these effects.

The coal fields around the Hunter Valley and Gunnedah basin in NSW are particularly prone to strong temperature inversions as indicated by the presence of Pasquill stability classes of F and G. These temperature inversions are most commonly caused by radiative cooling of the ground at night, leading to the cooling of the air interface and associated cold air pooling. This is especially prevalent on cloudless winter nights with little wind. In assessing noise impacts, criteria have been developed to apply under weather conditions that would be expected to occur at a particular site for a significant period of time including conditions of calm, wind and temperature inversions. Assessment of impacts is usually confined to the night period (10pm to 7am), as this is the time likely to have the greatest impact - that is, when temperature inversions usually occur, ambient noise levels are low and disturbance to sleep is possible.

A mining company will often acquire land within 3 km surrounding an open-cut mine site to create a noise buffer. These buffers are generally very effective, particularly under neutral meteorological conditions. However, under adverse meteorology, topographic shielding and buffer zones can be largely rendered ineffective.

4.1.1 Wind effects

The direction, strength and shear gradient of wind can substantially affect the propagation of noise. For downwind conditions, where wind is moving from source-to-receiver, the wind gradient will bend sound waves toward the ground, focusing acoustic energy on downwind receivers as demonstrated in Figure 1. Conversely, upwind conditions will bend sound waves upwards, directing noise into the sky and reducing ground level noise. The level of these fluctuations will vary with distance from the source, however may be up to 40 dB [6].

Increasing wind speed does however also increase ambient noise levels (background noise), particularly that of foliage. It can also result in highly fluctuating pressure levels, which affects the same mechanisms that allow us to perceive sound. In most cases, an increase in wind speeds will result in a corresponding increase in masking effect. With reference to the Beaufort Scale, at a Force 2 - Light Breeze (1.3 – 3.1 m/s), leaves will begin to rustle whilst at a Force 3 - Gentle Breeze (3.1 – 5.4

m/s), leaves and small twigs will be in constant motion. It can therefore be assumed that at Force 3 or beyond it would necessary to assess the impact of wind on ambient noise levels because it can generate extraneous noise.

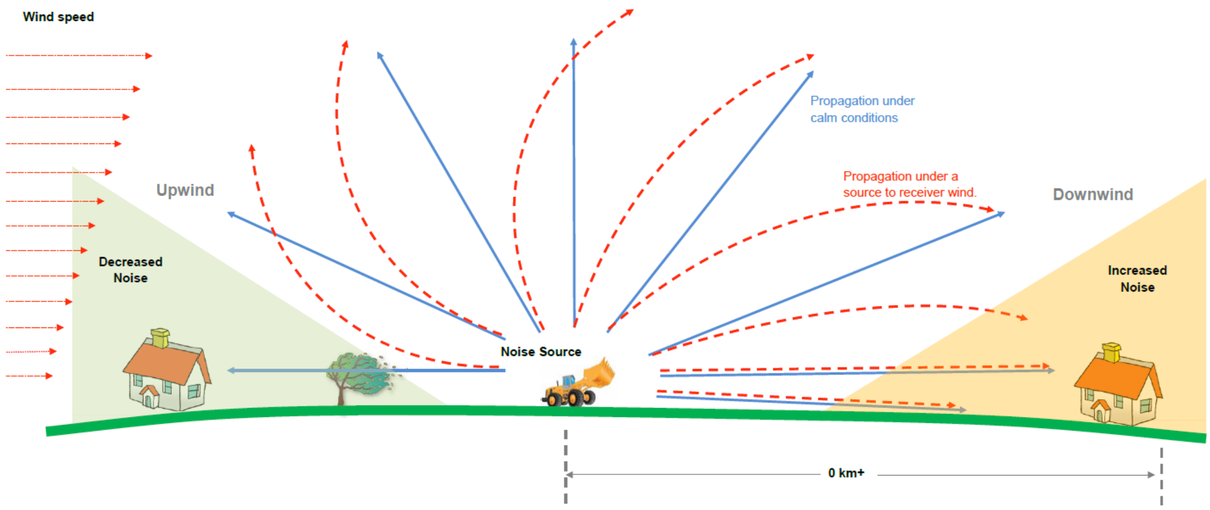

Figure 1. Influence of wind on propagation of noise

4.1.2 Temperature inversions

For most of the 150 km or so of Earth's atmosphere, temperature tends to decrease with increasing elevation above ground level. This is known as the 'normal adiabatic lapse rate'. Layers of air that don't follow this trend are called 'inversion' layers. They usually form near the ground on cold nights with little or no cloud cover and are a common occurrence in some areas. The acoustical significance of such layers comes from the fact that the speed of sound is higher at higher temperatures, approximated by the equation:

$c = 331.3 + 0.6T$ where c is the speed of sound in m/s and T is temperature in ^{0}C (1)

Within inversion layers, this means that the speed of sound is highest at the top and lowest at the bottom. At some given altitude, the normal decrease of temperature with height is resumed, thereby forming an 'atmospheric boundary layer'. This layer can also act to trap air pollutants or reflect noise.

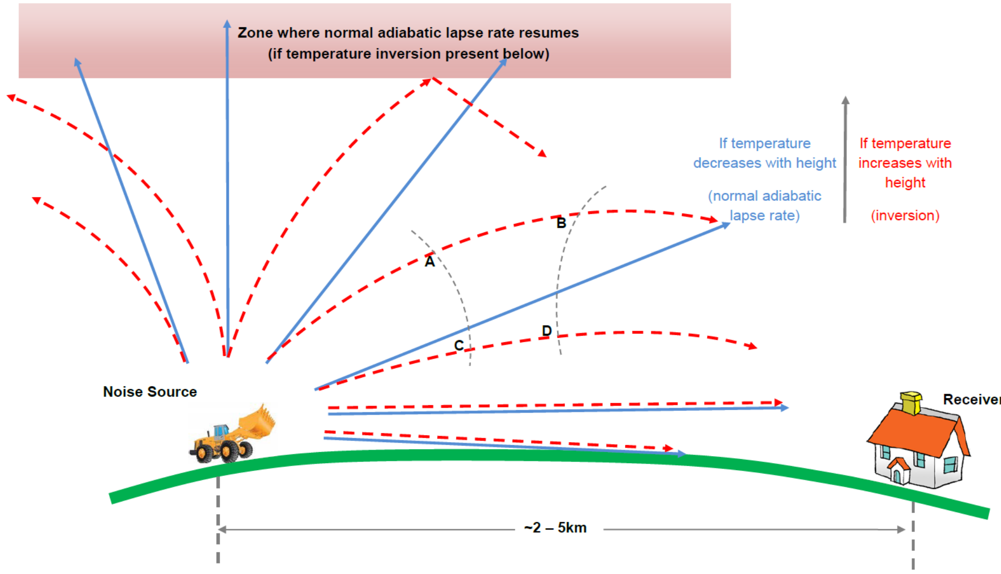

Figure 2. Influence of temperature inversions on propagation of noise

The conceptual diagram in Figure 2 compares the distribution of acoustic energy under neutral conditions (blue rays) and under inversion conditions (red rays). Under neutral conditions, the acoustic energy spreads out hemispherically with a portion of that energy being lost to the upper atmosphere. However, this same energy may be redirected back towards the ground under inversion conditions, enhancing the level of noise experienced at some receivers. ISO 1996.2 [7] provides calculations for the radius of the curvature of sound paths caused by atmospheric refraction, however generally this enhancement is noticed where the distance between the noise source and receiver is greater than 2 km and will regularly enhance noise levels by around 3 – 5 dB under Pasquill Stability Class F (an increase of up to 4^0 C/100m) conditions. Enhancements of up to 20 dB have been reported in NSW when strong G Class inversions (around 8^0 C/100m) are present, particularly in arid areas.

Temperature inversions are quickly dispersed by any wind or turbulent air flow and therefore can only exist simultaneously with very light winds (generally taken to be less than 2 m/s at 10 m height). To understand how the curved paths taken by sound when an inversion is present can occur, we need to compare the path segments A-B and C-D in Figure 2. Figure 2 is drawn in such a way as to represent the idea that noise which travels out from the source might arrive at the points A and C at about the same time, and likewise go on to simultaneously reach the points B and D at a later time. Thus, the time of travel between A and B on the upper path is equal to the time of travel between C and D on the lower path. However, due to the fact that the speed of sound in an inversion layer is higher at higher altitudes above the ground, we expect the upper path A-B to be longer than the path C-D, because of the relative differences in the speed of sound at the two altitudes.

Thus we see how it is that the ray paths that go out from the source and up into the inversion layer could curve downward and reach ground level receivers whereas they would otherwise go off to dissipate in the atmosphere without impact. As demonstrated, the upper path segment A-B is traversed in the same time as the lower segment C-D, but it is longer, hence the overall curvature downward. The consequence of this refraction of skyward-bound sound toward the ground is that the noise levels on the ground can be greater than they would otherwise be if only the direct path along the ground between the source and receptor were available to the sound. One could almost say, by way of an analogy with optics, that the source of the noise is magnified by the temperature inversion.

The effect is most dramatic when the direct path along the ground is blocked by intervening structures or terrain, but even when there are no such obstructions the ground absorbs a significant amount of acoustic energy every few hundred metres, so we expect that the direct path would generally not be effective at transporting sound over long distances. Thus the skyward paths that reach the ground when an inversion is present, but which don't during other calm periods, are of primary importance for long-distance propagation of noise.

4.2 Atmospheric Absorption

Mine noise is prone to being regularly audible over distances of 5 km or more under certain conditions. This is a result of their relatively high sound power levels and because they are often located in quiet surroundings. At these distances there is a significant frequency shift in the acoustic signal as the higher frequencies are differentially attenuated mainly due to atmospheric absorption, resulting in the residual and characteristic low frequency rumble that is often associated with industrial noise sources located at large distances.

This is documented in International Standard ISO 9613.1 [8] which establishes the reductions due to atmospheric absorption alone over 4 km under 20 ^{0}C and 50% humidity conditions, as reproduced in Table 4:

Table 4. Atmospheric Attenuation over 4 km

Atmospheric Attenuation	**Frequency Hz**					
	50	**160**	**500**	**1000**	**2000**	**4000**
Rate per km dB	7.84×10^{-2}	6.6×10^{-1}	2.73	4.66	9.86	29.4
Total dB reduction over 4 km	0.3	2.6	10.9	18.6	39	118

As the standard shows, the residual acoustic energy will be mostly below 500 Hz due to the very large attenuation coefficients at higher frequencies. This is not to say that the plant and equipment are generating particularly high levels of low frequency noise, or that their noise signatures are ‘unbalanced’. Rather, this confirms that only the lower part of the noise spectrum is identifiable at large distances as a consequence of differential attenuation.

4.3 Cumulative Attenuation

In Figure 3, Environmental Noise Model has been used to model pink noise (which has equal energy in octave bands) over a distance of 4 km. Flat terrain with grass has been assumed in the model parameters.

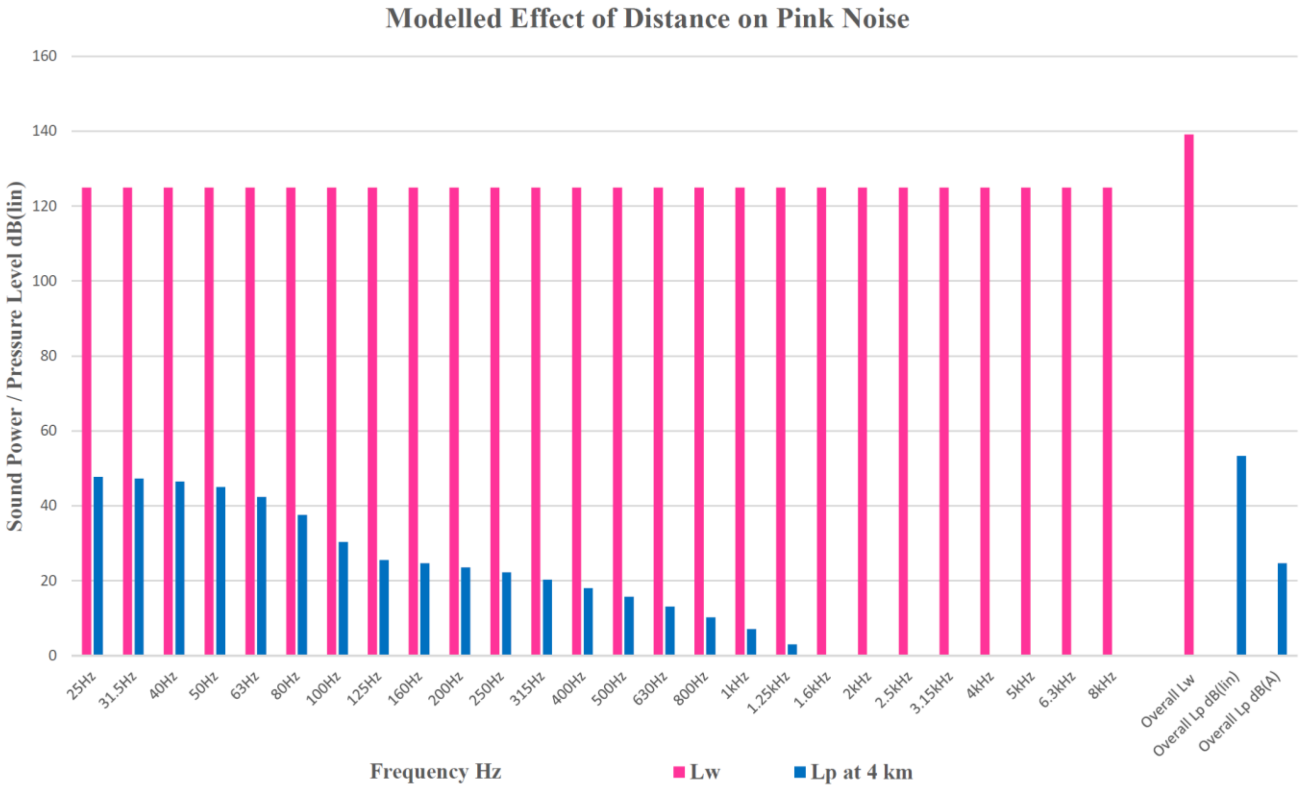

Figure 3. Differential attenuation of Pink Noise over distance

As can be seen in Figure 3, despite starting with a completely broadband acoustic signal at x = 0, by the time x = 4 km differential attenuation will result in a dB(lin) – dB(A) value of around 28 dB.

4.4 Noise Spectrum

When measuring noise several km from a mine, there is typically a mix of acoustic signals. Some of these signals generated at the mine site will have been altered significantly over the distance they have travelled, while others have been altered much less. Close proximity extraneous noise sources may not have had their acoustic signals altered very much at all. If measured in close proximity to an active pit, the mine noise generated is fairly broadband mid frequencies, although some surface facilities like washeries tend to include emissions in 1/3rd octave bands around 16 – 25 Hz. However, differential attenuation of high frequencies due to atmospheric absorption and ground effects results in a very different noise spectrum shape being experienced at distances of more than around 2 km. At these distances, the sound pressure levels of frequencies >250 Hz are such that they do not contribute to the A or C weighting of the audible noise level. Figure 4 below shows an example of a typical measurement spectrum at around 4 km from an open cut mine.

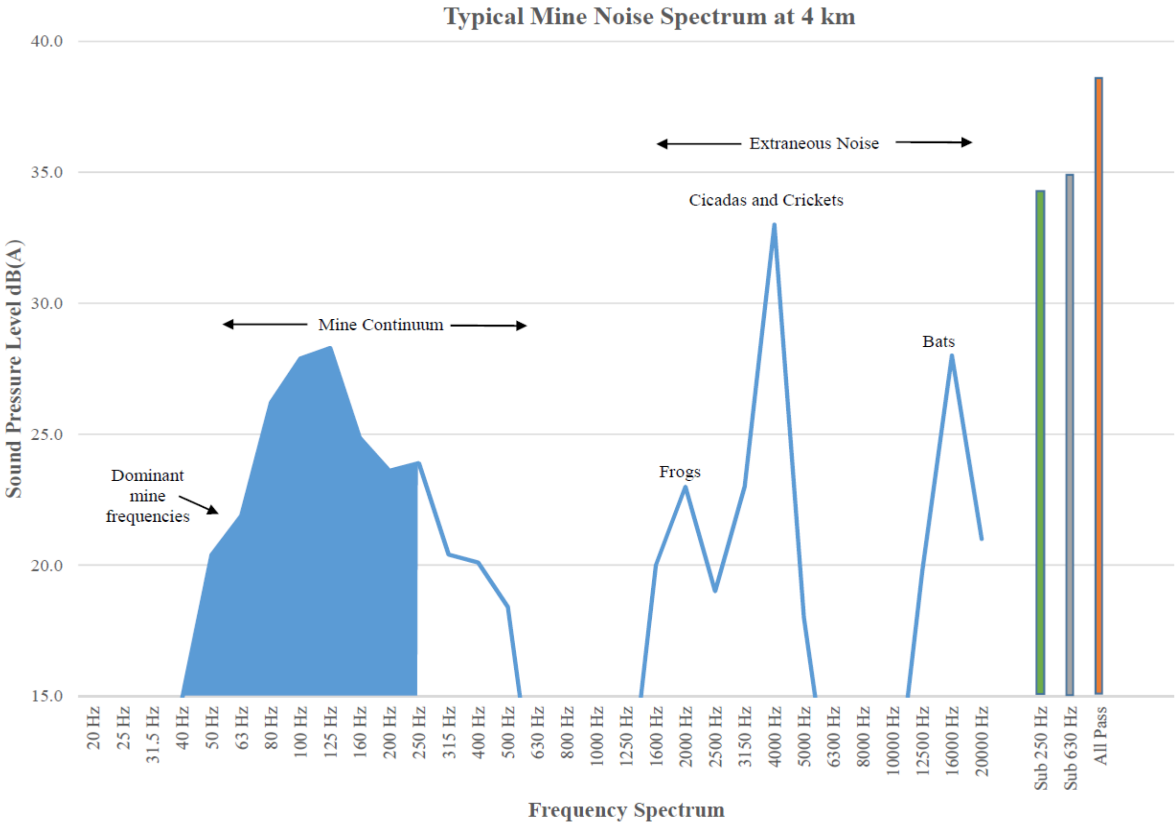

Figure 4. A typical spectral signature of a large open cut mine at around 4km.

5 Techniques for Managing Noise on Mine Sites

There are two types of techniques that can be employed to mitigate the generation and propagation of noise, these being static techniques, and dynamic techniques.

5.1 Static Techniques

Static techniques include passive measures that are employed to mitigate generated noise at all times. For example, mines often have large amounts of spoil material which can be strategically located and shaped to produce large bunds over 50 m high. These bunds can be used to shield receivers from visual impacts (like light spill) in addition to noise. Static techniques may also include sound attenuated mobile equipment which continuously reduce noise generation or egress, or it may refer to the acquisition of noise affected properties to provide a buffer zone.

5.2 Dynamic Techniques

These techniques employ measures that are taken to reduce the impact of noise at specific sensitive times like the night period or under temperature inversion conditions. They often come at a cost to operational efficiencies and therefore are not implemented continuously. These techniques include restricting equipment to low areas of the mine pit or close behind highwalls, standing down equipment at night or when noise enhancing conditions occur and preferentially using only highly noise attenuated equipment in high risk areas.

As dynamic techniques can be reactive or proactive, they will often involve a level of subjectivity and risk assessment. Guidance on employing such practices is generally outlined in a NMP which typically include a set of trigger levels that instigate these techniques. Tools used to support dynamic techniques includes predictive meteorological forecasting and real-time monitoring. Below are some examples of the more established noise reduction techniques some of which may be site specific.

5.2.1 Attenuated plant and equipment.

One of the major sources of noise on an open-cut coal mine is the mobile fleet. Older haul trucks may generate L_W of 125 dB(A), whilst newer factory attenuated trucks may have an in-service level of 115 dB(A). With fleets often greater than 80 haul trucks, the use of an attenuated fleet can have significant effects on the overall noise levels generated on a mine site. Audits of L_W are generally performed on a rolling 3 year average.

5.2.2 Restricted night time operations

The night period is generally subject to the most stringent noise limits, being the most sensitive period of the day for receivers. It is during this period that noise-enhancing meteorological conditions tend to occur and is therefore common practice for mines to undertake restricted activities during the night. This includes:

- *Selective utilisation of fleet* – planning the location and use of the mobile fleet in order to minimise noise during the night period or under adverse meteorological conditions;
- *Preferential deployment* – assigning attenuated equipment in higher noise risk areas;
- *Use of shielding* – undertaking extraction operations in close proximity to highwalls (often about 100 m in height) or bunds to effectively shield noise ;
- *Working at the bottom of pit* – restricting work to lower depths in the mine pit to take further advantage of shielding i.e. work below Reduced Level 150; and
- *Restricted access* – restricting the use of particular haul routes which may be closer or more exposed to sensitive receivers.

5.3 Examples of Other Mine Specific Noise Reducing Initiatives

5.3.1 Rubber trays

To reduce high Lmax noise level events, one mine is currently trialling the use of suspended rubber trays in the back of its haul trucks. These trays reduce the high impact noise that regularly occurs when rock is dropped onto the metal trays of haul trucks.

5.3.2 Staged removal of hard rock

Following a series of complaints, an underground coal mine worked with the DPE to develop a strategy to manage the high level noise impacts associated with the transport and stockpiling of coal with high content of hard rock material. This issue occurs when extraction encounters igneous dyke intrusion material, or when the coal seam thickness changes and sedimentary floor or roof material is inadvertently cut.

Under the strategy, the mine schedules the extraction of known occurrences of these intrusions during daytime only. Where there are unplanned encounters with other hard rock, floor or roof material, then extraction of this material is restricted to no more than 10% of product brought to the surface during evening or night periods.

5.4 Noise Management Plans

NMPs serve to fulfil several functions including:

1) Outlining the regulatory requirements regarding noise that are contained in the conditions of approval and the EPL;
2) Reiterating any commitments that have been made as part of the approval stage eg. commitments to restrict mobile fleet movements at night and/or contract only best practice locomotives and rolling stock etc;
3) Describe the implementation of noise management practices and reviews; and
4) Establish a Noise Monitoring Program.

Given that the first three points have already been covered, the proceeding discussion focuses on the fourth point regarding noise monitoring.

5.4.1 Data collection

Any new or modified mine site is subject to noise monitoring requirements. Noise monitoring results are used to ensure the accuracy of noise predictions undertaken as part of the environmental assessment process and to record any exceedances. It is a long term objective of DPE that real-time monitoring results will be published electronically and that mines will employ proactive management based on weather data. However, whilst the technology is available, it is difficult to implement and highly prone to extraneous noise contamination. Moreover, open cut mines are particularly difficult facilities to manage or change operations at short notice. There are however some very good systems available as is further discussed below.

5.4.2 Real-time noise monitoring

Most mines will have a system of real-time noise monitors strategically located to allow for the ongoing assessment of noise impacts on sensitive receivers for the purposes of noise management. As a consequence of difficulties identifying low level noise signals (generally less than 40 dB(A)) in a noise catchment that will often contain similar levels of extraneous noise, industry has developed techniques to improve precision including low pass filtering and directional monitoring.

In particular, directional monitoring has proven to be an extremely useful improvement on normal omni-directional data collection. By use of techniques such as beam forming arrays, directional monitors have been able to identify the arc in which a noise source is located and estimate its contribution. This information can then be used to better manage mine noise contribution in complex acoustic environments.

GPS tracking of mobile fleets are a common practice at mine sites and used as an audit measure. It can also be used for forensic acoustics, allowing mine activity scenarios to be modelled to investigate why particular historical noise levels were experienced.

5.4.3 Predictive meteorology forecasting

Mines are not something that can quickly reduce noise by altering work processes or moving equipment to less sensitive locations. Since 2011, DPE has been requiring mines investigate the use of predictive meteorological technologies to assist in the implementation of pre-emptive measures before meteorological conditions develop which will result in exceedances of noise objectives. More recently those mines have now been required to implement such technologies.

The principle is that if a mine has a reasonable advance expectation that a particular noise enhancing condition will occur, then it should be able to have a range of off-the-shelf measures to progressively implement to reduce the onset of adverse noise impacts.

5.5 Demonstrating Compliance

As evidenced by the options and techniques described in Section 5, the coordination and implementation of noise management tools is not a simple task. Ultimately, a mine will be judged on its noise performance and this must be done by demonstrating compliance. Public reporting of environmental compliance is a requirement of all NSW coal mines.

Whilst many mines operate sophisticated real-time noise monitoring systems, the assigning of $L_{Aeq(15minute)}$ noise levels to a particular mine can still be difficult when in a complex noise environment. Currently most compliance reporting is still based on attended monitoring results with real-time monitoring used to add an additional layer of regulatory confidence.

6. Concluding Remarks & Summary

Open-cut coal mining in NSW presents considerable noise management difficulties. Despite the setting of some of the most stringent noise criteria in the world, these mines continue to be the source of significant levels of community complaint. Property acquisition is not an ideal form of noise management as it can impact upon the social fabric of small villages and can be socio-economically divisive despite it being a commercial option for managing excessive noise.

The NSW Department of Planning and Environment is committed to driving continual environmental improvement and is achieving this by requiring mines to demonstrate best practicable noise management. Mines are responding to this challenge by adopting and developing world leading innovative technology that allows monitoring under challenging topographic and meteorological conditions. The use of real-time noise monitoring and alarm triggers are assisting in reducing response times to noisy incidents. The capturing of sound files allows for post-incident analysis and when combined with directional information, this leads to improved noise isolation and identification of offending noise sources. However, there is room for improvement in this reactive noise management area and it is hoped that predictive methods like those designed to assist in the timing of blasting can be further improved in a move towards better proactive noise management.

In terms of setting noise criteria for receivers located at significant distances from the source, it is preferable to set noise objectives based on low frequency content as this is a variable that is least likely to be affected by topographical and meteorological effects. Several options are available for this including the use of a C weighting, a linear weighting or A weighting of a band pass filtered signal. This is an area that requires more research. The author believes that there is merit in exploring the latter option as this has a long history of being used to assess annoyance and has the advantage of representing the acoustic signature of a mine to the exclusion of extraneous noise traditionally at frequencies above 1 kHz.

Acknowledgements

The work reported in the present paper was based on experience, data and information from a number of sources, including some which are anecdotal and some of which are unreferenced. The author acknowledges all the sources and expresses appreciation for being able to report the work. Any opinions expressed are those of the author and do not necessarily reflect those of the NSW State Government.

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