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Department of Resources, Energy and Tourism

AIRBORNE CONTAMINANTS, NOISE AND VIBRATION

LEADING PRACTICE SUSTAINABLE DEVELOPMENT PROGRAM FOR THE MINING INDUSTRY

SOCIAL
ECONOMIC
ENVIRONMENTAL

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OCTOBER 2009

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Leading Practice Sustainable Development Program for the Mining Industry.

This publication has been developed by a Working Group of experts, industry, and government and nongovernment representatives. The effort of the members of the Working Group is gratefully acknowledged.

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Cover image: Birdseye view of a ventilation shaft worksite in residential Ballarat.
Source: LGL – Ballarat Goldfields.

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FOREWORD

A strong commitment to leading practice sustainable development is critical for a mining company to first gain and then maintain its 'social licence to operate'.

The handbooks in the Leading Practice Sustainable Development Program for the Mining Industry series integrate environmental, economic and social aspects through all phases of mineral production from exploration to construction, to operation and finally mine site closure. The concept of leading practice is simply the best way of doing things for a given site. Leading practice is as much about approach and attitude as it is about a fixed set of practices or a particular technology.

The International Council on Mining and Metals (ICMM) defines sustainable development as investments that are technically appropriate; environmentally sound; financially profitable; and socially responsible. *Enduring value: the Australian minerals industry framework for sustainable development* provides guidance for operational-level implementation of the ICMM principles and elements by the Australian mining industry.

A wide range of organisations have helped develop this handbook, which will assist all sectors of the mining industry to reduce the impacts of minerals production on the community and the environment by following the principles of leading practice sustainable development.

The Hon Martin Ferguson AM MP

Minister for Resources and Energy, Minister for Tourism

1.0 INTRODUCTION

1.1 Background

The issues covered in this handbook have a number of things in common. Of all the topics covered in the leading practice handbook series, this group of issues is arguably the one that generates more complaints and more opposition from the local community than any others. The complaints are often immediate and are usually directed to the mine or, in many cases, to the regulator. Residents living near a mine site will not hesitate to phone the local environment protection authority or mines inspector to demand action.

Their concern might be dust from a haul road, truck reversing alarms or a suspicious dust cloud. Blasting generates a high proportion of complaints in all of the three areas covered by this handbook. These complaints are not restricted to open-cut mines, as inefficient blasting practices in deep underground mines also give rise to community concerns, particularly when firings take place at night.

A recent newspaper article highlighted the issue of noise and its impacts, both real and perceived, on the local community (Safe 2009). The article detailed the formation of an anti-noise lobby group, Noise Watch Australia. One featured case involved a retiree who moved to a heavily timbered block some distance from a capital city. A sawmill increased its production to 24 hours per day, seven days per week. In his words, 'the noise drove us darn crazy'; consequently, he sold up. Another complainant stated 'the growth of noise in communities across Australia is still not recognised for what it is—another form of pollution that's having serious health impacts on many people'. The World Health Organization was quoted in the article as saying that up to 3 per cent of heart disease deaths, or more than 200,000 globally, are due to long-time exposure to chronic traffic noise.

But are noise levels increasing? The Environment Protection Authority Victoria indicates that noise across Melbourne has not increased since the 1970s, yet community complaints have risen considerably (EPA 2007). In the United Kingdom, noise complaints are five times higher than they were 20 years ago. Assuming that noise has not increased at a commensurate level it is clear that people are becoming less tolerant of noise than they once were.

The issue of dust emanating from a mine site has been the focus of intense media scrutiny in Western Australia recently. The issue surrounds the export of lead concentrate from Magellan Metals' Wiluna mine from the ports of Esperance and Fremantle. The extent of community dissatisfaction can be seen from newspaper headlines in November 2008: '*Unions promise to fight Barnett over lead shipments*', '*Port's mayor vows to fight risky lead exports*' and '*Lead leaches hope of Esperance future*' (Clarke 2008).

These issues are important in all sectors of our industry—coal and metalliferous mining, and quarrying. Indeed, in November 2007 the front cover of *Quarry* magazine, the official journal of the Institute of Quarrying Australia, headlined '*Ensuring your neighbours don't eat dust*'.

The issues are also important regardless of whether the mine is situated in the Tanami Desert in the Northern Territory, the Hunter Valley in New South Wales, or a more densely populated area, although it is often in the latter situation that most problems arise. In Australia, these situations are typical of quarries for construction materials; mines with a residential workforce, such as those at Kalgoorlie in Western Australia, Mt Isa in Queensland or Broken Hill in New South Wales; or mining fields in locations where mining is often not considered the most desirable land use, such as the Hunter Valley. Of course, many Australian mining companies operate internationally—in countries where far higher densities of populations exist in the vicinity of mines, the community impacts of airborne particulates, noise and vibration are exacerbated.

1.2 Scope

Using text, photographs, figures, tables and selected case studies, the handbook provides a toolkit for implementing leading practice in the management of airborne contaminants, noise and vibration on mine sites.

This handbook is the successor to two handbooks in the Best Practice Environmental Management in Mining Series, *Dust control* and *Noise, vibration and airblast control*. Although it deals with a range of gaseous and particle emissions, the management of greenhouse gas emissions is beyond the scope of the handbook, due to the complexity of the issues involved, including the variety of stakeholder groups and the extension beyond local boundaries.

The contributors to this handbook have a wide range of experience in their respective fields. We trust the information provided, including the numerous case studies, will be of considerable practical use in helping readers integrate leading practice into mining operations, thereby maintaining the social licence to operate mines and quarries in Australia and beyond.

1.3 Leading practice

Leading practice considers the latest and most appropriate technology applied to seeking better financial, social and environmental outcomes for present stakeholders and future generations. A long-term timeframe is considered so that potential adverse outcomes are managed in both the short and long terms. Consideration of long-term outcomes is particularly challenging as the predictive data sets may be incomplete, a number of variables may modify the outcomes, and actual outcomes may not be fully understood or predicted. Nevertheless, leading practice demands that a best estimate of future impact is assessed and reasonable steps are taken to implement financially, socially and environmentally appropriate outcomes. The level of precision of such estimates also needs to be communicated.

Leading practice is about identifying, using and possibly developing appropriate technology in an enterprise to provide enhanced outcomes for all stakeholders. A key feature is the measurement of variables and performance outcomes to identify potential modifications to the processes for the mutual benefit of all stakeholders.

Leading practice includes a program to monitor inputs, processes and outputs. This information is incorporated in one or a number of managements systems. This may be incorporated in existing management systems such as safety management systems, environment systems and quality systems.

Leading practice includes being able to identify and manage competent technologists and communicators and ensure that they participate in programs to maintain their competence. A peer review process is important to ensure leading practice evolves with changing technology and social expectations and standards. While not essential, active participation in the application of teaching and research activities should be considered.

Useful information is available from professional bodies such as the Australasian Institute of Mining and Metallurgy, Engineers Australia, the Safety Institute of Australia, the Australian Institute of Occupational Hygienists and the Environment Institute of Australia and New Zealand, as well as government authorities and industry representative bodies.

Airborne contaminants include dusts, gases, fumes, odours, and airborne biological material. They may produce some financial, social or environmental adverse outcomes. The emission may:

- be a one-off event due to some plant or system failure, such as a major fire
- be intermittent but regular, such as blasting fumes
- be continuous and considered acceptable in terms of the risk of adverse short-term outcomes.

These all need to be fully investigated and appropriate measures taken. The outcomes need to be monitored and the process periodically reviewed.

Noise emissions may have a number of forms, from single or intermittent events to continuous noise. Noise also has several dimensions, including intensity and signal frequency. Vibration may or may not be connected to noise emissions in an indirect way.

Leading practice also examines the varied nature of the impacts of airborne contaminants, noise and vibration. Impacts may affect workers, passing members of the community and local residents. The impacts may also have some environmental implications that need to be considered.

Particular consideration is given to the sources and impacts as they relate to mining operations and quarries. To investigate the sources and impacts, a detailed analysis of the mining inputs, outputs and processes is required. This extends from exploration, project design and evaluation, through construction, commissioning and operations, to decommissioning and closure. The process of assessment also requires a characterisation of the materials extracted and consumed in the mining and processing activities. The potential and unintended interaction of these materials also needs to be considered.

Before embarking on leading practice systems, it is important to ensure there is a level of agreement between stakeholders on what are the broader objectives of the enterprise. From the perspective of shareholders or investors, there is a clear need to ensure that an acceptable financial return is obtained. Leading practice systems seek to manage financial and sovereign risk by ensuring all the stakeholders are engaged and considered, so that outcomes are not just expressed as the financial bottom line but rather as a triple bottom line that includes financial, social and environmental positive outcomes for all stakeholders.

Social outcomes include a broad range of issues including worker safety, long-term worker health, community health, and freedom from community annoyance or outrage. The community may extend beyond nearby residents and include state and national authorities and pressure groups. A part of the process of ensuring broad community support is the need to establish and promote the concept of the 'value chain', in which the full range of stakeholders gain a reasonable level of benefit from the mining operations. Any groups that can demonstrate that they have been disaffected have the potential to apply political or other pressure on mining operations.

With most management systems, it is important to identify and characterise the various stakeholders who participate in or have potential to disrupt the project under consideration. The different stakeholders need to be identified, as do their values and objectives. In leading practice, some strategy for communicating with different stakeholders needs to be developed. It is important to identify stakeholder networks and explore how effective different approaches might be. Consultative groups with local representation should be formed as a conduit for communicating with the community. Local and regional interest groups should be consulted.

In leading practice, stakeholders need to be engaged so they have some sense of control, responsibility and ownership. The success of the project then becomes a benefit to each stakeholder. This creates an environment where potential problems and conflicts are identified at early stages and their management can be incorporated into the project systems

Dialogue also needs to be established with a range of regulators who have obligations to ensure that there is compliance with community expectations as set out in legislation and standards.

1.4 Hazard identification and risk management

The generic risk assessment processes are covered extensively in the leading practice handbook *Risk assessment and management* (DRET 2008). In the context of air contaminants, noise and vibration, there are a few issues that need to be considered in some detail.

These include the complex issue of managing the risk of chronic and potentially fatal disease and disorders with long latency periods arising from cumulative exposures to certain emissions. Examples include asbestos, silica dust, coal dust, and smelter emissions (such as those at Mt Isa in Queensland and Port Pirie in South Australia). The long-term effects of noise and vibration include hearing loss, circulatory disorders and a wide range of illnesses and disorders associated with loss of sleep. Assessment of these hazards needs to consider those most at risk and most susceptible, including the very young and the elderly.

In addition to health hazards, risks that need to be considered include hazards to community amenity and local flora and fauna. A good example of this is nuisance dust, which is monitored and controlled not because it is a health hazard but because of the annoyance caused by its presence. Similarly, community noise exposure standards are framed in terms of minimising the disruption to the community.

Environmental monitoring standards have been derived to address these hazards. State, territory and federal environmental agencies can provide details of relevant standards to adhere to: for example, the National Environment Protection Measures (EPHC 2009). These standards are referred to in more detail in the later chapters.

The legislative framework on environmental management and health and safety in most states and territories is framed as requiring mine managers to implement substantial risk management processes. The legislation also makes reference to standards in guidance on compliance. Management of risk should be initiated at the design stage, as promoted by Safework Australia (2009).

It is important to follow the hierarchy of control when implementing controls and, wherever possible, to focus controls at the top of the hierarchy by eliminating the hazard. If this is not possible, the next step is to consider substituting the process that creates the hazard. If this is not feasible, engineering controls should be applied at source to manage the hazard. Control at the receptor should be considered only when these other options are not possible.

In Australia, the proponents of major projects are required to submit and have approved environmental impact statements and environmental management plans that identify environmental hazards, assess the risk, identify the measures by which their performance should be judged, implement monitoring and engage third-party auditors to confirm the effectiveness of the program. This approach facilitates continuing improvement of industry environmental standards, but is costly and is a burden for smaller operators and projects.

1.5 Planning and life cycle approach

In the subsequent chapters, airborne contaminants, dust, noise and vibration are each discussed in detail as separate issues within a common 'life cycle' approach covering exploration, design, evaluation, construction, operations, rehabilitation and closure.

1.5.1 Exploration

A range of airborne contaminant, noise and vibration issues are associated with exploration. The transient and often isolated nature of exploration creates an environment for potential clashes with local residents, unless operations are carefully monitored and considerable effort is made to keep the community informed of activities.

1.5.2 Design and approvals

The hazard identification, risk assessment and risk control planning discussed in Section 1.4 should be incorporated into the project design and communicated to stakeholders for comment and review. After the design and environmental impact assessment phases have been completed, a vast array of approvals for a wide range of commercial activities may be required. While the scope of this discussion precludes detailed analysis of the approval processes, it is sufficient to identify that considerable resources need to be devoted to identifying all the approval processes and ensuring that they are tracking effectively.

For small mines or quarries, such as those typically found in the opal fields or supplying sand and gravel, the hazards and risk management requirements in relation to air contaminants, noise and vibration are generally limited, as is the ability of the site operators to identify hazards and manage risk. The format of materials to address these problems should focus on the development of simple checklists that address specific issues at the site. The site operators may need assistance to develop the checklists and identify appropriate responses when a significant issue is identified. Assistance from corporate centres, consultants or government officials should be sought as appropriate.

1.5.3 Monitoring plans

While all management systems need some form of planned monitoring, the strategy in developing the nature and frequency of data collection may be quite complex. Variables to consider include the nature of the hazard and the potential rate at which the risks in relation to the hazard may change. The cost of monitoring needs to be balanced by the potential cost of an adverse incident. Changes in monitoring technology need to be regularly reviewed as effective new systems emerge on a regular basis.

Monitoring for potential long-term impacts of occupational exposures (and the risk of such) is an area where new science and practice is slowly emerging. Interventions have traditionally been based on a level of harm, but there is increasing regulatory pressure to develop systems that trigger interventions based on elevated risk of harm.

1.5.4 Audit and review

While a health and safety or environmental management system may be leading practice at the time of its development, elements within the mine site or aspects relating to the community and technology may change. There is a need for regular audits of the system to ensure practices are being followed. At less regular intervals, comprehensive reviews are necessary to reassess the objectives and examine how the current system is meeting the objectives, and what modifications are necessary to improve performance.

1.5.5 Mine closure and rehabilitation

Mine closure is a process. It refers to the period of time when the operational stage of a mine is ending or has ended, and the final decommissioning and mine rehabilitation is being undertaken. Closure may be only temporary, or may lead into a long-term program of care and maintenance. The overall objective is to prevent or minimise adverse long-term environmental, physical, social and economic impacts, and to create a stable landform suitable for some agreed subsequent use.

The long-term objectives of rehabilitation can vary from simply converting an area to a safe and stable condition, to restoring the pre-mining conditions as closely as possible to support the future sustainability of the site. Rehabilitation normally comprises:

- developing designs for appropriate landforms for the mine site
- creating landforms that will behave and evolve in a predictable manner, according to the design principles established
- establishing appropriate sustainable ecosystems.

It is in the second process that the potential for dust and noise will become a problem. Creating sustainable landforms from spoil piles in strip (coal) mines, waste dumps in open-cut (metalliferous) mines, tailings disposal sites, and associated infrastructure such as roads, hard stand areas and the like will require extensive earthmoving. The earthworks will require large machinery and will usually result in dust and noise hazards that need to be controlled.

In most cases, the rehabilitation works will be carried out by contractors who may not have been involved in the mining process and may not be sensitised to the noise and dust management strategies employed when the mine was operating. It is important therefore that an appropriate induction program takes place to ensure contractors are aware of the potential hazards and can mitigate the risk arising from them.

Once the earthworks stage of the rehabilitation process has been completed, and all equipment has been removed from the mine, the noise hazard should be eliminated. However, a dust hazard may remain. A mine operator has ongoing responsibilities at the site until it is able to obtain a clearance certificate or relinquishment 'sign off' from the appropriate regulatory body. Governments are reluctant to absolve companies of their responsibilities, so they will be careful to ensure that there is low or no risk of dust emanating from the site.

If the site is affected by drought and the replanting program fails, the mine operator will need to carry out revegetation maintenance, particularly over waste dumps and tailings storage facilities. In high-wind areas it may be necessary to use additional surface capping, such as rock mulch, rather than rely on the success of the revegetation program. The impacts of fires on revegetation, potentially reducing rehabilitated surfaces to bare areas, should not be underestimated. This is particularly important in the Top End of Australia where the prevalence of fire in the dry season is widespread.

Further information on mine rehabilitation can be obtained from the leading practice *Mine closure and completion* and *Mine rehabilitation* handbooks (DITR 2008a, 2008b).

2.0 AIR CONTAMINANTS

OVERVIEW

Air emissions from mining and related activities may affect the environment on a local, regional and global scale. Despite the remoteness of most mines in Australia, many are located near settlements where management of emissions is a vital concern for the miners, their neighbours and regulatory authorities. Although dust is the predominant emission associated with mines, a range of gaseous and particle emissions are associated with mining and other on-site processing activities. This chapter identifies the main emissions issues and their management. (As noted in Section 1.2, this handbook does not address greenhouse gas emissions.)

Unlike other environmental issues, the most effective way to control particulate emissions is to consider the entire process from the pit to the port. This is because any measures taken by the mine to reduce particulate emissions caused by handing of the valuable material at the mine will result in reduced particulate emissions at the port when that treated valuable material is handled there.

2.1 Sources of air emissions

The principal activities associated with the life cycle of a typical mine site that lead to air emissions are summarised in Table 2.1.

Table 2.1: Summary of major mining activities associated with air emissions

Activity/source	Coal mining		Metalliferous mining	
	Open cut	Underground	Open cut	Underground
Earthmoving associated with construction and development of surface facilities	P	P	P	P
Shaft/drift access and ventilation development		P		P
Removing vegetation and topsoil for mine preparation	P		P	
Drilling and blasting[a]	P,G,O		P,G,O	
Removing and placing overburden	P		P	
Extracting, transporting and dumping coal or ore	P	P	P	P
Crushing coal, ore and other materials	P	P	P	P
Screening	P	P	P	P
Washery operations	P	P		

(continued)

Activity/source	Coal mining		Metalliferous mining	
	Open cut	Underground	Open cut	Underground
Beneficiation of the material[b]			P,G,O	P,G,O
General materials handling	P	P,G	P	P,G
Transporting and placing washery rejects	P	P		
Workshop and/or power plant operations[c]	P,G,O	P,G,O	P,G,O	P,G,O
Rehabilitation	P	P	P	P
Wind erosion from open pit, stockpiles, and exposed areas (including tailings)	P	P	P	P
Rail transport	P	P	P	P
Ship loading	P	P	P	P

Note: The cells are denoted as 'P' if dust or primary particle emissions occur and 'G' if significant gaseous emissions occur and 'O' if significant odorous emissions are possible. Note that in some cases, individual source activities may not apply: for example, beneficiation does not occur at all metalliferous mine sites. Note also that exhaust emissions from vehicles and machinery have not been included in the tabulation, as generally these emissions are relatively minor in quantity and impact compared to other emissions. In some cases, specific particle hazards such as respirable crystalline silica (RCS) or asbestos fibres may be emitted.

a. The gaseous pollutant of most concern is nitrogen dioxide (NO_2)

b. The gaseous pollutant typically of most concern is sulphur dioxide (SO_2). For gold ore processing, hydrogen cyanide can be emitted.

c. Gaseous emissions can include SO_2, NO_x and various volatile organic compounds

In addition to the emissions noted in Table 2.1 are exhaust emissions from mining equipment and motor vehicles, emissions from spontaneous combustion (especially in coal), and emissions of volatile organic compounds from fuels and solvents. Transport of coal and ores from mines to export terminals or customers can lead to significant emissions, predominantly dust.

2.2 Reasons to control emissions

The impacts of air emissions depend on the types of pollutants, their release characteristics and the nature of the receiving environment. The intrinsic hazards associated with each pollutant, such as particulate matter, lead or sulphur dioxide, are well documented (substance fact sheets are available through the National Pollutant Inventory at www.npi.gov.au).

Particulate and various gaseous emissions need to be controlled because they may be harmful to personal health or the health of fauna and flora in the environment, cause concern for local communities, become a hazard to safe operations or, in the case of dust, cause increased wear to moving machinery. Dust and odour can cause annoyance and lead to complaints.

Air quality is influenced by the concentrations of a vast number of substances that may be present, some naturally occurring and others due to human activity. Pollutants emitted from mining and related activities constitute both gases and primary particles (such as dust). Secondary particles are formed in the atmosphere due to reactions involving non-particle primary pollutants: the in-plume formation of sulphate particles from emissions of sulphur dioxide is an example. In the context of this handbook, secondary particles are not of significant concern.

Dust derived from the mechanical breakdown of rocks and soil is the most widespread and abundant emission from mines, and occurs across a wide range of particle sizes. Total suspended particulate matter (TSP) refers to the full size spectrum of suspended dust particles. Of more direct relevance to health are the finer fractions, PM_{10} (particles less than 10 microns in diameter) and, especially, $PM_{2.5}$ (less than 2.5 microns). Finer particles are more readily transported into the lungs where they can become lodged and cause irritation and disease.

While particle size is the main focus of regulatory standards, the potential for particles to damage health is also influenced by their chemistry and shape, and research into detailing these aspects continues. In the case of earth dusts, mineralogy is a key. Depending on the rocks being mined and handled, dust may contain significant amounts of hazardous substances such as lead and other heavy metals, crystalline silica, asbestos or radio nuclides, which adversely affect health at very low exposure levels. Hence, it is important to understand the characteristics of emitted particles to ensure that especially hazardous components are properly controlled.

In general, smaller particles are carried further by the wind than larger particles. Particles that are finer than 10 microns can be carried around the world; they provide the hazy mornings and evenings that we often see when there has been strong wind. Wind strength, particle size, moisture, porosity and density all play a role in the distance that a particle will be carried from the source. Local communities can be affected by the nuisance effect of particulate emissions through dust deposition on sensitive surfaces such as washing, furniture and cars. Safety on and off site can be adversely affected by dust clouds that limit visibility, increasing the risk of motor vehicle accidents.

Dust increases maintenance costs as it gets in between moving parts of machinery. For example, dust ingress into bearings causes the oil and dust to mix to form a highly efficient grinding paste which can quickly destroy the usefulness of that bearing. Fan impellers are impacted and worn away at the tips by larger (greater than 30 microns) particles of dust. In order to manage dustiness, the material characteristics must be analysed to provide the information that leads to a solution. The particle characteristics that must be understood include the mineralogy, particle size distribution, moisture, porosity, density and, in some cases, the particle charge.

Gaseous emissions arising from fuel combustion (for example, power generation) or mineral processing (for example, ore roasting or smelting) include pollutants such as sulphur dioxide and nitrogen dioxide which have well-defined human health effects and are tightly regulated in the ambient environment and workplace. Odour emissions can arise from some mining and related processes, such as oil shale processing, and gold ore roasting or leaching.

The occurrence of annoying odours, especially on a regular basis, can cause concern in a community. In the same way, nuisance dust can lead to complaints. Complaints are normally a symptom of severe annoyance, but an absence of complaints does not necessarily mean the absence of a problem: there can be complex drivers behind a person's decision to lodge or not lodge a complaint.

Complaints can lead to regulatory intervention and potentially expensive programs to deal with complaints management and process rectification. If odour or dust problems do occur, it is important that each complaint is properly investigated and followed up with the complainant and regulator, and is fully documented. A pattern of complaints may point to specific process or weather conditions, informing the design of a reactive management program which avoids certain activities during the identified adverse conditions.

2.3 Regulation and standards

Controlling dust and other emissions is a legal obligation, set out through laws on environmental protection, workplace health and safety, and common nuisance. Environmental regulatory authorities in the various Australian jurisdictions have developed specific criteria for the control of emissions and ambient air quality. Health authorities are also concerned about the risks to human health posed by emissions from mining activities, both on site among workers and off site in nearby communities.

2.3.1 Responsible authorities

The regulation of ambient air quality (outside the workplace) is the responsibility of government agencies in the states and territories, primarily the departments responsible for mining activities and environmental protection. Broad national policy direction on protecting air quality is provided by the Environment Protection and Heritage Council of Australia and New Zealand, which incorporates the National Environment Protection Council (see www.ephc.gov.au/).

In all jurisdictions, regardless of the administrative arrangements for approving and managing mining activities, the environmental performance criteria that have to be met by mining and industrial activities are established by the relevant environmental protection agencies.

2.3.2 Standards, policies and guidelines

Air quality regulation is achieved by a range of measures under the umbrella of environmental protection laws. Generally, environmental protection or similar legislation in each state sets out general principles and administrative structures. Details of air quality regulation tend to be contained in a hierarchy of separate policies, standards, objectives and guidelines.

Federal programs

At the federal level, the National Environment Protection Measures (NEPMs) are the key instruments affecting the mining industry. The most relevant of these are the National Pollutant Inventory (NPI) and the NEPM for Ambient Air Quality (EPHC 2009).

The NPI is a national web-based annual inventory of emissions of 93 hazardous substances that pose potential risks to environmental quality. Mining and related activities contribute very significantly to national emissions of particulate matter (including PM10 and PM2.5). By virtue of the quantities of dust emitted, most mines are required to report to the NPI.

The NEPM for Ambient Air Quality sets out objectives, goals, protocols and guidelines for ambient air quality, specifically for six pollutants. Table 2.2 lists the standards and goals.

Table 2.2: Ambient Air NEPM standards and goals

Pollutant	Averaging period	Maximum concentration	Goal within 10 years maximum allowable exceedences
Carbon monoxide	8 hours	9.0 ppm	1 day per year
Nitrogen dioxide	1 hour 1 year	0.12 ppm 0.03 ppm	1 day a year none
Photochemical oxidants (as ozone)	1 hour 4 hours	0.10 ppm 0.08 ppm	1 day per year 1 day per year
Sulphur dioxide	1 hour 1 day 1 year	0.20 ppm 0.08 ppm 0.02 ppm	1 day per year 1 day per year none
Lead	1 year	0.50 µg/m^3	none
Particles as PM_{10}	1 day	50 µg/m^3	5 days per year

PM_{10} = particulate matter less than 10 microns in diameter, ppm = parts per million, µg/m^3 = micrograms per cubic metre

Note: These are the standards and goals defined by the National Environment Protection Council in July 2003; the standards and goals were under review when this handbook was being prepared.

The NEPM ambient air standards were not designed specifically to regulate ambient air quality at and beyond the boundaries of individual industrial and mining facilities. However, they are the same as, or similar to, the criteria used for that purpose by various state and territory regulations.

The 50 µg/m^3 PM_{10} criterion in particular has led to problems of interpretation and compliance for the mining industry, for example, in the Hunter Valley where the combined emissions of multiple mines can affect the air quality in nearby communities. Invariably, other (background) sources of emissions can be significant. For mining projects committed to the application of best practice controls, the 50 µg/m^3 criterion is often applied as an incremental goal, that is, the concentration above background emissions from other sources. In Victoria, for example, a total concentration of 60 µg/m^3 applies to mines and quarries.

In many parts of Australia the 50 µg/m^3 24-hour standard can be breached by the effects of bushfires, deliberate burning-off or dust storms on some days in a typical year.

In relation to the more hazardous finer particles, an advisory NEPM for $PM_{2.5}$ has set numerical values for $PM_{2.5}$:

- 8 micrograms per cubic metre annual average
- 25 micrograms per cubic metre maximum 24-hour average (EPHC 2003).

At this stage, the advisory $PM_{2.5}$ standard is not formally part of the assessment criteria used in regulation by all states. For example, the Victorian *Draft protocol for environmental management—mining and extractive industry* sets out an assessment criterion of 36 µg/m^3 (24-hour average) (EPA 2006).

State and territory programs

The state and territory authorities responsible for air quality have implemented ambient air quality policies and guidelines specific to their legislative frameworks. In general, though, the ambient air concentration goals for controlling dust and other emissions from mines and related industries are similar across the jurisdictions, and closely reflect the standards set out in Table 2.2. Nevertheless, in each jurisdiction it is necessary to know the actual limits and how they are applied: for example, are they absolute limits or can they be exceeded on a small number of occasions per year?

In addition to airborne particles, deposited dust is a major amenity issue associated with mining. In some states there is no formal guideline for dust deposition, mainly because the relationship between deposition rate and the likelihood of annoyance or complaint is not straightforward. In New South Wales, the dust deposition guideline in residential areas is a maximum of 4 grams per square metre per month in total, while the deposition due to any new activity must not exceed 2 grams per square metre per month. This guideline, or similar, is applied in most states. All states have policies and guidelines pertaining to odour management, aimed at avoiding nuisance in potentially affected communities.

2.4 Monitoring

Monitoring of air quality is commonly required to establish baseline conditions to use in an air quality assessment before a mining proposal is decided on. It may also be required after operations start, either for model validation or as part of an ongoing air quality management plan. The reader here is also referred to *Evaluating performance: monitoring and auditing* leading practice handbook (DRET, 2009).

2.4.1 Monitoring design and logistics

The sensible design and operation of a monitoring program involves some strategic and logistic considerations. Many a monitoring program has failed to yield its potential value through inadequate planning and poor quality control.

The purpose of monitoring influences its design. If it is required as part of a baseline study, the authorities will require a certain period of data to be gathered (usually at least a year) to capture seasonal variations. It is necessary to adhere to accepted standards for instrument choice, siting, calibration and data management. Similar requirements will apply if the monitoring is required for compliance and model validation as part of a licence condition. However, if dust monitoring is instigated for real time management, where responsiveness and flexibility are more important than data precision, the use of instruments complying with Australian Standards or other authorities is not as critical.

Baseline studies

If a monitoring program is required as part of a baseline air quality study, it is important to check with the agency overseeing the approval process to clarify what specific monitoring is expected. For mines, the relevant aspect is usually dust, typically represented by PM_{10}. A monitoring program may require simultaneous measurement of TSP, PM_{10} or $PM_{2.5}$, or a combination of these (PM10 is the most widely used indicator, while $PM_{2.5}$ is routinely considered in some jurisdictions). Various types of instrumentation can achieve this, but the choice of instrument will determine whether it is possible to gather continuous data averaged over 10 minute periods, or 24 hours, for example.

Measurements over short intervals (such as 10 minutes) provide a better basis for identifying and understanding the sources of emissions. However, this requires meteorological data as well: the simultaneous monitoring of wind speed and wind direction, as a minimum. A well-configured weather station forming part of an air quality monitoring program will also measure fluctuations in wind speed and direction (the fluctuations are indicators of turbulence), solar or net radiation, temperature, rainfall, air pressure and humidity. It may also have wind and temperature sensors at two or more levels above the ground.

Deposition monitoring

An aspect of dust that most directly affects neighbours of mining operations is fallout or deposition. The accumulation of dust deposits causes annoyance because of its aesthetic impact and the need for frequent cleaning. Dust deposition monitoring using dust gauges is a simple method and more directly measures the cause of complaint than methods that measure suspended dust concentrations (PM_{10}, $PM_{2.5}$ or TSP).

The standard dust deposition measurement involves passive collection of the sample over a 30-day period, while most dust deposition problems are caused by short events, typically over some hours. The standard 30-day sample tells nothing of the timing of the fallout, and may not be a very good indicator of the level of annoyance caused. Nevertheless, this type of deposition monitoring remains common because it is relatively cheap and simple.

Targeted emissions monitoring

In some cases, there may be site-specific issues that require more targeted monitoring. For example, if rocks contain significant silica content, the respirable crystalline silica concentration should be measured. If there is a radioactive component, monitoring of radio nuclides and/or radon may be important. For most mining proposals and operations, there is no need to be concerned with monitoring of gaseous pollutants such as sulphur dioxide for environmental baseline or compliance purposes.

For operational mines, it is possible that the threshold for annual reporting to the NPI or National Greenhouse Gas and Energy Reporting scheme will be triggered. Reporting for these programs involves various methods, typically 'default', simple methods that use emission factor calculations that require the input of data on characteristics of materials, rates of activity and throughputs: for example, the estimation of PM_{10} emissions from haul roads requires input of data on vehicle mass, distances travelled, road silt content and daily rainfall.

However, emission factors are relatively crude, especially when used with default, rather than site-specific, values for various inputs. Hence, it may be decided to gather more site-specific data (for example, on road silt content). Depending on the specific emission source and pollutant under consideration, there will be one or more parameters to be measured on site in order to obtain more reliable emissions data. Such monitoring programs are voluntary, and usually require some specialist input or advice.

Instrument selection

The selection of instruments for monitoring is an important step, and needs to take into account any necessary standards (such as Australian Standards, United States Environmental Protection Agency standards, and methods approved by state regulatory authorities), particularly if monitoring is for compliance or statutory purposes. The selection also needs to consider cost, maintenance needs, power requirements, siting (for example exposure to wind), security and site accessibility.

2.4.2 Data quality

Many monitoring programs pay insufficient attention to maximising both data quantity and quality. Data loss can be minimised by regular checking and maintenance of equipment. The more quickly sensor or logging problems are identified, the better the chances of quickly rectifying the problem and reducing data loss. The best results are achieved by having data available in real time or downloaded frequently and checked at least daily.

Data quality is highly important, but can often be taken for granted. The regular maintenance and calibration of instruments assists in ensuring good data quality, but data needs to be regularly screened and checked. Real time data-checking software with alarms communicated to the user provides the best results, but regular 'reality checking' of data by skilled staff is also very useful. Checks should be made to test whether data are within expected ranges for the season and time of day, and whether expected relationships between measured parameters exist (for example, whether wind speed and temperature increase during the day). If data outliers are identified and checked routinely, instrumental errors can be quickly dealt with.

Ultimately, a monitoring program should aim to consistently achieve at least 90 per cent to 95 per cent valid data return. Specific performance level requirements may be specified by regulators; this should be checked. Monitoring in remote locations without power poses particular logistic problems, so it might be necessary to use low-power samplers with solar recharge instead of more standard instruments such as high-volume samplers or TEOMs (tapered element oscillating microbalances) which require 240 volt power. There is a greater risk of data loss from remote monitoring sites.

2.5 Modelling

Plume dispersion models are routinely used to inform assessments of air quality impacts, to either predict events or analyse past events. They can also be used in real time air quality management. The needs for real time models are different in some respects from those typically used for compliance assessments.

2.5.1 Basic description of models

Plume dispersion models mathematically simulate the dispersion (and deposition) of pollutants in the atmosphere after they are emitted from specific, defined emission sources. In common use today there are two main types of dispersion model: steady state and non-steady state.

Steady state models assume that, for each calculation of the plume (typically an hourly average), the meteorological conditions for that hour are in steady state—that is, they have always been and will always be the same. An example is the Australian regulatory model AUSPLUME, which is a steady-state Gaussian plume model, so named because it assumes that plume material, when averaged over time, has a Gaussian or normal distribution around the centreline of the plume. In performing its calculations, AUSPLUME steps from one hour to the next using the meteorological data for that hour to calculate the distribution of plume material downwind from the source(s). The steady state assumption means that each hour is independent of other hours.

A non-steady state model, on the other hand, tracks the location of plume segments through time. This means that variations in wind and other meteorological parameters that affect ground level concentrations can exert an influence on the predicted plume patterns.

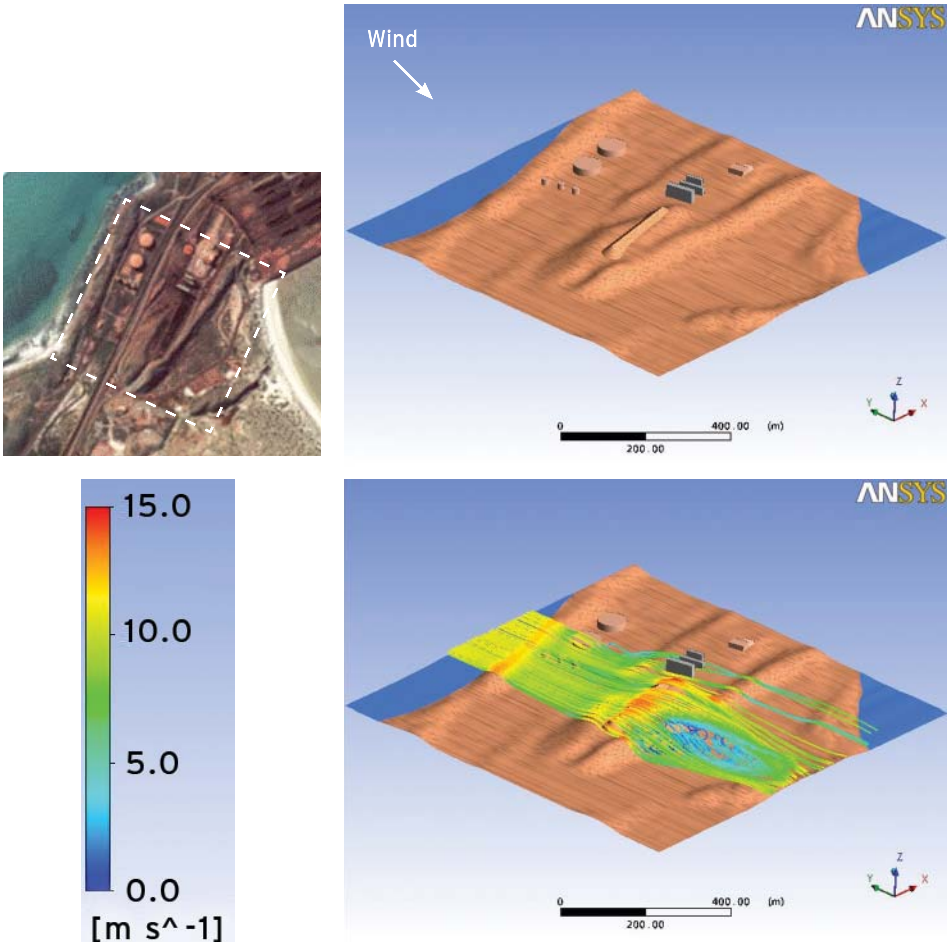
2.5.2 Applications of modelling

Despite the sometimes large differences in model results for specific situations, the simpler steady state models such as AUSPLUME are widely used for regulatory purposes. However, more advanced, non-steady state models, such as TAPM (The Air Pollution Model) developed by CSIRO, and the CALPUFF model preferred by the United States Environmental Protection Agency, are increasingly being used as their costs and accessibility improve.

The main applications of dispersion models are:

- predicting the impact of a proposed activity such as a mine or smelter
- designing chimney heights or emission control systems
- apportioning ambient impacts of emissions to specific sources
- ranking emission sources in terms of priority for applying controls
- analysing past air quality events
- estimating emission rates (by back-calculation modelling—this can be particularly useful for estimating dust emissions from area sources).

Computational fluid dynamics (CFD) produces dynamic models that simulate the air flow over and around objects and barriers, or within enclosed and semi-enclosed spaces. CFD models have a multitude of applications, ranging from assisting in the design of combustion chambers and ventilation systems, to designing barriers to prevent dust lift-off. With respect to dust, they are particularly useful in understanding how far dust will be carried, where it will land and how effective the wind barrier will be.



Examples of CFD air flow lines modelled using computational fluid dynamics. Source: Richard Meloy, Rio Tinto.

2.5.3 Modelling cumulative impacts

For the assessment of a new mine or emission source, the existing levels of dust (or other pollutants as relevant) need to be taken into account. For pollutants which have well-defined sources, such as sulphur dioxide, it is possible to include the new sources as well as existing or background sources in the model and yield acceptable results. However, for particles, a complete accounting of background sources is not possible: the background of airborne particles comes from a variety of local and distant activities such as natural wind erosion, agriculture, industry and transport.

In the case of PM_{10}, for example, the best approach is to conduct monitoring and to apply the results as a background to which the new sources are added. Depending on the sensitivity of the activity and regulatory needs, the background can be included either as a fixed value, such as the seventieth percentile of the daily values, or as daily or hourly varying background. However, particularly where there are multiple mines or other sources nearby, such as in the Hunter Valley, cumulative impact modelling is not straightforward and there are multiple sources of uncertainty.

2.5.4 Model validation and uncertainty

All models are simplifications of the real world and carry inherent uncertainty, as well as uncertainty associated with inaccuracies in the input data. Data on emissions used in an impact assessment may turn out to be significantly in error; particularly if the assessment shows a small difference between predicted impacts and the acceptable limits, the agency approving a mining proposal may require the model to be validated.

Once the operation is underway, this involves monitoring ambient PM_{10} (or another critical air quality indicator) and meteorology for a year or two, then compiling a more accurate emissions inventory. With the new data, the model is re-run and the results are compared to the measured PM_{10}. Once a validated model exists, any future expansion or changes to emissions can be predicted with greater confidence.

2.6 Air quality management plans

A dust or air quality management plan is a way of systematically dealing with or avoiding problem issues, and may be required as part of an environmental approval to operate a mine.

Identifying rational and effective solutions to air quality problems requires a sound understanding of the nature, causes and effects of the problems. For example, if there is a risk of dust nuisance impacts in a neighbouring community during dry northerly winds, the plan needs to identify the main contributing dust sources (such as haul roads or topsoil dumps) and prepare mitigation actions (such as increased watering, reduced haulage activity or alternative activity locations) for times when those winds occur. Advising the community of the risks and actions taken is also important. If complaints occur, they need to be handled systematically and documented from time of receipt, through the consultation and investigation stages, until they are remedied.

In other words, a plan needs to be more than just a list of isolated actions. Important elements for a management program include:

- well-defined objectives
- appropriate methods of implementation
- effective monitoring and assessment of performance against compliance targets
- well-defined lines of responsibility
- auditability
- communication of essential information to stakeholders
- periodic program review based on measured performance.

2.7 Controls

There are many controls that can be implemented in solving dust problems, including using water, chemicals or wind breaks, and redesigning materials handling equipment.

The most effective process for determining which controls to use for mitigating dust is to understand the controls and how they apply to a specific situation, and use the hierarchy of controls to make the final choice.

2.7.1 Hierarchy of controls

Efforts at controlling emissions of any type should follow the engineering hierarchy for control: source, then dispersion pathway, then receiver. The most beneficial controls are usually those applied at source, so that emissions are minimised or even eliminated. This is most effective for sources that have a small size and can be enclosed to enable filtration or other forms of capture and removal. Source control is not as straightforward for area sources or roads, where the application of water or chemicals is typically the most effective option.

Where emissions are unavoidable, there may be opportunities to reduce the downwind impact by installing windbreak systems, in the form of either vegetation or engineered structures. Such methods are most effective when they are close to the source, when the plume still has relatively small dimensions and thus can be more readily intercepted.

The least effective and least acceptable option is to mitigate effects at the receiver. This is rarely done, but can take the form of fully air-conditioning or paying for regular cleaning of the receiving premises.

2.7.2 Dust

Dust is by far the most prevalent problem air emission associated with mining and quarrying. The following mining or quarrying activities can lead to particulate emissions:

- the movement of top soil, the raw material or product and waste or overburden
- blasting, mining, hauling, conveying, stacking, loading (onto trains and/or ships) and reclaiming material
- clearing of open areas
- medium to heavy traffic on unsealed roads
- use of tailings dams where the surface has dried but has not been treated for dust mitigation (particularly if equipment is driven across the surface).

Before the final choice of control or controls can be made to solve a specific situation, it is vital to gain an understanding of the essential characteristics of the dust that is to be controlled. These characteristics are the material characteristics of the dust, its moisture characteristics, size distribution and hydrophobicity.

Mineral characteristics

Some soil, waste and raw material types tend to be dustier than others. If clay minerals are present, not only will particulate dustiness be more prevalent but particulate emissions will also be higher. The size distribution also plays a role in the severity of the particulate dustiness of the raw material, waste and/or soil, as does the porosity, density and hydrophobic nature of the material. It is important therefore to examine what is known about the dust characteristics of the raw materials, wastes and soil types that will be disturbed.

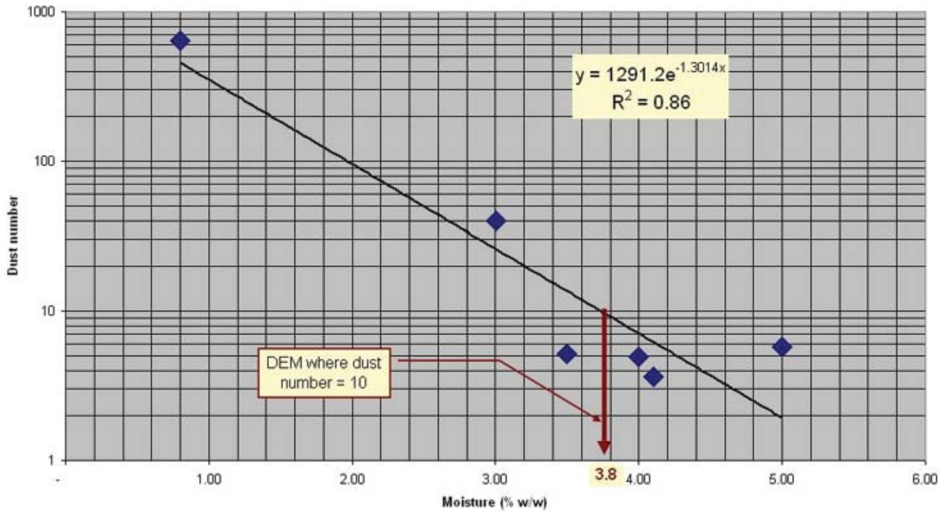
The extent to which a material will produce fine particles is a function of the minerals present. For example, the grains of clay minerals tend to be finer than those of most other minerals, so clays typically produce finer particles and larger volumes than most other minerals. In general clays are softer, less dense and more porous, and can be broken down by water if exposed to it for some time. This means that clays will absorb more water per tonne than most other minerals. It is important therefore to understand the mineralogy of the raw materials, wastes and soils in the operational area.

Moisture

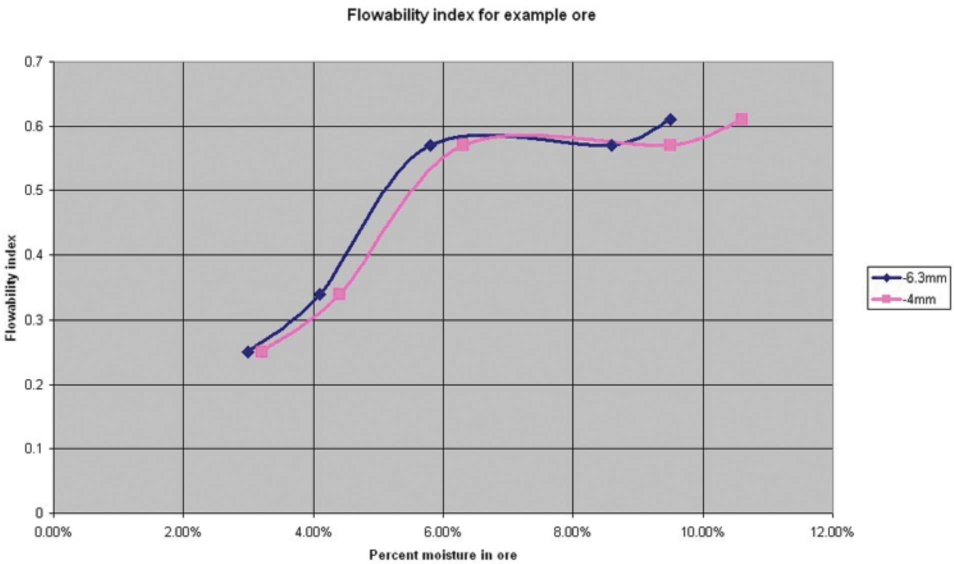
Moisture is the most significant mitigating agent available for controlling particulate emissions. In general, higher moisture means less dusty conditions. Unfortunately, there is also a point of moisture addition at which most materials become sticky, which can cause blockages in the plant and cause the material to 'hang up' in dump trucks and rail wagons.

Several moisture factors are tested for in order to understand the nature and behaviour of a material. Each raw material has two moisture limits that are critical to understanding the nature and behaviour of the material: the dust extinction moisture (DEM) and the materials handling moisture (MHM). The DEM, which is the lower moisture limit, is the moisture at which the material is no longer dusty. The MHM, which is the upper limit, is the moisture at which the raw material becomes sticky and begins to cause materials handling problems. These upper and lower limits are not exact figures and should be reported as ranges, not as a single point, in much the same way as tolerances are given with an engineering specification.

The two levels are determined during the same test program. The DEM and MHM can be determined by a suitably equipped materials handling testing facility such as Newcastle Innovation at the University of Newcastle. The figures below depict typical data sets associated with DEM and MHM determinations.



DEM (upper moisture limit). Source: John Visser, Rio Tinto.



Flowability index of a typical iron ore. Source: John Visser, Rio Tinto

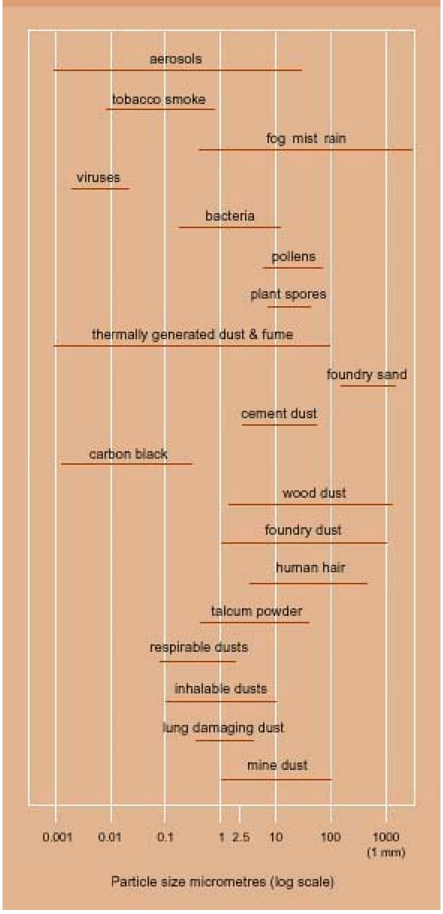
Because moisture is constantly being drawn from raw material by the sun and wind, it is prudent to ensure that the moisture level of any raw material that will be handled is kept at least 1 per cent or 2 per cent above the DEM, to ensure that particulate emissions are not generated. Moisture analysers are required to keep track of the moisture of the raw material as it is handled and water addition points should be placed at all available sites.

The DEM and MHM levels of each raw material body should be determined by test work, and a test program should be developed to perform this work. If the nature of the raw material changes (for example, if there is a change in the fine to coarse material ratio or the clay content) its DEM and materials handling moisture levels will also change, so the test work should be carried out again. When raw materials with known moisture limits are blended, the blended raw material behaves differently to the separate raw materials, so it is always best to perform the test work again using the planned raw material blends.

Particle size distribution

The next factor that affects the dustiness of products is the particle size distribution. In general, the finer the grain size the more dusty the behaviour of the material. Finer grains are lighter and can therefore be more easily blown about. Once suspended by the wind, finer grains tend to stay airborne more readily and are therefore also transported further from the source. Fineness is of course a function of the mineralogy, but it also depends on the energy imparted into the material by blasting, crushing, grinding and so on.

Figure 1 Sizes of common particles (after SIMTARS & Wark K and Werner CF, 1981)



Fine particle sizing. These particle sizes are typical of most dusts, but mine dusts can easily be as small as 1 micron. Source: *Air Pollution: Its origin and control*; Wark, K and Warner, C 1981.

Hydrophobic characteristics
Very dry, very fine particulate emissions particles can often behave as if they are hydrophobic for three reasons:

- Particulate emissions can be electrostatically charged, resulting in widely dispersed clouds of particles; if they have the same charge as the water droplets that are being used to wet them, the water droplets and the particulate emissions particles repel each other.
- The particulate emissions particles can be hydrophobic for a chemical or surface tension reason.
- The particles can behave in a hydrophobic manner because each particle has a high surface area, which means that coating the particles with water requires larger volumes of water per tonne of raw material than would normally be the case.

Appropriate test work is the only way to determine which of these three causes is affecting the materials that have been labelled hydrophobic.

2.8 Planning phase

Impacts of dust and other emissions need to be carefully considered in the planning phase of a mining project. The design and layout of any operation are vitally important in achieving an operation that is dust free. Equally important to reducing emissions are the levels of environmental assessment carried out and approaches to obtaining of approvals.

2.8.1 Environmental assessment

An air quality environmental assessment is normally required for a new project. It is important that the assessment team is suitably qualified and experienced. Much time and money can be lost in responding to regulators' questions arising from inadequacies in air quality assessments. The assessment should be as complete and accurate as possible, identifying all the potential sources of emissions and assessing their impacts.

The air quality assessment may involve establishing the baseline conditions, identifying emissions sources and their characteristics relevant to dispersion, compiling data on meteorology and emission rates, modelling the ground level concentrations of key pollutants (usually particles), describing mitigation measures and, importantly, conveying information to the potentially affected community.

The Victorian Environment Protection Authority's *Draft protocol for environmental management—mining and extractive industry* sets out three levels of project assessment:

> A level 1 assessment is required when developments are located close to residential areas or urban areas and have the potential to give rise to significant offsite impacts. These assessments are the most rigorous and require the most extensive modelling and monitoring data.
>
> A level 2 assessment is required when the proposed development is in a rural location with residences in close proximity or where a small operation is located in an urban area. A level 2 assessment is required when the proposed development is less likely to give rise to significant off-site impacts due to reduced scale, greater distance from residential areas or inherently lower emissions.

> A level 3 assessment is required when the development is in a rural location with no residences nearby. A level 3 assessment is the least onerous due to a lower potential risk arising from emissions from the proposed operations compared to operations requiring a level 1 or level 2 assessment. A level 3 assessment may be required when the development is small, in a location remote from residences, or where it is considered that the off-site impacts would be small compared to sites requiring level 1 or level 2 assessments.
>
> For mines and quarries with less than 20,000 tonnes/yr extraction, no modelling assessment of air quality is required, but emissions on site must be controlled by the application of best practice site management. (EPA 2006)

The specific requirements will differ in detail from one jurisdiction to another, but these Victorian examples are indicative of the rationale for environmental assessments.

The major pollutants of concern are related to dust and specific substances that may be contained within the dust (such as crystalline silica or heavy metals). For proposals requiring an air quality assessment, it is normally necessary to assess PM_{10}, which is the main airborne particle indicator. Depending on the jurisdiction and the circumstances of the site, it may also be necessary to consider $PM_{2.5}$, respirable crystalline silica (defined as the $PM_{2.5}$ fraction), arsenic, heavy metals (for example, antimony or lead), hydrogen cyanide, polycyclic aromatic hydrocarbons (such as benzo-a-pyrene), naturally occurring asbestos and radio nuclides or radon. Dust deposition may also be required. Early advice from the regulatory agency is strongly recommended.

Uranium mining poses specific issues around potential exposure of workers and the public to radioactivity. For members of the public, the most important pathways for an operating mine are generally radon transport and ingestion of radio nuclides following surface water transport. For a rehabilitated mine over the short term, the most important pathways are likely to be inhalation of radon progeny and radioactive dust re-suspension, and direct irradiation. Over the long term, groundwater and surface water transport of radio nuclides and/or their bioaccumulation into edible animals and plants that feed or grow on site or associated water bodies may become more significant (DEWHA 2009). Uranium mining proposals require detailed evaluation of these risks.

Some assessment procedures are deemed significant enough to warrant a public inquiry, to ensure that all issues are suitably aired and decisions on approval and conditions are appropriate. In New South Wales, for example, some projects are subject to public hearings by expert panels who make technical comment and recommendations for government to consider. An example is the process that was invoked for the assessment of the Anvil Hill (now Mangoola) coal mine project in the Hunter Valley. A key aspect of this process was the way in which decisions about private property acquisition were made in the light of uncertainties about the accuracy of model predictions of air and noise impacts in the surrounding community.

2.8.2 Value chain planning

The most effective way to manage total group operational costs, human resources and so on is to take a value chain approach—the same applies to mitigating particulate emissions. The effect of a particulate emissions reduction project carried out in the pit will benefit not only the pit and the associated plant but the downstream operations as well.

As a result, it is important to understand where and how particulate emissions mitigation projects can be carried out in the value chain and what benefits can be realised elsewhere.

CASE STUDY: Approval process for the Anvil Hill (Mangoola) coal mine project

The proposal for the Anvil Hill (now known as Mangoola) coal mine in the Hunter Valley of New South Wales was classified as a major project under Part 3A of the New South Wales *Environmental Planning and Assessment Act 1979*. After the environmental assessment (EA) had been publicly displayed, the Minister for Planning directed that an independent hearing and assessment panel would be constituted in accordance with section 75G of the Act, to assess key aspects of the proposal in more detail.

Under the Act, the Minister for Planning was required to consider the panel's report in deciding whether or not to approve the project. A panel of experts exercises its functions in accordance with arrangements made by the minister, but is not subject to the direction of the minister regarding the findings and recommendations of its report. The panel provided a report on its findings to the Director-General of Planning.

The panel held meetings with community stakeholders, government agencies and the project proponent in Muswellbrook from 17 to 19 October 2006. The Department of Planning received a total of 2,040 submissions on the proposal and the panel heard 28 submissions at the hearings.

The then Department of Environment and Conservation (now the Department of Environment and Climate Change) initially stated that it could not support the proposal, on account of noise, vibration, air quality, threatened species, Aboriginal cultural heritage and water quality impacts. The department was concerned that the proposal would 'represent an unacceptable impact on an entire community' at Wybong, 20 kilometres west of Muswellbrook.

The main grounds for objection were (in decreasing order of mention) greenhouse gas emissions and associated global warming/climate change; impacts on flora and fauna, and surface water and groundwater; noise and blasting; dust; and socioeconomic impacts (given the large number of property acquisitions required for the proposal).

(continued)

After extended consultation and the design of measures to address these concerns, the Minister for Planning approved the project, subject to conditions under the Act (see majorprojects.planning.nsw.gov.au/files/6563/Project%20approval%20and%20conditions.pdf).

Air quality

The panel recognised that air quality modelling contains inherent uncertainties, and that the available criteria do not fully address all aspects of dust impacts, particularly in relation to the nuisance potential from dust deposition. Therefore, it could eventuate that, over time, either more or fewer properties than were identified in the EA would be adversely affected by dust.

A primary issue with the predicted dust impacts was the potential for nuisance, associated with excessive dust deposition, which tends to be concentrated over time into discrete events. However, there are difficulties in adequately measuring and assessing such short-term events, and 24-hour average PM10 concentrations are the main short-term assessment benchmark.

The EA identified proposed measures for controlling both wind-blown dust and dust generated by mining. These measures include disturbing the minimum area necessary for mining, and rehabilitating completed overburden areas as soon as practicable; using water carts on coal handling areas and haul roads; using water sprays on coal stockpiles; using dust suppression equipment on drill rigs and lowering dust aprons; and confining blast charges.

Given some uncertainty about precisely how many and which properties might be affected by 24-hour PM_{10} concentrations above the 50 $\mu g/m^3$ assessment criterion, effective ongoing monitoring, dust management and community consultation was identified as an essential requirement. The panel indicated that the property acquisition program might need to be expanded further if actual mine performance were to result in higher than predicted impacts.

Approval condition 27 for the project requires an air quality monitoring program that includes a combination of real time monitors, high-volume samplers and dust deposition gauges to monitor the dust emissions of the project, and an air quality monitoring protocol for evaluating compliance with the air quality impact assessment and land acquisition criteria in the approval. Condition 26 requires the operator to regularly assess real time air quality monitoring and meteorological monitoring and to relocate, modify or stop mining operations as required to ensure compliance with the air quality criteria.

Noise

The EA indicated that, under worst case operational and meteorological conditions, the project would have a moderate to significant impact on a large number of private properties at some stage during the course of the project. Notwithstanding mitigation measures, the project would result in a residual noise impact to a large number of private properties.

(continued)

The number of properties identified in the EA as likely to be affected by operational noise was 179, including 106 significantly affected properties. By the time the panel made its report, the proponent's land acquisition program had reduced the number of affected private properties to 118, including 49 significantly affected properties. Independent analysis by the panel indicated that the noise predictions in the EA may have been marginally underestimated for properties to the north-west, meaning that around 10 additional properties might be significantly affected.

To compensate for noise impacts, and given the very low background noise conditions of the locality, the noise conditions placed on the project are significantly more stringent than the standard approach to noise management. They included requirements for the proponent to:

- undertake (with landowners' consent) architectural noise treatments at
  - all residences where operational noise levels meet or exceed a noise criterion of 35 dBA
  - all residences where traffic and rail noise levels exceed the relevant road and rail noise criteria
- purchase (with landowners' consent) any private property that experiences operational noise levels at or above 40 dBA
- establish and implement a comprehensive noise monitoring program which includes real time monitoring of noise impacts with the view to modifying mining operations as appropriate to reduce noise impacts.

2.8.3 Baseline monitoring

As outlined in Section 2.4, baseline monitoring is normally required to gather site-specific information on existing air quality. The level of monitoring will depend on the potential size of the impact and the sensitivity of the surrounding land use. Monitoring will typically not be required if the site is remote from sensitive receivers and there is an absence of other major emission sources.

For baseline monitoring it may be sufficient to establish one monitoring site, but if there are existing sensitive sites around the project area the possibility of local variations in existing air quality should be considered, and additional monitoring sites established if warranted.

Issues of instrument selection, siting, power requirements, maintenance and data quality must be carefully considered. If a level 1 type of assessment (as described in Section 2.8.1) is required, it will be necessary to measure PM_{10} (and $PM_{2.5}$) and to analyse samples for hazardous components such as crystalline silica. For the monitoring of PM_{10}, if a continuous time-varying background is required for modelling a sophisticated instrument such as a TEOM will be required. These instruments can record data every 10 minutes. Alternatively, a less detailed approach would entail a more traditional high-volume sampler or a partisol sampler, gathering 24-hour average data.

It is important to gather meteorological data as part of an air quality monitoring program. Weather data are important for interpreting air quality data and can be used in dispersion modelling. If it can be demonstrated that representative background data are available from a nearby site, monitoring may not be required.

2.8.4 Modelling and impact assessment

Modelling the dispersion of emissions involves the input of data on emissions, meteorology, terrain and surface roughness (which can be represented indirectly by land use categories). Models require slightly different details for point, volume or area sources to be handled. However, for each source type data are required on location, dimensions, release height and emission rate. Emission rates may be entered as constant values, or may be allowed to vary according to season, time of day or meteorological conditions.

At the planning stage, emission rates for the project must be estimated using best available data and methods, since they cannot be measured. The most common approaches are to use actual data from very similar sources and to scale them according to size, or more commonly to apply emission factors. Emission factors are often used for NPI reporting, and are documented in NPI manuals (www.npi.gov.au/handbooks/index.html) for a wide variety of activities. However, emissions estimates are inherently prone to uncertainty, and it is important to be aware of the sensitivity of emission rates to the assumptions and data choices involved in using emission factors. Default values provided for various parameters in emission factors can and should be replaced by site-specific data whenever possible.

The planning phase should involve early engagement between project planners and engineers on the one hand and the air quality consultants on the other. Preliminary modelling will identify any potential problem issues, identifying specific emission sources that are likely to have high impacts. This allows for feedback to the design process to modify layouts, processes and the like and iteratively reach a satisfactory result.

2.8.5 Planning for locations of operations and clear areas

In terms of the hierarchy of control, the most important way to prevent dust impacts on mining operations and the local community is to eliminate the problem entirely. Careful planning of the location of operations is the best way to prevent dust becoming a nuisance.

Distance from other activities and consideration of prevailing winds

The geographic location of the operation must be as far away from any existing sensitive receptor (dwelling, village, town, school, hospital, etc.) as is practically possible. This consideration will mitigate visual, dust and noise impacts. In addition, the location must always be downwind (in terms of the prevailing winds) of any such settlement. Once the site has been purchased the location of the mine, plant and stockpiles must be the first consideration in the design of the site. They must be located as far as possible from, and downwind of, any offices or workshops.

Size of the site
When considering the area of land to be purchased/leased, the larger the site the better it is. When a new site is established the land is relatively cheap, so this is the best time to establish a large site. Purchasing a large area prevents the establishment of a local community close enough to the site to be bothered by the site's operations.

Once a site has become operational, people not associated with the operation will migrate towards the site and, in time, they will begin to impose their will on the operation in terms of their environmental needs. If the site is sufficiently large, the operation's impact on this new community will naturally be minimised.

Local hills or rises
Never place an operational site on a raised area such as a hill. This is the worst scenario that can be considered, since it exacerbates the effect of the visual, dust and noise impacts of the site on the surrounding area. If a hill is on the site, the most useful place to put the operation is on the downwind side of that hill. The hill will force any wind to blow up and over the site, which will reduce the adverse impact that the site will have on the region.

Existing flora
When preparing the site for construction, do not clear (or allow a contractor to clear) the entire site of trees, bush and grass. The natural flora play a significant part in reducing the impact that an operation will have on the region, by hiding the infrastructure, collecting dust in the foliage, slowing and disrupting wind flows and absorbing noise. Specific areas should be designated and cleared as roadways, lay-down areas and construction sites and all other areas of the site should be designated no-go areas for any use.

Roads
The most well-known dust sources on a mine site are the roads. On an annual basis, the roads at an operation will produce as much dust lift-off as the dust generated by the movement of the raw material. When designing or laying out a new operation, the location and design of the roads should take into consideration particulate emissions.

A well designed road will last longer and produce fewer emissions than a quickly and usually poorly built road. Roads and parking areas that are environmentally friendly are usually sealed by one of the chemicals mentioned in Table 2.5. Roads that are laid out with particulate emissions in mind will tend to be downwind of offices, workshops and so on.

2.8.6 Mitigation measures

The planning phase should establish a solid outline of mitigation measures needed to ensure that the future operation will be able to meet air quality objectives. These measures may include:

- applying specific engineering controls on significant emission sources, such as watering systems for stockpiles
- sizing the elements of the project to limit emission rates
- tactics to be implemented in unfavourable conditions, such as limiting or ceasing activities, or applying controls such as watering, under critical weather conditions.

A critical aspect at this stage is to understand the implications of model uncertainty for the extent and type of mitigation measures that might be necessary once the operation is in place. If actual impacts are greater than expected, additional measures will be needed, so it is important to explore the 'worst case' possibilities at the planning stage.

2.8.7 Community consultation

Most communities faced with a new mining project in their neighbourhood will have some negative feelings about it and may vigorously object to the proposal. The onus is on the company to fully and openly explain the project's impacts on the neighbours, to be mindful of their concerns and, as far as possible, to work with them to resolve any misunderstandings and unreasonable impacts.

Generally, community concerns and their level of negativity are greater if people perceive that the information given to them is incomplete, unreliable or dismissive of the true nature of their objections. Hence, a strictly technically based consultation process may do more harm than good, as there are usually purely personal and perceptual concerns, as well as more pragmatic concerns about property value, amenity and community continuity, that need to be addressed.

A sensitive and serious approach to community consultation is essential at the planning stage, and an experienced consultant expert in this area is an important team member.

2.9 Exploration, development and detailed design phase

2.9.1 General

At this exploration and design stage, there is usually a limited amount of activity that will generate significant emissions. Nevertheless, any drilling, excavation and handling or transport of materials that could potentially impact on neighbours should be conducted with that impact in mind. It may require the location or timing of various activities to be managed so that they have minimal impacts, and/or the watering of dusty operations that are close to sensitive areas.

As design detail progresses, there may be a need to refine emission control specifications based on improved inputs for modelling. Hence, it is important that the engagement with air quality consultants continues as required. Baseline monitoring, if any, should be in progress through this stage.

2.9.2 Risk assessment

Prior to any ground disturbance, a risk assessment of the operation should be carried out. An environmental specialist with particulate emissions experience should be involved to provide a sound understanding of the effects of any event being planned.

There are many cases in the mining industry where an incorrect understanding of the fundamental principles of particulate emissions formation has led to the creation of a particulate emissions problem and resulted in the mining operation's having to expend disproportionate effort to resolve the problem. This kind of situation can be avoided when the risk assessment is carried out, if the risk assessment team contains the necessary skills.

2.10 Construction phase

During the construction phase, there is a range of activities, such as earthmoving and road construction, which generate dust, possibly at higher levels than during the operational stage, at least for parts of the project site. If those parts of the site are close to sensitive areas, attention will need to be given to controlling dust emissions, especially under adverse dry and windy conditions.

Any baseline monitoring will continue through this stage. Also, if there is a potential for dust impacts on neighbours arising from construction, the situation may warrant the installation of one or more dust-monitoring instruments which can be used (at the boundary or at the sensitive location) to capture real time data and send an alarm when a predefined dust concentration is reached. In this way, activities can be controlled to minimise short-term dust events in response to the early-warning capability. These types of instruments are not compliant with regulatory standards and cannot be used for compliance monitoring, but are very useful for real time management.

2.11 Operations phase

At the operational stage, the major emissions and air quality issues occur, requiring an ongoing management plan that is both rigorous and flexible.

2.11.1 Management plan and system

A dust or air quality management plan may be required as a condition of approval. Even if it is not mandatory, there are good reasons to have a plan in place to deal with any issues that could adversely affect the operation.

Even where there are no sensitive neighbours to consider, there may be value in limiting dust impacts on machinery wear or vehicle operator safety. Generally, however, the main focus will be on limiting impacts on neighbours (which, apart from residents, might include sensitive ecosystems or farmland) and staying in compliance with regulatory requirements.

A management plan's success is gauged by measurable performance: it must be more than a document that sits permanently on a shelf; it should be a document that is of daily relevance, not only to the environmental manager but also to senior management and the site operators.

An essential part of the management plan is a well-structured system for monitoring, recording, quality checking and reporting information transparently and consistently. All data have a value, which in some cases may not be completely obvious until a later time when readily available, high-quality data is important for a purpose such as an air quality impact assessment.

2.11.2 Monitoring

Compliance monitoring may be required by licensing conditions, in which case the regulatory agency will specify the requirements. However, the specific location(s) for monitoring may require negotiation with landowners, and allowances may need to be made for finding suitably exposed sites, power supply, ready access and so on.

Once a monitoring site has been established, it is important that correct maintenance and calibration is carried out to maximise the return of reliable data. Capturing all information in a single data repository is also an important feature: many problems can occur when data is captured on disparate platforms and cannot readily be consolidated or tracked over time.

Compliance monitoring requires a system that complies with the relevant Australian Standards and regulatory requirements. For particle monitoring, this will typically entail high-volume, partisol or TEOM instrumentation. In specific cases, specialised monitoring or analysis may be required: for example, for respirable crystalline silica, asbestos, radio nuclides or radon. In these cases, it is important to receive expert advice.

For many sites, there may be an additional requirement for real time monitoring, similar to the needs at the construction phase but perhaps on a larger scale. The requirement may be to address approval conditions or may be a voluntary undertaking. In either case, it should be set out in the air quality management plan.

A real time system may entail an array of monitors set out to provide indications of dust levels over periods as short as 1 minute. The regulator or a consultant will be able to establish a suitable trigger level for the short-term concentration that signals a need for intervention, in order to maintain compliance with the 24-hour standard. Most real time monitors are capable of sending out electronic, audible or visual alarm signals. The siting of a real time system should aim to provide information about the current or imminent impacts on the most sensitive locations around the mine.

At the opposite extreme to real time monitoring, dust deposition measurement using standard dust gauges, which collect samples over 30 days, is a useful adjunct to the monitoring program and also may be required by consent conditions. Deposition measurement is relatively inexpensive, but measurements can be prone to problems of sample contamination and vandalism, and care needs to be taken over siting, security and liaison with neighbours.

Most dust nuisance occurs as a result of specific short-term events rather than a gradual background accumulation of dust. Because dust gauges can yield only a monthly deposition rate with no information on short-term events, their results may not correlate well with the level of annoyance or complaints being received.

Nevertheless, dust deposition monitoring remains a common way of obtaining an indication of nuisance impacts, and can also be important in determining whether the deposition rates of hazardous components, such as lead, are at acceptable levels. An array of deposition gauges around the boundary and near sensitive locations is recommended.

2.11.3 Control and mitigation

A variety of control and mitigation efforts come into play during the operational phase. The matrix in Table 2.3 can be useful as a starting point in designing an appropriate mix. The matrix provides a useful checklist for the selection of an appropriate mitigating control in various particulate emissions situations.

Table 2.3 Control and mitigation matrix

	Barriers	Capture	Chemicals	Design	Greening	Moisture	Replace	Surface treatment
In the pit	YES		YES	YES	YES	YES		
Underground	YES		YES	YES		YES		
Stockpiles	YES		YES	YES	YES	YES	YES	YES
Transfer points		YES	YES	YES		YES		
Roads	YES			YES	YES	YES	YES	YES
Materials handling plants	YES	YES	YES	YES		YES	YES	
Smelting operations	YES	YES	YES	YES		YES	YES	
Tailings dams, open areas	YES			YES	YES	YES		YES

Note: Barriers = these could be trees, hills, or man-made barriers

Capture = collecting the dust using a bag house, precipitator or scrubber

Chemicals = modifying the raw material characteristics

Design = this refers to the design stage during which engineering solutions can be applied to mitigate particulate emissions

Greening = planting trees, shrubs, grasses

Moisture = using water to control dust

Replace = using either roads, rail, or conveyors whichever produces the least dust

Surface treatments = using bitumen, concrete, chemicals etc.

2.11.4 Mine

If the moisture content of the product is modified in the mine there can be a beneficial knock-on effect all along the value chain. This is true because the sooner that newly exposed raw material is conditioned by water, the more easily it absorbs water later on. The benefits are different for different products but the following benefits can accrue:

- Additional moisture will reduce the dustiness of the product, and can lead to some binding of the very fine particles which will cause them to behave as larger particles which are easier to manage.
- When raw materials are particularly dry and prone to being dusty, spraying water onto the blast prior to mining not only conditions the raw material but improves safety, as it reduces the particulate dustiness caused by the operations of the shovel or front-end loader. By wetting the raw material prior to mining, the number of poor visibility events will be reduced, increasing mine availability.

A typical mobile irrigator, used on an iron ore mine in the Pilbara region of Western Australia. Source: Southern Cross SX2500 3500 Operators Manual V2.

The mobile irrigator being used to wet the iron ore in the pit. The direction of travel is towards the anchor. A rotameter driven by the water winds the cable up onto the cable reel. Source: John Visser, Rio Tinto.

2.11.5 Plant

The principles in this section are applicable to both process plant and any type of materials-handling plant. Transfer points, operating equipment and discharge points within the materials-handling systems provide the potential for significant dustiness at the operation. The topics in this section describe particular dust-related issues that arise at certain points in the mining operation.

Designing seals and enclosures

Following the hierarchy of control, the most successful solution to dust arising from operations lies in eliminating ultra-fine particles from the raw material stream. This can be accomplished by bringing the raw material stream up to the DEM point. However, this is not a perfect solution, because water addition systems can fail and maintaining the DEM does not produce a dustless raw material. Substitution, the next level in the hierarchy of control, is not an option in this case.

The third level of control, preventing dust from leaving the raw material stream, can be applied by ensuring that all the transfer points and operating equipment within the plant are enclosed, and that the seals of the enclosures operate in a way that takes into account the specific application. So, for example, the design and sealing method for the enclosure for a crusher are different to those for the enclosure of a transfer point.

It is important to ensure that, when the raw material stream enters a transfer hood/chute, there is as little open space in that entrance as possible. This limits the volume of air drawn into the chute, which in turn prevents the fine particles from being blown around when they become airborne while falling.

The design of the seals for enclosures in the plant should be practical and maintainable so that the operators use them and the maintainers keep them working and replace the covers after working on the chute. There are several companies that specialise in designing this kind of equipment.

When the material stream has a high moisture content prior to being separated into coarse and fine material, the dustiness of the stream is less than the dustiness of the separated coarse material and fine materials. There are two reasons for this:

- The ultra-fines tend to adhere to the coarse particles, which provide stability to the fine particles.
- Coarse particles provide localised wind breaks for the fine particles lying next to them, which reduces local particulate lift off.

These effects occur on conveyors, stockpiles and trucks.

Changing the flow of raw material

Impact plates create particulate dustiness by imparting energy into the moving raw material stream by changing the direction of flow in the same way that the flow direction is changed when the raw material hits the top of the stockpile. This results in particles bouncing away, opening up the raw material stream and releasing the fine particles which are caught up in the moving air stream that always follows a moving raw material stream. In addition, the larger particles with sharp points often lose those points when they impact on the impact plate, which causes more particulate emissions.

There are three ways to control the resulting particulate emissions, described in the section below on transfer chutes and stockpiles. The same solutions can be applied to impact plates in other plant, such as crusher and screen feed boxes.

Tipping the raw materials

Dust generation occurs at truck tipping points, such as the crusher dump pocket/grizzly feeder, because the material is allowed to free fall, it is disturbed from its resting place, there are always high impact zones associated with tipping points and the moisture of the material is usually lower than the DEM. This is an excellent point at which to modify the moisture of the raw material stream and/or add an appropriate chemical.

Using conveyors

There are three potential sources of dust resulting from the transfer of raw material along a conveyor:

- the movement of the raw material over idlers
- the resonations of the conveyor structure
- the failure of belt-cleaning mechanisms.

The raw material may develop small localised dust clouds at particular points along the conveyor, as a result of the movement imparted into the raw material as the belt passes over the idlers and down into the trough between the idlers. This is usually insignificant, because the fine particles usually fall back onto the conveyor and are removed. However, if even a gentle breeze is blowing, these fine particles are taken away from the source and a dust cloud forms. There are three solutions to this problem.

The first and best way to stop this from occurring is to add water to the raw material stream at some point/s upstream of the source of dust. The 'rules of thumb' for adding water into a moving raw material stream are:

- Add a maximum of 0.5 per cent by mass of water to the free-falling raw material stream at any one transfer point.
- If adding water to the surface of the raw material stream lying on a conveyor, do not add more than 0.2 per cent per string or, on an overland conveyor, per 350 metres length.
- Always remember that the sprays should be aimed to direct the water at the raw material stream with no direct impact on the conveyor parts or structure.

If there is insufficient water available, because of a lack of the resource itself, an inadequate delivery system or a lack of transfer points in the raw material handling system at which water can be added, other solutions are needed.

The second solution that can be employed to stop wind erosion from the surface of the raw material on the conveyor is to treat the raw material stream with a chemical that will bind the ultra-fine particles together without detrimentally affecting the raw material itself. The chemical should contain a wetting agent to aid in penetration of the raw material stream.

The last way to solve the problem is to install a wind barrier over the conveyor structure, with an open end on the leeward side of the conveyor belt to allow access for maintenance. This solution has two benefits: it is effective, and it provides clear proof to staff and the community that the company is committed to dust mitigation. The disadvantages of this solution are the capital costs and downtime (in the case of an active operation) that are required for installation.

A similar source of dust, if the conveyor structure is not well designed, is the resonation of the entire conveyor structure. The solution to this is to modify the structure and stop it from resonating.

The third cause of dustiness is the dust that clings to the conveyor belt and is systematically removed, portion by portion, at each return idler. This is best resolved by the installation of belt-cleaning stations that are robust and work. There are a few suppliers that provide solutions that consistently work without significant maintenance costs. They supply both dry and wet cleaning systems; the wet cleaning systems are the most effective in removing this clinging dust.

Transfer points

Transfer points involve a falling stream of raw material which generates dust as described under 'Changing the flow of raw material'. Transfer points are to be found at junctions between conveyors and unit processes such as screens, crushers and so on or between one conveyor and another conveyor. They are usually the dustiest points in the entire plant.

Dust is created at transfer points in three ways:

- Fine particles are liberated from the raw material stream as the raw material cascades down the transfer point
- If impact plates are used to change the direction of the raw material as it cascades through the transfer point, dust will continuously be generated at this point. Small pieces of raw material are broken off larger rocks by the impact of the large rocks on the wear plates (and other steel members) of the transfer point. Impact plates create particulate dustiness by imparting energy into the moving raw material stream by changing the direction of flow in the same way that the flow direction is changed when the raw material hits the top of the stockpile. This results in particles bouncing away, opening up the raw material stream and releasing the fine particles which are caught up in the moving air stream that always follows a moving material stream
- The raw material stream drags air along with it into the transfer chute and this air is expelled at the exit point, taking with it ultra-fine dust particles.

The solutions to this problem accomplish two objectives. The first is to reduce the energy imparted into the raw material stream while it is being directed through the transfer point, through chute design. The other objective is to prevent the moving stream of material from spreading out, either to the side or from becoming elongated. The two main chute systems are:

- Hood and spoon chutes—There is much negativity surrounding hood and spoon type transfer chute systems, because of their perceived high capital and operating costs. However, if designed properly, these systems can provide a dustless operation. The benefits of a hood and spoon transfer point are that there is no impact point where dust can be generated, they are virtually noiseless, conveyor belt wear is reduced significantly and there are no housekeeping issues caused by dust build up.
- Cascade rock box chutes—Cascade rock box chutes can be retrofitted into most existing chutes. They introduce a series of 'rock boxes' located in a close cascade from the top of the transfer station to the bottom, increasing the number of impact points but significantly reducing the energy imparted at each drop by reducing the drop height considerably. This type of chute is not designed to transfer fine material.

Rock box style chute. Source: John Visser, Rio Tinto.

Any chute will become dusty if it is not properly maintained. Holes in the sides and wear plates allow the egress of fine particles from the chute.

Moisture splitting

During the screening process coarse and fine particles are separated from each other. After this separation any moisture remains in the fines, because of the significantly higher surface area inherent in fines, and the coarse material is dry. As a result, when coarse particles are broken in processes downstream of the separation they are prone to dustiness, which may mean that water needs to be added to the coarse material at that point. This factor must be considered during the design phase of the plant.

Moisture mixing
In general when wet raw materials are mixed with dry raw materials, the moisture from the wet raw materials mitigates dustiness from the dry raw materials simply by being mixed into the dry fines. There is a secondary dust mitigating effect that aids in reducing the dustiness of a dusty raw material when it is mixed with a less dusty raw material: the ultra-fine particles in the dusty raw material will find additional particles to which they can adhere.

2.11.6 Roads

The most well-known dust sources on a mine site are the roads. On an annual basis, the roads at an operation will produce as much dust lift-off as the dust generated by the movement of the raw material.

Wearing course material
The selection of a mine road surfacing or 'wearing course' material is central to the functional design of a road. Functional design of a haul road is the process of selecting the most appropriate wearing course material or mix of materials, typically natural gravel or crushed stone and gravel mixtures, commensurate with safety, operational, environmental (dust generation) and economic considerations. The most common wearing course materials for haul roads are compacted gravel or gravel and crushed stone mixtures.

A well-selected wearing course material will not generate excessive dust. The specifications for such a material are based on an assessment of the wearing course material shrinkage product (Sp) and grading coefficient (Gc), defined in the following equations:

$$Sp = LS \times P425$$

$$Gc = \frac{(P265 - P2) \times P475}{100}$$

LS	=	Bar linear shrinkage
P425	=	Percent wearing course sample passing 0.425mm sieve
P265	=	Percent wearing course sample passing 26.5mm sieve
P2	=	Percent wearing course sample passing 2mm sieve
P475	=	Percent wearing course sample passing 4.75mm sieve

Other tools for selecting a suitable wearing course material include a selection chart.

The choice of wearing course should also be evaluated in the light of other material property limits identified as important in the generation of dust, as shown in Table 2.4.

Table 2.4 Recommended parameter ranges for selecting haul road wearing course material for reduced dust generation

Impact on functionality below recommended range	Material parameter	Recommended range	Impact on functionality above recommended range
Reduce slipperiness but prone to raveling and corrugation	Shrinkage product	85-200	Increased dustiness and poor wet skid resistance
Increased loose stones, corrugations and potential tire damage	Grading coefficient	20-35	Increased raveling and poor dry skid resistance
Reduced dustiness but loose material will ravel	Dust ratio	0:4- 0:6	Increased dust generation
Increased loose stoniness	Liquid limit	17%- 24%	Prone to dustiness, reduced raveling
Increased loose stoniness	Plastic limit	12%-17%	Prone to dustiness, reduced raveling
Increased tendency to ravel, loose stoniness	Plasticity index	4-8	Prone to dustiness and poor wet skid resistance
Poor wet weather trafficability, churning, excessive deformation and cross-erosion, maintenance intensive	Soaked California Bearing Ratio at 98% Mod American Association of State Highway and Transport Officials	80	Increased resistance to erosion, rutting and improved trafficability
Ease of maintenance, vehicle-friendly ride and no tyre damage	Maximum particle size	40 mm	Poor surface finish following maintenance, potholing and potential tyre damage

Water-only treatment vs. chemical treatment

Roads whose surfaces are treated with water alone increase in their dustiness with time. This occurs simply because the water keeps the dust particles in place without protecting them, allowing the traffic on the road to continually grind the particles finer until the dust size becomes ultra-fine. There is some mitigation of this when the roads are graded and resurfaced as part of the normal road maintenance.

In addition, roads that are too wet can become a safety hazard, as the road surface becomes muddy and slippery. Poorly surfaced roads cause increased operational and maintenance costs due to high tyre wear and high rolling resistance. Poorly maintained road surfaces also lead to high vehicle operating costs.

Indeed, even roads treated with most chemicals will become a source of dust, because they cannot be swept clean on a daily basis since the sweeping activity slowly destroys the treated surface. A spray-on reapplication is often required to control this dust source. However, roads that are treated with chemical palliatives and regularly swept clean will lead to less dusty and safer operating facilities.

Dust palliatives

In broad terms, the effectiveness of any dust suppression system depends on changing the wearing course material's susceptibility to erosion. The wearing course silt and fine sand fractions (for example, 2 microns to 75 microns) are a good indication of its erodibility.

The motivation for using some additional agent to reduce a material's inherent erodibility is based on increasing particle binding. The finer fraction, although contributing to cohesiveness, also generates much of the dust, particularly when the material is dry. The presence of larger fractions in the material will help to reduce the erodibility of the finer fractions, as will the presence of moisture, but only at the interface between the surface and the mechanical eroding action. This forms the basis of the water-based dust suppression techniques used most commonly on mine haul roads.

The consequences of dust generation include:

- loss and degradation of the road pavement material, the finer particles being lost as dust and the coarser aggregates being swept from the surface or generating a dry skid resistance defect
- decreased safety and increased accident potential for road users, due to reduced or obscured vision and reduced local air quality
- higher vehicle operating costs, with dust penetrating the engine and other components and resulting in increased rates of wear and more frequent maintenance.

From a mining perspective, the following parameters would define an acceptable dust palliative:

- spray-on application with deep penetration (the ability to penetrate compacted materials), or (less preferable) mix-in applications requiring minimal site preparation (rip, mix-in and recompact)
- straightforward applications requiring minimal supervision, not sensitive nor requiring excessive maintenance or closely controlled reapplications
- short product curing period, so that the road is trafficable within a maximum of 24 hours
- availability in sufficient quantity at reasonable prices
- adequate proven or guaranteed durability, efficiency and resistance to deterioration by leaching, evaporation, ultra-violet light and chemical reaction with the wearing course or spillage on the road
- effectiveness over both wet and dry seasons
- independently evaluated against local and international safety standards and environmental requirements.

The broad classes of products available are listed in Table 2.5, which also provides a tool to identify classes of palliative which would suit a certain application.

Table 2.5 Dust palliative products and application parameters

	Hygroscopic Salts	Lignosulphonates	Petroleum-based products	Others [a]
Climatic limitations	Salts loose effectiveness in continual dry periods with low relative humidity. Selection dependant on relative humidity and potential to water road surface.	Retains effectiveness during long dry periods with low humidity.	Generally effective, regardless of climate, but will pothole (small diameter) in wet weather where fines content of wearing course is high.	Generally effective, regardless of climate.
Wearing course material limitations	Recommended for use with moderate surface fines (max 10% to 20%<75 micron suitable for low-fines materials or high-shrinkage product/plasticity index, low CBR[b] or slippery materials.	Recommended for use where high (<30%<75 micron) fines exist in a dense graded gravel with no loose material.	Performs best with low fines content (<10%<75 micron). Use low-viscosity products on dense fine grained material, more viscous products on looser, open-textured material.	Plasticity index range 8–35 Fines limit 15%-55% < 75 micron. Minimum density ratio 98% MDD. Performance may depend on clay mineralogy (enzymes).
Treatment maintenance and self-repair capability	Reblade under moist conditions. Calcium chloride is more amenable to spray-on application. Low shrinkage product materials may shear and corrugate with high speed trucks. Tendency to shear or form 'biscuit' layer in dry weather–not self-repairing.	Best applied as an initial mix-in and quality of construction important. Low shrinkage product materials may shear and corrugate with high-speed trucks. Shear can self-repair.	Requires sound base and attention to compaction moisture content. Slow speed, tight radius turning will cause shearing–not self repairing, but amenable to spot repairs.	Mix-in application–sensitive to construction quality. Difficult to maintain/rework. Generally no problem once cured.
Tendency to leach out or accumulate	Leaches down or out of pavement. Repeated applications accumulate.	Leaches in rain if not sufficiently cured. Gradually oxidises. Repeated applications accumulate.	Does not leach. Repeated applications accumulate.	Efficacy depends on the cation exchange capacity of the host material. Repeated applications accumulate.
Comments	A high fines content may become slippery when wet. Corrosion problems may result.	Generally ineffective if wearing course contains little fine material or there is excessive loose gravel on the road.	Long lasting–more effective in dry climates.	Generally ineffective if material is low in fines content or where loose gravel exists on surface. Curing period required.

Notes

a Includes sulphonated petroleum, ionic products, polymers and enzymes.

b California Bearing Ratio (%).

Importantly, a poor wearing course material cannot be improved to deliver an adequate performance solely through the addition of a dust palliative. The haul road wearing course material should ideally meet the minimum specifications presented earlier. If not, the inherent functional deficiencies of the material will negate any benefit gained from using dust palliatives.

In road surfaces with too much gravel, dust palliatives do not appear to work effectively, more especially where a spray-on technique is used as opposed to a mix-in. The palliatives do not aid compaction of the surface because of the poor size gradation, nor form a new stable surface. New surface area is created from exposed untreated material while, with a mix-in application, poor compaction leads to damage and raveling of the wearing course, traffic-induced breakdown of the material and eventual dust generation. With regard to water-soluble palliatives, rapid leaching may be problematic in some climates.

In compact sandy soils, tar and bituminous emulsion products appear effective where leaching of water-soluble products may be problematic. However, in loose medium and fine sands, bearing capacity will not be adequate for the tar/bitumen products to maintain a new surface and degeneration can rapidly occur.

In road surfaces with too much silt, it is unlikely that a dust suppression program will be effective. Excessive silt or sand fractions may lead to slipperiness while poor bearing capacity leads to rutting and the need for road rehabilitation or maintenance, which destroys most products. Small-scale potholing has been observed on a number of pavements following spray-on application or reapplication, as a result of traffic lifting fine cohesive material from the road. Again, where no depth of treatment has built up, this will lead to the creation of new untreated surfaces.

In general, spray-on applications do not appear appropriate for establishment of dust treatments, especially with regard to depth of treatment required. A spray-on re-application or rejuvenation may be more appropriate, but only if penetration of the product into the road can be assured; otherwise, it will only serve to treat loose material or spillage build up, which will rapidly breakdown and create new untreated surfaces. A spray-on treatment is however useful to suppress dust emissions from the traffic-free roadsides, since it would be easier to apply and, because the material is typically uncompacted, would provide some depth of penetration and a reduction in dust emissions due to traffic-induced air turbulence.

Finally, vehicle speed can be controlled not only for safety reasons but also to improve the effectiveness of dust control measures. In general, vehicle speeds of 40 kilometres per hour and less do not result in dusty conditions being experienced.

Idle open areas

Active areas must be kept to the absolute minimum, with roads, parking areas and no-go zones specifically designated. Drivers, particularly those with 4X4 vehicles, should be educated about the need to drive only on designated roads. Keep the roads treated with a suitable chemical.

All open areas that are not required for vehicle access or construction should be isolated and sprayed with a hydromulch chemical. Hydromulch will provide seeds, the required nutrients for germination and immediate cover against dust lift-off.

If chemical veneers can be used on the open area in question, dust can be controlled very effectively by chemically treating the area. The application can be achieved with mobile irrigation systems or aeroplanes for large areas. Mobile irrigators can also be used to spray open areas. As shown in the figure in Section 2.11.4, the irrigator pulls itself along, which means that its use is not labour intensive.

2.11.7 Stockpiles and stockyards

Stockpiles are often dusty during the stacking and reclaim processes, and they are also a source of dust when the wind blows. There are many ways to stop dusty conditions in the stockpile area.

Primary stockpile discharge points

Stackers must have sprays installed onto the boom as a matter of course. Sprays that can modify the moisture of the material should be installed but used only when necessary. They should be directed into the falling material stream.

Misting sprays should also be installed to provide a mist curtain that will behave in the same way that fine dust will behave when the wind is blowing. The dust-water interaction results in dust particles that become too heavy to continue to be blown away and fall to the ground. These sprays should be directed to form a curtain around the falling stream so as to trap the fine particles.

An example of a well-designed stacker spray system. A stacker boom requires spray at the discharge end only. Source: John Visser, Rio Tinto.

If the raw material is already at DEM, the nozzles should be low-volume misting nozzles directed along the raw material stream to stop the immediate dust. This will prevent run-off (which creates housekeeping work) caused by too much water. If it is necessary to add water to the raw material at this point, both misting and water addition nozzles will be needed to stop the immediate dust as well as to increase the raw material moisture. Both sets of nozzles should form part of the water curtain around the raw material stream.

The nozzles on the stackers should have automatic and local control valves. The objective of installing local control valves is to allow an operator/maintainer to perform work on the nozzle/spray bar while the stacker is operating. The valves should however remain in automatic setting under normal conditions, which means that the manual valves should always be in the open position. A spray system that includes misting nozzles and low-angle fan nozzles for trimming purposes is required.

Mobile reclaimers

Bucket wheel reclaimers generally require two sets of nozzles to manage dust. One set is needed to spray into the face of the stockpile immediately ahead of and behind the cutting wheel, to stop dust that is caused by the raw material as it rills down the face. The second set is needed to spray into the raw material stream as it cascades out of the buckets into the transfer chute and onto the boom conveyor. The water must not be allowed to impinge onto the structure of the boom because that will cause fine raw material to stick to and build up on the structure, which will in turn upset the balance of the machine.

A bucket wheel reclaimer spray system that requires an upgrade. Good curtain sprays deliver to the face above the bucket wheel, but additional sprays are needed to stop dust arising from the material drilling down the face. The nozzles are not directed at the source of the dust and there are no misting nozzles. This photo demonstrates how dry raw material will produce dust even if some sprays are installed and turned on. Source: John Visser, Rio Tinto.

Drum reclaimers

Drum reclaimers also require sprays that are directed at the material falling down the face of the stockpile as it is reclaimed. There should be no water directed at any structure or moving parts, since this will cause housekeeping issues and increase the wear on the equipment without improving the effectiveness of well-aimed water or mist sprays.

Static reclaim systems

Stockpiles that are designed with a reclaim tunnel are inherently less dusty than are surface stockpiles. A stockpile with a large, well-designed tunnel provides a safe and dust-free reclaim operation.

The source of dust is the reclaim feeder and its delivery onto the reclaim conveyor. Dust can be mitigated by misting sprays directed into the falling raw material stream.

Water trucks and water cannons

Water trucks and water cannons provide different ways to deliver water to the surface of the stockpile. While the cannon is the mainstay of the delivery system, trucks can reach areas not covered by the cannon and can be deployed when the canon system is down.

Stockyard water cannons play an important role in managing dust from the fine material stockpiles, because moisture continuously evaporates while the stockpile lies dormant. The key aspects of ensuring the effectiveness of the cannons include:

- Spray pattern height—The water delivered by the cannon nozzles should be able to reach just over the top of the stockpile.
- Spray pattern coverage—There is usually a portion of the side of the stockpile that is not covered with water by the sprays. This occurs at the midpoint between the cannons and is a function of the circular arc produced by the spray cannon motion. Such areas can be covered by a water truck with correctly installed nozzles.
- Distance from stockpile—The cannon stands should be located as close to the stockpile as possible, ensuring that they do not foul the movement of equipment. Generally, the further the water jet has to travel the more it breaks up and loses its effectiveness.
- Wind conditions—In a high wind, the spray is blown about and entirely controlled by the wind; therefore, water must be sprayed onto the stockpiles prior to any strong wind event. The Bureau of Meteorology website can be used to plan for these events, and specialised services can provide more detailed local information. Trend information on wind speeds produced by the local weather station can also be used to trigger the commencement of the cannon spray sequence.
- Air—Droplet fineness can be increased by introducing air into the water nozzle.

Chemicals

If fines are a problem, adding a chemical into the water deluge nozzles in the crusher dump pocket and the grizzly underpan will modify the raw material's characteristics to prevent fugitive dust from being generated.

The use of a chemical veneer on stockpiles prior to any significant wind event will stop dustiness from the stockpiles. Chemical veneers bind the fine particles together but do not stop water ingress or evaporation from taking place. The veneer looks somewhat like a spider's web when viewed close up.

The chemical veneer can be sprayed onto the raw material using the cannon system in a reconfigured state, or using water trucks. The concentration of the chemical should be determined taking into account the estimated wind speeds and duration of the anticipated wind event, which means that the cost of the chemical spraying depends on the event.

Foam can be employed to drop dust at the discharge points of transfer chutes and along conveyors. However, to date no tests have proven successful with this type of chemical.

2.11.8 Water management

Dust mitigation is most effectively achieved with water, which means that a representative of the operation's water management team should be involved in discussions, plans and changes to any dust mitigation system. Someone from the water management team should also be present during a risk assessment that is focused on dust mitigation.

2.11.9 An automated particulate emissions control system

Managing particulate emissions effectively requires a coordinated, site-wide system, whether the system is automated or not. An automated system can make use of information such as:

- weather prediction data (anticipated wind speed, precipitation, relative humidity and temperature)
- local weather station data (measured wind speed, precipitation, relative humidity and temperature)
- scheduling of raw material, waste and soil movement (blasts, mining, area clearing, delivery to and reclaim from stockpiles, plant operation, road use)
- raw material, waste and soil characteristics (DEM, flowability)
- moisture information from analysers and laboratory samples
- weightometer readings
- site real time particle monitors.

This information is used to control the movement of material and the set-up of:

- water addition and mist spray systems
- chemical treatment systems
- belt wash systems
- particulate emissions removal systems.

Particularly for larger operations, these systems should be linked together to create a whole-of-site particulate emissions management system which is monitored by the operator, internal and external particulate emissions monitors, moisture analysers and weather monitoring systems, and principally controlled by a programmable logic controller (PLC). The operator should turn the system off only when there is a system failure.

Specific menus for each raw material type can be written for the PLC. They become the principal determinant of the water management scheme for that raw material type, using local weather conditions and anticipated storage time on the stockpile as variables that modify water addition and/or chemical treatment.

There are many scenarios that can be set up to run automatically if a complete system is implemented. For example, an automatic scenario could mean that when rain is anticipated the use of water through the cannon system is reduced or turned off. In the case of predicted high winds it may be necessary to spray the stockpiles with either water or chemically treated water, depending on the strength of the winds, prior to the arrival of the windy period. If a period of dry, hot weather is expected the water cannon sequence start frequency can be increased to deliver more water.

The particulate emissions control system at Dalrymple Bay Coal Terminal in Queensland is an example of a system that controls water dams, borehole and delivery pumps and water addition, using raw material movement, moisture analyser data, Bureau of Meteorology information and local weather station information as the inputs. Other systems now available incorporate the various data inputs into a real time model that not only shows current impacts but also uses forecast data to predict impacts on air quality (including dust, sulphur dioxide and other contaminants), enabling various control scenarios to be tested by modelling.

2.11.10 Taking the wind into account

Windbreaks can comprise fences, trees, hills and simply distance between the dust source and sensitive receptor.

Trees, bush and grass
The most effective way to create a barrier to wind erosion and, therefore, dustiness is to plant trees, bushes and grass both upwind and downwind of stockpiles, open areas and operating plants. These natural barriers provide both wind and noise protection. This is obviously a long-term solution.

Wind fences
Wind fences are used to stop dust from interfering with the local community in many places around the world, particularly, and very successfully, in Japan.

Hessian fences stopping dust being blown away on a local scale.
Source: John Visser, Rio Tinto.

Hessian fences stopping dust migration. Source: John Visser, Rio Tinto.

Wind fences positioned upwind can be used to prevent dust problems by lifting the wind up over areas that have dusty materials on them. The wind fence will change the wind speed on the ground at a distance away from the fence as far as 30 times the height of the fence. For example, in a wind speed of 14 metres per second, a 12 metre-high fence will stop dust lift-off for up to 200 metres. In general the dust lift-off wind speed is 10 metres per second.

A fence is a more effective windbreak if the top of the fence is significantly higher than the highest point in the area which it is designed to protect. The fence porosity should be between 60 per cent and 90 per cent.

Wind fences positioned downwind of the area with the dusty material will act as a dust barrier, halting dust that has been picked up by the wind and dropping it at the foot of the fence. The problem with this option is that, to be completely effective, the fence must reach the height that the dust cloud reaches, and this is usually impractical. However, this kind of wind fence provides partial protection, by:

- dropping the lower layers of dust—these layers generally contain the nuisance dust that causes community issues
- disrupting the wind—forcing the wind to go up and over the fence slows the speed of the wind on the leeward side of the fence, which causes more dust to be dropped at that point.

2.11.11 Modelling

With each terrain there are particular disruptions to the wind velocity profile that will either increase or decrease the effectiveness of the wind fence. CFD modelling can provide the means of understanding these effects and therefore optimising the effectiveness of a wind fence.

Modelling the prevailing wind velocity and terrain interaction is critical to understanding the effect that a windbreak will have on reducing dustiness. The CFD modelling provides the wind velocity information and the dust plume modelling takes that information and demonstrates where and how the dust will be blown and deposited.

CFD modelling should go hand in hand with wind tunnel test work, because there is always a need to calibrate the CFD model. Two different calibration types are necessary: the dust lift off factor and the wind velocity profile.

Once a CFD model has been calibrated for a material, it can be used to model many scenarios on that site in future without significant cost per run. The total cost of performing CFD and wind tunnel modelling can be paid back in months, based on the likely costs if a wrong location is selected if no modelling is done.

CASE STUDY: Blast overpressure prediction system

Blast overpressure levels experienced from operations on open-cut mines depend on many factors, including the design of the blast, the distance from the blast to the receiver and the prevailing atmospheric conditions. The way in which temperature and wind vary along the path through which the overpressure wave travels from the source to the receiver is particularly important in determining the overpressure experienced at the receiver.

Australian Coal Association Research Program Project 12036 provides mine operators with information on meteorological conditions that allows the effects of atmospheric conditions to be taken into account before making the decision to blast (Holmes & Lakmaker 2009).

The approach taken uses the MM5 mesoscale meteorological model, with 24-hour hour forecasts from the Bureau of Meteorology supplemented by local observations of wind speed, wind direction and temperature in the lower atmosphere, to predict three-dimensional meteorological fields in the Hunter Valley. The local observations are provided by a sonic detection and ranging (SODAR) and radar acoustic sounding system (RASS) stations centrally located in the modelling domain. In addition, wind speed and direction data from ground-based (10 metre) sensors are supplied to the model.

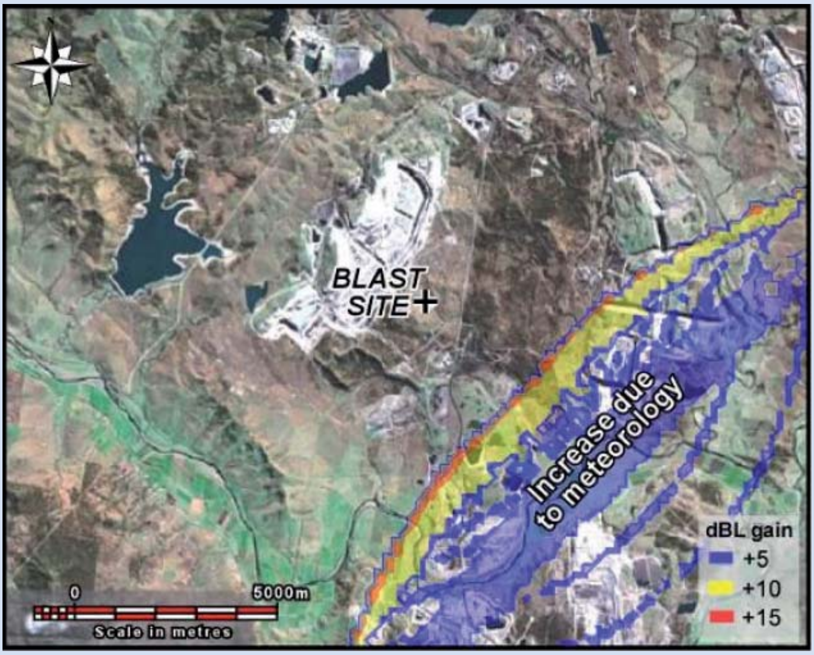
The model is run at least once a day and at user-selected intervals. The output is processed to extract information on the predicted vertical profiles of wind speed, wind direction and temperature, extending from ground level up to 1.6 kilometres. Each time the model is rerun it assimilates local meteorological observations provided by the SODAR, RASS and other surface stations.

The model results are reprocessed to create tabular and graphical summaries for selected sites coinciding with mine sites and other sites of interest. Data are uploaded to a website where registered users can obtain data on wind and temperature profiles for any area of interest on the grid, in a format suitable for input to a blast overpressure prediction model, or for any other use such as predicting dust events.

(continued)

The model predictions are ultimately used to predict the enhancement of blast overpressure levels. This is done using a model provided by Terrock, which uses MM5 data to predict the level of enhancement (positive or negative) caused by meteorological conditions, and the absolute level of overpressure resulting from a blast. The results are presented as contour plots overlaid on a map of the area surrounding the blast. An example showing blast overpressure enhancement is provided in the figure below.

The results of the project are promising and the system appears to be a useful tool, in its current state of development, to improve the management of impacts from blasting.



Predicted blast overpressure levels showing zone of reinforcement due to atmospheric conditions.

2.11.12 Real time and forecast weather information

The Bureau of Meteorology website (www.bom.gov.au) helps operators to keep abreast of the wind and weather predictions for the next day and week. This information can be used to plan activities that involve land clearing, raw material movement and the like, and enables planning to avoid periods when there will be strong winds. In addition, the site's real time weather station data is useful to verify conditions.

Detailed wind and rain predictions tailored to specific sites can be helpful if Bureau of Meteorology data are not sufficiently targeted. Commercial services are available from some consulting firms, providing web-based data and predictions that utilise sophisticated models. An example of a frequently updated predictive model is the Australian Coal Association Research Program forecast system for the Hunter Valley.

2.11.13 Complaints management and community liaison

One of the aims of dust management is to avoid or minimise the level of complaints. Complaints are an indicator of problems; they should be taken seriously and investigated, and their causes should be addressed.

However, because complaints represent a subjective response to specific events or series of events, you cannot simply use the number of complaints as a definitive measure of performance. Complaints may be withheld for various reasons, or may be exaggerated to make some (sometimes broader) point. The absence of complaints does not mean that people are not being annoyed by dust. Therefore, it is important to maintain regular contact with potentially affected neighbours to ensure that there are no hidden issues that should be addressed on site.

Complaints should be documented in detail and recorded in a database that forms part of the air quality management system. Recorded information should include:

- the time and location of the complaint
- the details of the complainant
- the nature of the complaint
- the details of the person who took responsibility for interviewing the complainant, and what they reported
- the investigations conducted on site to establish a cause
- the actions identified and taken to rectify the problem
- the communication of the actions back to the complainant.

In rare cases, there may be a vexatious complainant who will demand a significant amount of attention without providing evidence of a real problem. It is important to assess such situations carefully. A vexatious complainant cannot be judged on the basis of a single complaint: a vexatious complainant can only be identified after a series of unwarranted complaints, forming a clear pattern of behaviour. Once such a pattern becomes clear, however, it is important to discuss the problem with the regulatory agency. A well-documented approach to dealing with this problem will be vital.

With dust or other air quality complaints there is often a question of properly identifying the specific emission source. A weather station on site, recording wind and other data at intervals of up to 10 minutes, will provide a very useful basis for identifying the source. The short-term data will identify wind variations, which may be crucial in getting a good result, as often the travel time between source and complainant will be only minutes or tens of minutes.

It is now possible to use real time systems to quickly display a calculated air trajectory from the site of the complaint back to a potential source. Such an approach is particularly useful where there are multiple possible sources of emission that could contribute to the problem—either different mines or industries in the area, or specific sources on an individual mine site.

As part of keeping the community informed about environmental performance, some companies provide public access to websites that display current and recent air quality monitoring data. When making real time data available via the internet, it is important to make the distinction between validated and un-validated data, and inform the user that sometimes raw data will need to be corrected or discarded after quality checks.

2.11.14 Reporting and performance reviews

An important part of the air quality management plan is reporting and review. The data collected by monitoring systems should be reported in ways that clearly show compliance with imposed or voluntary targets and objectives, and provide explanations of causes and remedial actions associated with any non-compliance. While a suitably detailed report should be provided, it is also important to make a simplified summary that conveys the essential performance measures in an easily appreciated graphical format.

Periodic, at least annual, internal review of performance is necessary to ensure that:

- compliance efforts are effective, both technically and administratively
- objectives remain appropriate
- no new issues are emerging that require systematic attention
- information is being communicated to stakeholders effectively.

In addition, regular third-party audits of the program and performance are strongly recommended and may be part of site's quality system requirements. A successful outcome from the audit process will require that the management plan and associated reporting are complete and transparent.

2.12 Closure and rehabilitation phase

At the final stage of a mine's life, the key air quality issues are generally associated with wind-generated dust from exposed areas. For closed uranium mines, radon flux from rehabilitated areas may also be significant, requiring careful monitoring procedures for accurate flux determination and consequent management of the area (Bollhöfer et al. 2006).

Rapid rehabilitation of waste dumps and mined areas is the best way to reduce the dust potential. This can occur progressively through the operational stage, as areas reach this condition, as well as during mine closure. Apart from incompletely rehabilitated areas, there may be other sources of residual emissions, notably tailings disposal areas, which by nature may be difficult to revegetate and which may be potentially large reservoirs of fine dust particles, in some cases containing hazardous components. For tailings areas there is no silver bullet for dust control or prevention.

The best way to stop dust from affecting sensitive areas is to use several diverse factors or methods of dust control. As described in Section 11, these methods can include:

- natural barriers, such as grass, shrubs and trees
- chemical veneers
- water (although this is always a temporary measure)
- wind fences.

Each of these methods provides different dust control effectiveness, utility and cost implications.

3.0 NOISE

Overview

Noise is among the most significant issues for communities located near mining projects. The growth in public awareness and expectations about environmental performance has led mining companies to focus their attention on the management and mitigation of potential impacts.

Noise can interfere with day-to-day activities, particularly relaxing at home in the evening and trying to sleep at night. Noise from the resources sector is a common source of community concern, because operational noise can be generated on a continuous basis. Large mines plan to operate 24 hours per day, seven days per week, and a mine may operate for many years. As the mine develops over a wide area, different receivers are affected at different stages of the mine life.

Although quarries may not operate continuously throughout the night, they may prefer to commence loading at sunrise and work into the evening. They are also often located much closer to residences than are mine sites. Ancillary processes, such as transport of product by road, rail or ship, including port operations, also generate their own unique noise impacts.

While site noise at source, or even at the site boundary, is generally well understood and is within the control of the mine, understanding the likelihood of complaint is far more complex, for two key reasons:

- Changes in meteorological conditions can result in significant daily fluctuations in noise levels at receivers (for identical on-site operations). This is primarily a factor of wind direction and prevalence of temperature inversions.
- Sensitivity to noise can vary significantly from person to person, and carries a degree of subjectivity.

In other words, what happened yesterday is no indication of what will happen today, and the fact that one resident is happy does not mean that their neighbour is—or that the person to whom they sell their house will be. Whether the mine or the resident was 'there first' has little relevance in whether the noise is judged offensive, and if a newly-arrived resident is dissatisfied the mine could be considered to be in breach of its approval conditions.

An acoustic consulting company can assist mine management to conduct detailed analysis including interpreting state regulation, undertaking noise measurements and predictions, assessing potential impacts and designing mitigation measures. Such consultancies need to be effectively managed by the mine's managerial, operational and/or environmental teams, who need to have an informed appreciation of the important issues.

This chapter provides an overview of how a mine can achieve leading practice in environmental noise management during three critical phases of mine development:

- Planning phase (environmental assessments)—In this phase, the mining project proponent establishes the existing environmental conditions and identifies potential impacts and mitigation methods, including optimisation of the mine layout or the way in which the exploration program is conducted.
- Exploration, development and detailed design phase (management plan)—Once a mine development has been approved there is more certainty about a project and the opportunity for business to invest more heavily in the detailed design. This phase may involve repeating many of the tasks undertaken in the planning phase, to establish a comprehensive noise management plan. The plan should detail the methods for managing and monitoring noise, in compliance with the mine's environmental objectives, and arrangements for proactive liaison with the community.
- Construction, commissioning and operations (monitoring and audit programs)—This is the phase in which most noise is generated on site. Management activities focus on ensuring that the management plan is implemented and quality objectives are continually verified, and responding to any complaints.

The benefits of leading practice environmental management to minimise noise are immediate. While some may require an upfront capital investment, they ultimately provide cost savings through increased efficiency and, in many instances, improved occupational health and safety.

In addition to benefiting individual companies in the short term, effective noise management will benefit the wider the resources sector, both economically and in terms of improved community attitudes towards mining activities.

3.1 Sources of noise

Resource exploration, extraction, processing and transportation have the potential to produce significant levels of noise which may impact on the surrounding environment. Communities can experience noise and vibration impacts from mining operations in many ways, not just from the mine site: noise may occur at all stages of the logistics chain, including rail and truck haulage, and activities at ports.

Open-cut mines require large earthmoving equipment such as dozers, excavators, loaders, haul trucks and face shovels, plus kilometres of conveyers. Air track drills are required for blasting. For underground mines, large ventilation fans are required. The processing of materials requires stackers and reclaimers, crushing and screening plant, coal washeries with the associated noise of material being tipped and separated, more conveyers and rill towers. Rail or truck unloading facilitates are common.

The use of explosives creates airborne pressure fluctuations (airblast) over a wide frequency range. When in the higher frequency range, this energy is audible and is perceived as 'noise'. At frequencies of less than about 20 hertz, the sound energy is inaudible but is capable of causing objects to vibrate such as the rattling of loose windows and crockery.

3.2 Health amenity

Noise levels at residences surrounding mines are generally not high enough to have direct effects on health, such as hearing loss. The indirect effects of noise and vibration on the health of people exposed to excessive levels have been extensively documented. Investigations have found that prolonged exposure can adversely affect mental and subsequently physical health, particularly in those most sensitive to noise.

Noise produces psychological effects in very specific ways. These are, essentially, interference with communication or concentration, and sleep disturbance. These factors lead to irritability, which is the first sign of the psychological impact of noise. The psychological response to noise is determined by personal factors and by factors associated with the noise itself.

Low-frequency noise can be particularly annoying and can result in complaints many kilometres away from the source. Low frequency noise can be considered to range in frequency from about 10 hertz to 200 hertz. The common sources are large pumps, motors or fans and crushing circuits and screens. The perceived loudness and annoyance due to low-frequency noise increases extremely rapidly with increasing levels above the threshold of hearing.

Sound in the frequency range below 20 hertz is normally defined as 'infrasound' and can be heard (or felt) as a pulsating sensation and/or pressure on the ears or chest, or can cause secondary effects such as rattling of windows or doors.

Because low-frequency noises between 20 hertz and 200 hertz propagate with minimal attenuation over large distances and transmit easily through building fabric, it can be quite prominent inside residences without the masking effect of higher frequencies. Low frequency noises are perceived as more annoying than typical mid-high frequency noises by residents. When determining compliance, most regulatory authorities have objective tests to determine whether low frequency noise is present. Where low frequency noise is found to be characteristic of the noise source, an adjustment must be made to measured levels to account for the increased annoyance.

Factors such as the attitude or mood of the person, his or her environment, the degree of arousal or distraction experienced, and whether the noise is felt to be an invasion of privacy or disruptive, will dictate personal response. This is important for shift workers who sleep during the day. The predictability of noise and how frequently it occurs will also influence the reaction.

3.3 Effects on fauna

The effects of noise on animals can be similar to the effects observed in humans. Noise can adversely affect wildlife by interfering with communication, masking the sounds of predators and prey, cause 'stress' or avoidance reactions and (in the extreme) resulting in temporary or permanent hearing damage. Experiments have also shown that exposure to noise impulses throughout their sleep periods resulted in poorer task performance (noting that some animals are nocturnal).

Research into the effects of noise on animals is relatively scarce. The results obtained from the studies conducted are frequently contradictory or inconclusive. However, it does appear reasonably clear that animal reactions to noise vary from species to species.

3.4 Meteorological effects on the propagation of noise

One factor the mine has no control over is the influence meteorological conditions have on the propagation of noise, particularly over large distances (greater than 500m). Some understanding of these effects is critical if the mine is to effectively manage noise impacts. Of most importance is downwind propagation and the effects of temperature inversions, which both cause noise to be 'bent' back towards the ground, thus increasing noise levels.

3.4.1 Wind effects

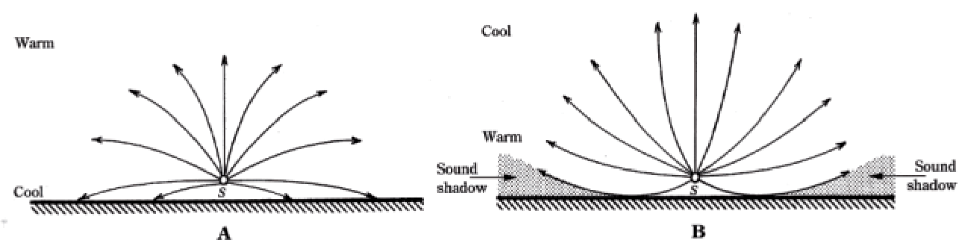
Steady light to moderate winds produce higher noise levels downwind, and lower noise levels upwind, than in still air.

In general (and depending on the amount and type of local vegetation), a steady, gentle breeze of less than about 1.5 metres per second can increase noise levels without increasing background noise levels. On the other hand, winds of higher velocity tend to increase background levels due to turbulence or movement of trees and shrubs, and obscure other noise sources. Downwind, wind velocities up to about 1.5 metres per second can enhance noise levels by around 5 dBA relative to still conditions, assuming flat topography between source and receiver, and more if shielding is provided by natural topography. Conversely, noise levels upwind may be reduced by a similar amount.

It should be noted that noise enhancement due to wind effects is extremely site specific and significant variations from the 'typical' changes in level can be expected.

3.4.2 Temperature Inversion effects

Air temperature normally decreases with altitude (as shown in B in figure below), a condition known as 'temperature lapse'. A 'temperature inversion' occurs when a layer of air has its temperature increasing with altitude, or at the boundary between a lower cool layer and a higher warm layer (as shown in A in figure below).



Effect of temperature inversion on the propagation of sound-normal sound propagation (A) and propagation with a temperature inversion (B).

In winter, temperature inversions are normally associated with drainage flows, where cool air flows down to areas of lower ground level, creating a light breeze. This 'drainage flow' is affected by the topography, and as such the extent of this effect depends on the depth of the inversion layer.

Wind and temperature inversion effects generally apply to all noises, including airblasts. Temperature inversions appear to affect low-frequency sound more than higher frequency sound. This is possibly because, over relatively large distances, the higher frequency sounds are readily attenuated by other effects (such as atmospheric absorption). Since temperature inversions normally appear at night and disperse an hour or two after sunrise in the summer period, noisy events (particularly blasting) should be planned around these periods. In areas which are prone to severe inversions, excessively noisy activities should be avoided on overcast days when possible.

3.5 Cumulative noise effects from multiple mines

Not all states have noise guidelines to effectively address and prevent the cumulative noise impacts from multiple mines, such that the individual mines need to understand and address this issue, in conjunction with their neighbouring mines.

In some regions there may be multiple mine sites which can affect the same residential receiver, albeit not at the same time. A good example is the village of Camberwell in the Hunter Valley, which has multiple separate approvals across several mining companies.

3.6 Blasting

Airblast overpressure is the energy transmitted from a blast site, travelling through the atmosphere in the form of pressure waves. As these waves pass a given position, the pressure of the air rises very rapidly, falls more slowly, then returns to the ambient value after a number of oscillations. The pressure wave consists of both audible (noise) and inaudible (concussion) energy. The maximum excess pressure in this wave is known as the 'peak air overpressure', generally measured in decibels using the linear frequency weighting.

The airblast levels received at a location remote from a blast are a function of many factors, including:

- charge mass
- stemming height and type of stemming
- burden
- blast hole spacing, blast initiation sequence and timing delay between holes
- ratio of the blast hole diameter to the burden
- face height and orientation of face
- topographic shielding
- distance from the blast
- meteorological conditions.

Models have been developed to assist in predicting the impact of airblast on neighbouring areas. These models are based on empirical data, and normally need to be refined using airblast overpressure measurements taken once the mine is operational.

3.7 Noise characteristics and measures

The annoyance characteristics of noise are subjective. Whether or not a noise causes annoyance mostly depends upon its reception by a person, the environment in which it is heard, the type of activity and mood of the person who hears it and how acclimatised that person is to the sound.

Sound is measured in decibels (dB). When measuring environmental noise, a weighting network is used which filters the frequency of the sound so that it better corresponds to the response of the human ear. Noise measurements made using this weighting network are expressed as dBA.

To manage the enormous range of sound pressures able to be detected by the human ear, the decibel scale is logarithmic, which often leads to confusion. For instance, if two machines emit exactly the same noise level of 80 dBA, the total noise level is not 160 dBA, but 83 dBA, a doubling of intensity which is barely noticeable from one day to the next. Also, while a 10 dBA increase in sound level, is a tenfold increase in intensity, it represents only a doubling of loudness. Typical examples illustrating the decibel scale are shown below.

Examples of dBA ratings of noise events

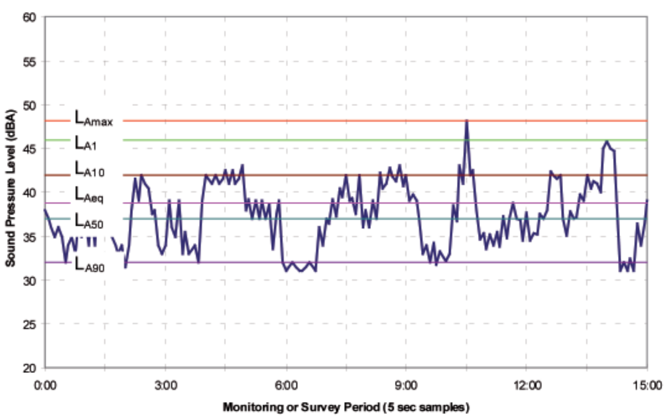
	Decibels dBA	
Threshold of pain	140	
	130	Jet engine
Typical airblast limit	120	
	110	Production blast at 100 m
	100	Rock hammer at 2 m
	90	Dump truck at 10 m
	80	
	70	Conveyor at 5 m
	60	Conversation at 2 m
	50	
Typical license condition	40	Quiet living room
	30	
	20	Night time, rural area
	10	
Threshold of hearing	0	

Noise emissions are measured using sound level meters which detect and record changes in sound pressure. More expensive models can also include frequency information. For surveys of background noise, environmental noise loggers are generally used. These are basically sound level meters, in robust, weatherproof cases, that can be set up and left unattended to monitor at suitable locations.

Airblast is measured in decibels, but is not weighted as for typical environmental noise, so is expressed as ‘dB(linear)’. Special equipment is normally used to measure airblast; it is designed to be left unattended and set to trigger when an emission levels exceeds a predetermined level. Waveforms of the event should also be recorded.

To describe the overall noise environment, a number of noise descriptors have been developed. These involve statistical and other analysis of the varying noise over sampling periods, typically taken as 15 minutes. The four most commonly used descriptors, which are demonstrated in the graph below, are:

- Maximum noise level (LA_{max})–The maximum noise level over a sample period is the maximum level, measured on fast response, during the sample period.
- LA_{10}–The LA_{10} level is the noise level which is exceeded for 10 per cent of the sample period. During the sample period, the noise level is below the LA_{10} level for 90 per cent of the time. The LA_{10} is a common noise descriptor for environmental noise and road traffic noise.
- LA_{eq}–The equivalent continuous sound level (LA_{eq}) is the energy average of the varying noise over the sample period and is equivalent to the level of a constant noise which contains the same energy as the varying noise environment. This measure is also a common measure of environmental noise and road traffic noise.
- LA_{90}–The LA_{90} level is the noise level which is exceeded for 90 per cent of the sample period. During the sample period, the noise level is below the LA_{90} level for 10 per cent of the time. This measure is commonly referred to as the ‘background noise level’.



A noise survey sample demonstrating the main noise level measures.

3.8 Community liaison

Liaison between mining companies and the community is important at every point in a mining operation, from the beginning of the proposal stage, throughout the investigative, assessment and approval processes, and throughout the mine's operation.

Members of the community must be kept informed and involved in the decision-making processes that affect them if a good working relationship is to develop between all involved parties. A good working relationship is the keystone to a win–win approach to avoiding and resolving potential complaints. The implementation of an effective community consultation program will gain public confidence and lead to both a smoother planning and approval phase and a more efficient operational period.

Lack of knowledge and understanding frequently contributes to the community's fears surrounding a mining proposal. Misconceptions commonly result in objections and difficulties which serve no constructive purpose and promote a spirit of non-cooperation. By providing information and a contact point at the onset of a mining project, and continuing to respond to community concerns, mining companies put themselves in a better position to implement a successful environmental management program. Community consultation and involvement aspects are discussed in the leading practice handbook *Community engagement and development* (DITR 2006).

As part of a noise and vibration management plan, a mining company must develop a policy for liaising with the community in dealing with noise and vibration issues. The management plan should establish a protocol for handling complaints that will ensure that the issues are addressed and that appropriate corrective action is identified and implemented if and where necessary.

This protocol should be both proactive and responsive. As a minimum, it should involve the following actions (and identify the people responsible for each action).

- Identify contact persons at all potentially affected properties, and give them a project outline (together with details of the procedures for lodging complaints and the expectations they may have about the response mechanisms that will be implemented).
- Forward all complaints to the person responsible for handling them.
- Keep records regarding the source and nature of the complaint.
- Investigate the complaint to determine whether a criterion exceedance has occurred or whether noise and/or vibration have occurred unnecessarily.
- If excessive or unnecessary noise and/or vibration have been caused, plan and implement corrective action.
- Report details of complaints and corrective action.
- Inform complainants that their complaints are being addressed and (if appropriate) that corrective action is being taken.

- Carry out follow-up monitoring or other investigations to confirm the effectiveness of the corrective action.
- Inform complainants of the successful implementation of the corrective action.

3.9 Planning phase

Good planning is essential to mitigate noise impacts which might otherwise affect the surrounding community or the natural environment. Optimising the way in which an exploration program is conducted and the way the mine is designed from the very earliest phase, with the assistance of an acoustic specialist, can minimise impacts and assist in meeting community expectations.

The first step in implementing leading practice for a new project, or the redevelopment of an existing project, is to ensure the appropriate expertise is available in the team that will conduct the environmental assessment that examines the proposal in detail and identifies all the potential sources of noise.

The stages of work in the planning phase can be broadly categorised as follows:

- monitoring background or ambient noise within any potentially affected community
- setting noise criteria and design goals for assessing adverse impacts, including on-site and off-site noise (the mandatory regulatory criteria vary slightly between jurisdictions; more information is available from the environment protection authority in each state)
- predicting noise levels for a number of future scenarios, including on-site and off-site (transportation) scenarios—this typically involves developing a comprehensive computer model.

Where the environmental assessment shows that the noise criteria will be exceeded, there is a requirement to design feasible and reasonable mitigation measures that will enable the impacts to be effectively reduced. Where this is not possible it is likely that the acquisition of properties will be necessary.

3.9.1 Background or ambient noise monitoring

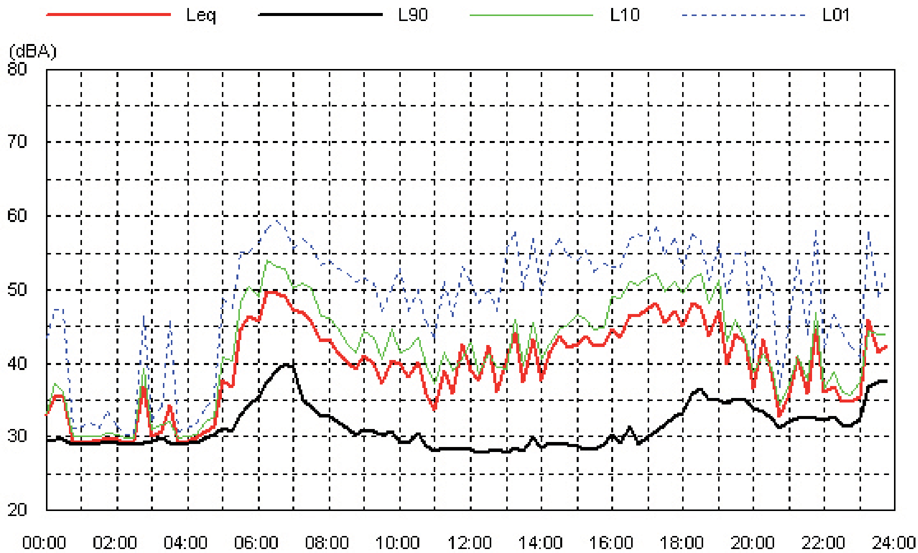
As part of the environmental assessment process for any project there is normally a requirement to understand and measure the existing ambient noise environment. Monitoring normally takes the form of collecting measurements using an unattended, automatic noise logger. The monitoring should be conducted over a sufficient time period to reflect the true and repeated conditions that are typically experienced in the area, and should not be unduly influenced by seasonal variations due to temperature inversions, winds, insects and so on. In practice, continuous monitoring is conducted for a minimum of one week at representative surrounding residences or other noise-sensitive receivers (such as schools or churches), ideally prior to the mine becoming operational or while the mine is not operating.

The information obtained from these measurements is normally used to set criteria for the project. The most important measure is the background noise level (the LA90), which is normally measured in 15-minute periods.

Meteorological conditions can significantly influence noise levels. Steady wind, for instance, generally causes an increase in background noise levels due to movement of trees. Strong winds and rain can lead to falsely inflated noise level measurements. To enable periods of adverse weather to be identified, a weather station should be set up to continuously monitor wind speed and direction and rainfall. Noise data should then be filtered to account for periods of weather conditions that had an influence over the recorded noise results.

Some residences surrounding new mine sites already experience noise from road traffic, rail lines, other existing mines or other sources of intrusive noise. In these situations, in addition to unattended monitoring there may also be a need to do attended noise monitoring to understand the existing noise levels and estimate the contribution from each source. These measurements may also provide a way of validating the noise prediction method to be used in assessing noise from the project. Often measurements may be done at one or two representative properties in order to validate any predictions.

Example of environmental noise logger in operation. Source: Wilkinson Murray.



Example of chart output from noise monitor. Source: Wilkinson Murray.

3.9.2 Regulations

Operational and construction noise

Noise guidelines vary across Australia. Generally, they comprise two aspects: a control on the emergence of mine noise above the background level, and/or an absolute level which varies between daytime, evening and night.

In very quiet areas the regulatory restriction is normally determined based on the emergence above background noise criterion, while in areas with existing industrial or road traffic noise it may be the absolute or 'amenity' criterion which is most stringent. The 'emergence' criterion is for mine noise (typically measured over a 15-minute period as either an L_{eq} or L_{10}) to not exceed the background noise level (normally measured as an L_{90}) by more than 5 dBA. If the mine noise has 'unpleasant' characteristics (such as tonality or impulsiveness) at the receiver, it is necessary to add a correction factor to the measured or predicted mine noise.

To prevent successive developments from causing 'background creep', planning levels are often set below the existing background noise level to ensure that the cumulative effect does not result in the background noise environment exceeding an acceptable level.

In addition to these criteria, there is also the requirement to consider the potential for sleep disturbance at night time. This could occur due to noisy crashes and bangs from shunting wagons, or the first load being dumped in an empty haul truck. The assessment normally considers an emergence above the background level, but addresses the short-term maximum noise level rather than an 'average' L_{eq} or L_{10}.

Transportation noise
Rather than needing to achieve a 'background +' criteria, the approach for transportation noise sources often just nominates an absolute limit to be achieved, based on an hourly limit or 24-hour limit. Where the existing traffic noise levels are already quite high and in excess of the absolute limit, the normal approach is to set criteria to limit any further increases in noise.

Airblast noise
Australian Standard AS 2187.2–2006 *Explosives—storage and use—use of explosives* provides recommended limits for the control of cosmetic damage to structures. A limit of 133 dB(linear) is recommended as a safe level that will prevent structural/architectural damage from airblast. The standard further notes that different limits may need to be developed for service structures such as pipelines, powerlines and cables located above ground.

The standard's criteria are designed to assess the risk of structural damage. They are not appropriate for assessing human reactions to airblast. The guidelines for these vary around Australia; however, limits in the order of 110 dB(linear) to 120 dB(linear) are typically recommended. These should be used for buildings that will remain occupied during blasting. Higher limits apply to unoccupied buildings.

3.9.3 Modelling future mining scenarios

Predicting noise emissions from mining projects is usually conducted using environmental noise modelling software. There are a variety of noise prediction software packages available; so long as they use industry-recognised algorithms, they should be acceptable. The ability to handle different meteorological conditions is also very important. The acoustic specialist will normally have a preference, and mine management should understand which model they are proposing to use and how output from that model will relate to noise levels in the community.

A noise model will require three types of information:

- ground topographic data to represent the mine footprint in several stages of its life—this includes the depth of pits, and the location and gradient of haul roads
- locations of all plant and equipment and estimates of their noise generation—this is like an aerial photo taken at a time representative of a 'typical worst case' operational scenario (not an absolute worst case), describing where equipment would be and what noise it would be generating (this will probably be revisited several times during the modelling)
- data on meteorological conditions over several years, from a weather station on or near the site.

Noise models can be particularly useful in determining the ranking of noise sources on site and, therefore, changes in noise contribution from a mine as a result of various operational scenarios or noise mitigation measures. As a planning tool they may provide data on 'average' noise levels expected at receivers, sufficient to allow planning type decisions.

Of course, at this stage of the project there is no alternative to using a predictive model, but the mine management must understand the limitations of any noise model. At the start of a planning process, a noise model cannot predict with a high degree of accuracy (1–2dBA) what the noise level will be at a particular residence over a 15-minute period for a specific operational scenario. Over time (several years), with enough validation during the detail design phase and the operational phases, the noise model should evolve such that it becomes very site specific and more accurate.

Noise models are only as good as the information entered. Most are developed using empirical data based on measurements conducted in various parts of the world over the past 30–40 years. They are poorly developed with respect to meteorological conditions and assume that only one 'set of conditions' exists along the noise path from source to receiver. This clearly does not occur in practice, hence a range of measured noise levels would be expected for a 'set' of wind speed and direction or temperature inversion factors. Models can represent the best fit or average of measured data. It is important to realise that the noise levels can vary by 5 dBA and even up to 10 dBA under different meteorological conditions.

3.9.4 Mitigation measures and acquisitions

In the planning phase, as well as identifying 'in principle' measures to reduce noise at source, the project proponent will often need to consider acquiring some properties.

On- site control measures that have been used successfully by companies employing leading practice include:

- selecting low-noise plant
- optimising mine layout to shield noise-generating plant and haul roads
- applying additional silencing measures for fixed and mobile plant and ventilation fans
- installing acoustic enclosures around process plant
- using 'smart alarms' to minimise complaints regarding vehicle reversing alarms
- minimising tonal components or impulsive or intermittent characteristics of noise
- strategically designing bund walls for acoustical screening
- incorporating buffer zones and landscaped setbacks.

3.10 Exploration, development and detailed design phase

Once planning approval has been granted or is expected to be granted, the detailed design phase commences. During this phase of the project most of the work that was done during the planning phase will be revisited in more detail. Three critical, interrelated outputs must be achieved and documented in this phase:

- a detailed plant and equipment noise specification for suppliers
- a detailed review and design of mitigation measures, including a schedule showing the position and height of noise mounds or engineering designs or performance specifications for special enclosures and cladding of buildings
- a noise management plan. Developing such a plan is often a condition of project approval, and implementing the plan will fulfil licensing requirements.

3.10.1 Plant and equipment specification

It is critical that the assumptions about noise levels of equipment made during the environmental assessment phase are understood and correctly transferred into specifications for the supply of plant and equipment. These should specify noise levels under certain load or speed conditions at certain distances from each side of the plant. There are Australian and/or international test standards which should be quoted where possible to avoid any ambiguities in the supply of equipment. The specification should also require the equipment to be tested by independent accredited personnel once delivered or installed on site (refer Section 3.10.1).

If buildings or claddings which house equipment are being specified, either a detailed design or a performance specification should be included. Where noise is concerned, attention to detail matters. A rule of thumb is that 90 per cent of the noise can escape from a 10 per cent opening. If the operator has gone to the trouble to design a concrete-clad building with excellent sound transmission loss, but forgotten to treat the openings for fresh air, the effort and expense will have been in vain.

3.10.2 Environmental management plan including noise and vibration

The noise and vibration management plan should be developed during the detailed design phase. Its major purpose is to demonstrate the company's commitment to achieving environmental goals (usually, the noise criteria in conditions of consent) by clearly establishing the existing environmental noise, stating the design objectives and statutory requirements, and describing the control measures, the emissions monitoring and reporting program, the procedures for handling of any exceedances, and the complaints and community liaison procedures.

It is likely that more ambient noise monitoring will be conducted and the computer model developed for the environmental assessment will be further refined and updated as more certainty about plant types and locations is developed (see Section 3.10). As this occurs, the noise mitigation techniques should be reviewed in detail.

CASE STUDY: The world's quietest haul truck

Mines in the Hunter Valley of New South Wales have some of the most stringent operational noise compliance criteria in the mining industry. A consultant was engaged to acoustically attenuate three new Caterpillar 789C haul trucks with the purpose of successfully achieving 113 dBA for both static and dynamic tests.

The first treated truck was successfully noise tested achieving 110 dBA for dynamic tests and 106 dBA for the static test, compared with 123 dBA/119dBA for an untreated truck. The noise performance was achieved with no impediment to the truck's cooling system.

The project began with discussion with the client, identifying the client's expectations. This was followed by testing an acoustically untreated 789C haul truck to gather baseline noise data. Sound intensity measurements were also undertaken. Sound intensity measures the directionality of a noise source, in addition to the magnitude of sound, which can provide a more accurate assessment of where problematic noise sources are located on a machine.

Baseline measurements, based on ISO 6395 and ISO 4872, enabled the consultant to establish how much a standard CAT 789C needed to be acoustically attenuated in order to meet the specification. However, these measurements did not provide sufficient information for the isolation of problematic noise and specific frequencies.

Detailed noise mapping and analysis of the trucks was undertaken using sound intensity with consideration to ISO 9614–1. The acoustic analysis enabled the consultant to isolate specific problematic noise areas and their dominant frequencies. The acoustic analysis also provided an indication of where the attenuation effort needed to be focused and where a less aggressive attenuation approach could be undertaken.

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Critical information gathered through discussion with the client (and operators) provided the engineering team with invaluable information to address key serviceability and functional performance criteria.

The design process encompassed:

- consideration of manufacturing techniques
- acoustic modelling
- exploratory manufacture and test manufacture
- consideration of serviceability, occupational health and safety, standardisation, functional performance (payload and truck cooling) and durability, including exposure to engine liquids, dirt accumulation and fatigue, as well as high-pressure water cannon cleaning
- design of related items such as access systems (stairs, bumper system, walkways).

3.10.3 Hierarchy of controls

Measures which are commonly adopted under the noise and vibration management plan include (in order of decreasing effectiveness):

- Selecting lower noise plant and equipment incorporating available noise control kits. This should be one of the first measures chosen to minimise noise impact. For example, exhaust and radiator silencers on large earthmoving plant will generally result in a 5 dBA noise reduction. When investigating engineered solutions for plant and equipment, at the very least consideration should be taken for thermal performance, servicing requirements, occupational health and safety, and weight limit restrictions.
- Adding attenuators to mine ventilation fans. As with silenced plant items, this should be one of the first management options adopted, to ensure that fan noise levels will be reduced by a predetermined margin and emissions will not exceed acceptable limits.
- Providing acoustical enclosures and acoustical treatment of process buildings. This is a very effective solution for crushing plant, coal washeries and the like. A reduction in the order of 10 dBA can be expected from a lightweight sheet metal enclosure. Ventilation openings should be oriented away from noise-sensitive receivers.
- Regulating emissions from reversing alarms. 'Smart alarms' can be selected which limit the reversing signal to 10 dBA above the ambient noise level, thus reducing intrusiveness (particularly at night).
- Identifying the optimum placement of waste dumps, location of haul roads, location of fixed plant such as crushers and loading hoppers. Waste dumps, stockpiles and the like can be used to shield fixed items of plant which generate noise.
- Eliminating tonal, impulsive or intermittent noise emission characteristics. These characteristics are more likely to cause annoyance because the likelihood of complaints is less for a continuous broadband noise than for one which is intermittent and/or tonal. Tonal components are often due to a fault in the machinery and may be eliminated by appropriate maintenance. Advanced control systems allow for switching between audible alarms during daytime operations and light alarms during the quieter night period. Using flashing lights for alarms will eliminate intermittent and impulsive noise generated by audible alarms.
- Providing sound walls and acoustical screening. This option is generally effective when plant is operating at ground level in close proximity to the bund wall. Also, earth embankments can often be constructed from overburden and materials from stripping and initial excavation works, and provide an alternative means of stockpiling soil for future rehabilitation works. However, the use of bunding becomes less effective as the distance between the bund and the noise source and receiver increases.

- Incorporating optimum buffer zones and setback distances. This is most effective where large distances are involved. In general, doubling the distance between the source and receiver will result in a 6 dBA reduction in noise level.
- Acoustically treating dwellings. This is generally seen as a last resort, as the overall reduction achieved often does not justify the cost involved. Also, no improvement in outdoor amenity is achieved.

Low-frequency noise can be particularly difficult to mitigate because of the long wavelengths involved. All building materials attenuate higher frequencies more readily than low frequencies. Massive building elements such as concrete walls, or drywall type construction with large air cavities, will be required. Ventilation openings are likely to be a particular issue, as most louvres and attenuators struggle to make any impression on low-frequency noise. Specialist advice should be sought for the design of enclosures around equipment with significant low-frequency components, such as pumps, crushing circuits, screens and large motors.

Measures commonly adopted to control the impacts of airblast include:

- reducing the charge mass
- increasing/optimising the stemming height and ensuring the type of stemming is adequate
- eliminating the exposed detonating cord and secondary blasting
- orientating faces away from potentially sensitive receivers
- using a hole spacing and burden which will ensure the explosive force is just sufficient to break the ore to the required size
- applying best practice design of the blast initiation sequence and timing delay (see Section 4.5)
- providing optimum buffer zones and set-back distances for sensitive structures
- acoustically treating dwellings.

CASE STUDY: Noise-suppressed surface exploration drill rig

For many years, a company has struggled to fully drill out its exploration leases, because of the noise restrictions involved with operating machinery in a built-up urban area. The company has experimented with many forms of noise suppression, including surrounding rigs with shipping containers and large hay bales, erecting sound walls, and even digging large pits for the drilling rigs to work in. These measures all had some degree of success but were far from ideal.

In 2007, the company purchased an Atlas Copco CS14 drill rig, with the intention of enclosing the unit within fully noise-attenuated containers.

The drilling department identified the need to make the system modular and self-contained. Six sea containers were used—four on the ground floor and two for the mast of the rig— to encapsulate the entire worksite. Everything, including drilling fluids, tools, drill rods, power generation and even the crib room, was enclosed within the system.

After consulting acoustic engineers, the company decided to use a mixture of noise attenuation products on the walls of the containers to reduce noise both internally and externally. The noise attenuation products included sound-deadening paint, 50 millimetre sound-absorbent foam and a 6 millimetre nylon sound barrier.

The combination proved to be extremely successful, reducing noise emissions from 110 dB at the machine to a measured 52 dB immediately outside the containers and 38 dB measured at 200 metres. With a 30 dB reduction inside the containers, the noise attenuation was celebrated as a great win in terms of operator comfort and safety.

The containerised rig has successfully completed six months of 24-hour drilling at two sites, both within 200 metres of residences. To date, no complaints from the surrounding neighbours have been received.

3.11 Construction, commissioning and operations phase

The third phase in the management of noise is to implement a comprehensive monitoring and audit program during the construction, commissioning and operations phase, and even the closure and rehabilitation phases. The monitoring program provides the mining company with a means to maintain a continuous record of environmental noise emissions. Technology also allows the mine manager to have real time access to data, from monitoring locations at residences around the mine, on which operational decisions can be made. The audit program also addresses the company’s procedures for dealing with complaints and ensuring quality objectives are met.

3.11.1 Compliance monitoring on site

During the commissioning or early operational phase of the mine, the mine owner will often want to confirm that the equipment supplied meets the sound power level values that were assumed in the environmental assessment process and incorporated into equipment specifications in the detailed design phase.

This form of monitoring is normally undertaken by experienced acoustic consultants in attendance at the mine site, using either a conventional sound level meter or more sophisticated measurement techniques such as noise intensity measures or even acoustic cameras. Generally, sound pressure level measurements are made at a known distance from a source then converted to a sound power level for comparison with a specification.

In addition to an overall sound level measurement (dBA), these sorts of measurements can also be done in octave bands or third octave bands in order to determine the frequency content of noise. Detailed procedures for such measurements are generally found in Australian or overseas standards. To enable comparison with contract specifications these procedures need to be followed accurately.

Intensity measurement techniques can be useful to isolate particular sources or breakouts of noise from buildings. The acoustic camera gives a clear visual indication of hot spots, when used by a skilled operator who understands the technical limitations of the particular device.

3.11.2 Compliance monitoring off site

On-site monitoring for compliance is probably the most controversial area of noise monitoring, not because the measurements are complex, but because there is much room for interpretation regarding the quality and quantity of data required to get the 'right' answer. Much of this interpretation relates to the question of whether consent conditions require that noise criteria never be exceeded under any circumstances, or whether they would allow noise criteria to be exceeded over a small proportion of the time (typically less than 10 per cent).

Compliance monitoring has traditionally required attended visits to the site once a quarter to monitor at a number of representative receivers surrounding the mine site, for possibly only one or two hours each. The monitoring is generally conducted at night. Clearly, the noise levels at are heavily dependent on the actual activities conducted and, in particular, the weather conditions on the night. On a particular night, a residence upwind could have noise levels that are virtually inaudible and not measurable, while a residence downwind has high levels of noise that are not experienced very often. There are clear shortcomings in compliance for a whole year being determined by measurements taken over such a short amount of time.

As an alternative to attended compliance monitoring, equipment similar to that used for background noise monitoring can be deployed at the site. However, in rural and semi-rural environments there are often many other sources of ambient noise which mask the noise from mine activities, meaning that it is almost impossible to determine whether noise can be definitely attributed to the mine. This technique can only be used with confidence in cases where the noise impact from the mine site is constant (for example, the noise impact on a residence very close to a ventilation fan).

One advantage of attended over unattended measurements is the ability of the engineer who is collecting the measurements to estimate what proportion of the noise is attributable to the mine site. However, depending on the relative contribution of mine noise and ambient noise, this could be up to 2–3 dBA in error. While this is not a large difference, in some cases it is enough to change the result from assumed compliance to non-compliance.

As a result of significant technological improvements in noise monitoring and communications equipment, approval conditions are increasingly being updated to include requirements for real time monitoring. As these sorts of conditions become prevalent, both unattended monitoring with 'unintelligent' devices and attended monitoring are likely to be used much less frequently.

A remote monitoring station including noise and weather instruments and wireless communications. Source: Wilkinson Murray.

The changes in measuring technology evolve as computing power increases. It is now possible to store large amounts of data, which can be downloaded either real time over a network or physically onto an external hard drive or 'memory stick'. As a minimum, unattended monitoring devices should now be able to:

- measure overall dBA levels
- include a low pass filter (so low-frequency noise normally associated with a mine can be separated from higher frequency noise from birds and insects)
- record audio data (continuously or on trigger as required) in a format dependant on quality required
- update a central database on a real time basis—typically, every 5 minutes.

These minimum equipment features, together with post processing of data (including listening to recorded files to eliminate non-mine noise), combined with some knowledge of the site and its operations, allow for a much better evaluation of compliance.

Enhancements to the technology are also available. One example is directional noise monitoring. This technology is capable of determining the level of noise which comes from the direction of the mine (including options such as low pass filtering), and can compare this value directly to the criteria for the mine, without the need for post processing.

Directional noise monitor. Source: Wilkinson Murray.

Monitoring equipment can be set up remotely (using solar panels and batteries) and, with either wireless or mobile phone communications, can feed data back to the mine site in real time. The information can not only be used for compliance reporting (on a daily, weekly, monthly or quarterly basis), but can also give real time information to the production manager such that mine operational activities can be altered on an hourly basis (if need be) to ensure that noise limits are achieved despite changing weather conditions.

In the context of maximising production and remaining within noise limits at all times this technology is a viable approach.

3.11.3 Noise profiling

As discussed in Section 3.10.2, often the ambient noise environment includes many noise sources, and noise from mining operations is only one component of overall noise. Therefore, if the ambient noise exceeds a project noise goal, this does not necessarily mean that the noise criteria have been exceeded because of the mine.

By using a site-specific noise model, the noise contribution from the mine can be predicted for the prevailing weather conditions and consequently compared to both measured levels and project noise goals to more accurately understand the likelihood of exceedances from the mine. Once a mine has been using this sort of approach to noise management over several years, with regular validation against measurement results, it becomes a very useful tool for managing noise and understanding likely implications for 'what if' scenarios when planning or changing operations.

Some leading practice businesses are already attempting to link their real time noise monitoring data with real time weather data in a noise modelling tool to deliver the most sophisticated information possible to assist mine managers to ensure operations can always comply with noise limits.

3.12 Closure and rehabilitation phase

Noise impacts are likely to be significantly reduced during the closure and rehabilitation phase, compared with the 'normal' operations of a mine. However, noise impacts from closure and rehabilitation cannot be ignored, as earthmoving equipment remains operational and often operates in exposed locations as the final landform is created. Any environmental management plans for the mine should remain in operation for closure and rehabilitation to allow for ongoing noise monitoring and community consultation as required.

CASE STUDY: Effective monitoring to understand a noise problem

One of the major dump stations for a large open-cut coal mine was located close to a residential property. The homestead for the property was located approximately 1,200 metres north-east of the dump station, on elevated land with a clear line of sight to the dump station.

The current owners had resided on the property since June 2000. Complaints had been received since the dump station was upgraded in mid-2002.

Ambient noise logging at the site showed low background levels typical of rural areas, but no clear pattern of elevated noise levels in relation to dump station activities. There was no clear correlation of high noise levels with high coal throughput, nor low noise levels with low coal throughput. This made it difficult to understand the extent and nature of the problem.

Measurements during the daytime period typically showed that mine noise was inaudible, and natural noises such as insect and bird noise dominated. Measurements were repeated during the night time period to understand the conditions during the times when complaints were typically made.

This demonstrated that noise levels at night increased by 5 dBA to 6 dBA compared to daytime levels, due to the presence of adverse weather conditions such as temperature inversions. Background noise levels were very low. As a result, noise emission from the dump station dominated the ambient noise environment.

(continued)

The major noise sources audible were:

- engine and track noise from dozers
- conveyor noise
- clangs from coal dropping through the rill tower
- noise from trucks unloading at the dump station.

The coal stockpile acted as a noise barrier for the mobile equipment operating behind the stockpile. It was found that noise levels from this equipment could increase by up to 12 dBA when the stockpile was low.

Methods were proposed to reduce these noise levels, including:

- replacing tracked dozers with rubber-tyre dozers
- controlling the size of the coal to reduce the impact noise on the rill tower
- shielding the overland conveyor
- maintaining coal stockpiles at a high level during night-time periods.

In the end, the mine operator helped to relocate the homestead to the opposite side of the property, away from the dump station. Noise emission from the dump station was completely inaudible at this location, even with background noise levels of 18 dBA.

This case study demonstrates that noise logging alone is often insufficient to properly characterise a noise problem and determine a solution. Background levels can vary considerably with seasons, which, coupled with variability in the noise source and weather effects, can make it difficult to draw conclusions from the logging. Sometimes there is no substitute for attended night-time measurements under the 'typical worst case' operating conditions.

Dump station showing the effect of coal stockpiles. Source: Emma Charlton, AECOM.

4.0 VIBRATION

Overview

'Vibration' is the term used to describe oscillation, reciprocation or other periodic motion of a body forced from equilibrium. A low level of vibration is a normal feature of the environment, and is typically not perceptible to most people. When this low background level is exceeded, vibration can cause annoyance and adverse reactions from the community.

In the mining industry, vibration is experienced and/or generated by many items of plant and equipment. The major source of vibration emission, which can be of sufficient strength to cause community concern, is blasting. This is described as an 'impulsive' vibration source, characterised by brief (typically less than one second) period of vibration that significantly exceeds the background level.

Conveyors, processing plant and other plant and equipment also emit vibration, but in a more steady state manner (that is, with relatively small fluctuations in amplitude over the operating period). Vibration emitted from this equipment is not typically perceptible at distances greater than 20 metres from the source. However, excessive vibration can create additional noise that can affect receptors significant distances away as noise, rather than vibration.

Also of significance is the vibration of machinery such as crushing and grinding circuits and vibrating screens, which emit very low-frequency airborne sound energy. Though not always strictly 'vibration', the low frequency sound waves can result in what appears to be vibration in a structure at the receptor.

Unwanted effects of vibration due to mining activities include:

- nuisance or annoyance from both vibration and noise levels
- fatigue, nausea and other health effects
- injury to people
- damage to sensitive equipment
- damage to structures (including rock strength in mines).

Complaints regarding vibrations in residential situations often arise when the vibration magnitudes are only slightly greater than the perceptible levels. In practically all cases, the magnitudes at which vibration is first perceptible are such that there is no possibility of fatigue or other vibration-induced symptoms.

However, because people are able to 'feel' very low levels of vibration, they often overestimate the risk of damage associated with vibration in buildings. This is especially true when the source of the vibration is outside the building, and not within their control. Conversely, people will often readily accept much higher levels of vibration from familiar sources such as wind, domestic appliances and people walking on floors and slamming doors.

Ground vibration from blasting is the radiation of mechanical energy within a rock mass or soil. It comprises various vibration phases travelling at different velocities. These phases are reflected, refracted, attenuated and scattered within the rock mass or soil, so that the resulting ground vibration at any particular location will have a complex character with various peaks and frequency content. Typically, higher frequencies are attenuated rapidly, meaning that at close distances to the source such frequencies will be present in greater proportion than at far distances from the source.

The magnitude of the ground vibration, together with the ground vibration frequency, is commonly used to define damage criteria. The choice of the appropriate damage criterion may require consideration of the frequencies arising from the blast. Studies and experience show that well-designed and controlled blasts are unlikely to create ground vibrations of a magnitude that causes damage. Particular structures such as tall buildings, or abnormal ground conditions such as water-logged ground, should be carefully considered in a specialist study.

Cracks in buildings may be attributable to causes other than ground vibration, including ground or foundation movements (settlement and swell) associated with reactive clay soils during periods of prolonged dry or wet weather. Seismic events from underground mine activity rarely affect surface structures. Where there have been cases of damage it has been associated with some caving operation or pillar collapse in conjunction with unusual geological conditions. There is usually a band of strong and brittle material that acts to collect and transmit the vibration to some zone at the surface where the hard band outcrops or comes near to the surface.

4.1 Statutory controls

Due to the potentially severe and irreversible impacts of excessive ground vibration, particularly in relation to structures, statutory limits have been put in place in most jurisdictions. These limits are based on studies and measurements designed to establish the minimum criteria to protect human comfort and prevent structural damage.

In Australia, there are a number of government agencies responsible for regulating ground vibration resulting from blasting. Mining authorities are generally responsible for regulating blasting activities by the application of legislation and subordinate standards. However, in respect of human comfort levels of ground vibration, diverse agencies such as a workplace health and safety authorities or environmental protection agencies may have jurisdiction. It is important to establish what agency or agencies have jurisdiction prior to commencing a blasting activity. In some cases, local government may also have a role in regulating the activity, usually through development consent processes.

Limits for other sources of vibration are significantly less than those set for blasting. Continuous vibration can excite resonant frequencies in a building and induce a much larger response than impulsive vibration such as blasting, increasing the risk of structural damage and human reaction. Where excessive vibration at the source causes higher noise levels at the receiver, the criteria for noise discussed in Section 3.9.2 apply.

4.2 Definition of ground vibration

Vibration transmitted through the ground may cause damage to structures and architectural elements or discomfort to their occupants. The vibration levels at which people become annoyed are well below the levels at which damage occurs. The likelihood of such damage or discomfort may be ascertained by measuring the vibration from a blast close to the location of concern, such as a building or other structure.

For all limits it is necessary to measure in three orthogonal directions, one in the vertical direction and the other two in perpendicular horizontal directions. Such measurements align with most structural members in man-made structures. From such measurements it is possible to derive the vector peak particle velocity (and the peak component particle velocity for each direction).

The magnitude of the vector particle velocity is the amplitude of the vector sum of three time-synchronised velocity components directly measured by an instrument. When not measured directly, it may be determined by the following equation:

$$v_p = \sqrt{v_x^2 + v_y^2 + v_z^2}$$

vx, vy and vz are the synchronized instantaneous velocity components of the x, y and z axes, respectively. The VPPV is the maximum of vp.

4.3 Reasons to control ground vibration

Blasting operations may cause excessive noise and vibrations impacts on the community. Excessive levels of structural vibration caused by ground vibration from blasting can result in damage to, or failure of, a structure. People are able to detect vibration at levels much lower than those required to cause even superficial damage to the most susceptible structures.

The criteria set out in this handbook assist in minimising annoyance, discomfort and damage that may be caused by blasting at activities such as mining, quarrying, construction and other operations which involve the use of explosives for fragmenting rock. Leading practice environmental management will minimise the likelihood of adverse effects being caused by the impact of ground-borne vibration in noise-sensitive places and among people living in or using the surrounding area.

4.4 Ground vibration limits

Frequency-dependent limits have the capacity to precisely deal with the hazards presented by ground vibration and are seen as the basis for best practice blasting. The particular frequency-dependent criteria should be reported with the measurements. All the limits given in this section are peak component particle velocities, as used in overseas standards and guidelines. The classification of type of structure may be difficult; when in doubt, a more conservative limit from the nearest description in the structural damage table should be applied.

4.1.1 Human comfort limits

Because the human response to vibration depends on a range of factors, such as vibration levels, location and time of day, different statutory requirements for human comfort limits for ground vibration may apply in different jurisdictions.

General guidance on human response to building vibrations is given in AS 2670.2–1990 *Evaluation of human exposure to whole-body vibration—continuous and shock-induced vibration in buildings (1 to 80 Hz)*, ISO 2631-2:2003 *Mechanical vibration and shock—evaluation of human exposure to whole body vibration—Part 2: Vibration in buildings (1 Hz to 80 Hz)*, BS 6472 -1:2008 *Guide to evaluation of human exposure to vibration in buildings. Vibration sources other than blasting*, and BS 6472–2: 2008 *Blast-induced vibration*. A typical set of limit criteria for human comfort is shown in Table 4.1.

Table 4.1 Ground vibration limits for human comfort

Blasting		
Category	**Type of operations**	**Peak component particle velocity (mm/s)**
Sensitive site[a]	Operations lasting longer than 12 months or more than 20 blasts	5 mm/s for 95 per cent blasts per year 10 mm/s maximum unless agreement is reached with the occupier that a higher limit may apply
Sensitive site[a]	Operations lasting for less than 12 months or less than 20 blasts	10 mm/s maximum unless agreement is reached with the occupier that a higher limit may apply
Occupied non-sensitive sites, such as factories and commercial premises	All blasting	25 mm/s maximum unless agreement is reached with the occupier that a higher limit may apply For sites containing equipment sensitive to vibration, the vibration should be kept below manufacturer's specifications or levels that can be shown to adversely affect the equipment operation
Other		
Category	**Period**	**Peak component particle velocity (mm/s)**
Residential	Night-time	0.2 mm/s
	Daytime	0.3mm/s
Offices	When occupied	0.6 mm/s
Occupied non-sensitive sites, such as factories and commercial premises	When occupied	2.5 mm/s

mm/s = millimetres per second

a A 'sensitive site' includes houses and low-rise residential buildings, theatres, schools, and other similar buildings occupied by people.

4.1.2 Building damage limits

Currently there exists no Australian Standard for assessment of building damage caused by vibrational energy. This section summarises the most relevant available standards from the United Kingdom, the United States and Germany.

Frequency-independent and frequency-dependent guide levels are described in both British Standard BS 7385–2: 1993 *Evaluation and measurement for vibration in buildings.*

Guide to damage levels from groundborne vibration and the United States Bureau of Mines (USBM) RI 8507 *Impacts to structures*. The levels specified are peak component particle velocities, and the methods used for assessing the frequencies are similar in both documents.

Frequency-dependent criteria are important for assessing the blast-induced vibration effects on buildings and other structures and are the recommended approach. Frequency-dependent criteria may not be readily implemented for all applications.

For blasting operators who do not have the facilities to use frequency-dependent assessment methods, the levels specified in Table 4.3, which are more conservative for most blasting applications, will reduce the potential for damage. The table should be used in conjunction with the notes.

Wherever possible, the ground vibration levels from all blasting operations must be limited to the damage limit criteria shown below at all sites not in the ownership or control of the organisation commissioning the blasting.

Table 4.2 BS 7385-2 Transient vibration guide values for cosmetic damage

Line	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	15 Hz and above
1	Reinforced or framed structures. Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structure. Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

Notes:

1 Values referred to are at the base of the building.

2 For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.

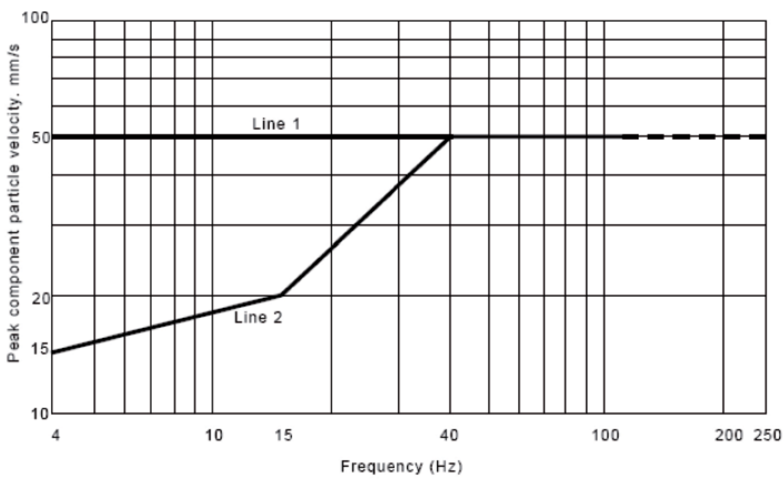
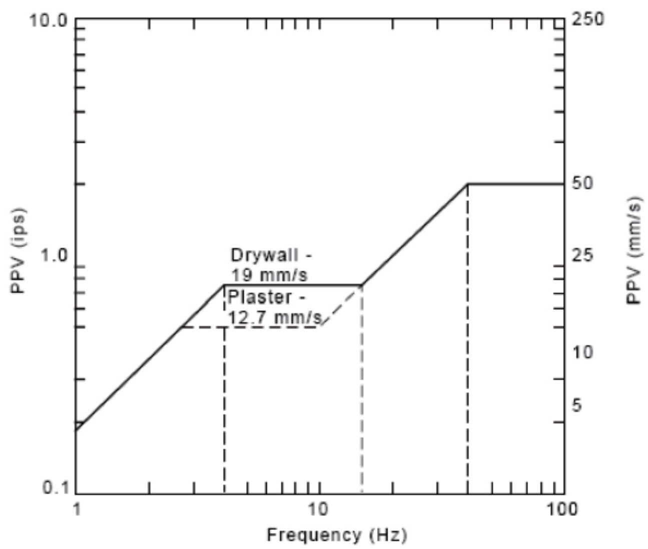


Table 4.3 BS 7385-1:1990—Damage Classification

Damage classification	Description
Cosmetic	The formation of hairline cracks on drywall surfaces or the growth of existing cracks in plaster or drywall surfaces; in addition, the formation of hairline cracks in the mortar joints of brick/concrete block construction
Minor	The formation of cracks or loosening and falling of plaster or drywall surfaces, or cracks through bricks/concrete blocks
Major	Damage to structural elements of the building, cracks in support columns, loosening of joints, splaying of masonry cracks etc.
USBM Damage Classification	
Uniform classification	**Description**
Threshold	Loosening of paint; small plaster crack at joints between construction elements; lengthening of old cracks
Minor	Loosening and falling of plaster; cracks in masonry around openings near partitions; hairline to 3 mm cracks (0 to 1/8 in); fall of loose mortar
Major	Cracks of several mm in walls; rupture of opening vaults; structural weakening; fall of masonry, e.g., chimneys; load support ability effected



USBM 'Safe' blasting vibration level criteria.

Research suggests that the guide values and assessment methods given in BS 7385-2 and (USBM) RI 8507 are applicable to Australian conditions, and are recommended for explosives users with the facilities to make use of them. The estimation of the frequency of each vibration component to be used in structural damage assessment is complex. Simple approaches suggested within the BS 7385-2 and (USBM) RI 8507 include:

- frequency of the maximum peak particle velocity amplitude peak
- dominant frequency of the component vibration time history
- zero crossing frequency of the peak particle velocity amplitude peak.

The (USBM) RI 8507 and BS 7385-2 methods for assessing frequencies have been widely used for many years, and were suitable for use with desktop and laptop computers with the power that was commonly available in the 1980s and early 1990s. It appears that the motion frequencies determined by simple methods, such as zero crossing, are conservative for assessing damage potential.

German Standard DIN 4150-3:1999-02 *Vibration in buildings—Part 3: effects on structures* provides recommended maximum levels of vibration that reduce the likelihood of building damage caused by vibration. These levels are 'safe limits', up to which no damage due to vibration effects have been observed for the particular class of building. 'Damage' is defined by DIN 4150 to include even minor non-structural effects such as superficial cracking in cement render, the enlargement of cracks already present, and the separation of partitions or intermediate walls from load bearing walls. If such damage is observed without vibration exceeding the 'safe limits' it can be attributed to other causes. DIN 4150 also states that when vibrations higher than the 'safe limits' are present, it does not necessarily follow that damage will occur.

Table 4.4 Vibration standards for buildings, DIN 4150-3

Group	Type of Structure	Peak Vibration Velocity, mm/s			
		At foundation at a frequency of			Plane of uppermost storey
		Less than 10 Hz	10 Hz to 50 Hz	50 Hz to 100Hz	All frequencies
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or use	5	5 to 15	15 to 20	15
3	Structures that because of their particular sensitivity to vibration, do not correspond to those listed in Lines 1 or 2 and have intrinsic value (e.g. buildings that are under a preservation order)	3	3 to 8	8 to 10	8

Source: DIN 4150-3:1999-02 *Vibration in buildings—Part 3: effects on structures*

4.5 Best practice blasting

Using electronic initiation of blasts rather than traditional shock-tube detonators significantly reduces vibration impacts caused by the blast. Electronic detonation has been shown to:

- reduce the maximum vibration readings
- reduce the number and intensity of high vibration readings
- increase the uniformity of the blast
- control the vibration frequencies to minimize the low frequencies
- increase dig rates.

Electronic detonation allows for precise timing of initiation of each charge. This reduces the vibration levels. This system has been extensively used at Newcrest's Telfer mine.

CASE STUDY: Comparison of electronic and traditional detonators

A trial was carried out at AngloGold Ashanti Sunrise Dam open-cut gold mine, where two blasts were carried out, one using electronic detonators and one using shock tube detonators. The design parameters of the two blasts remained constant. The selected location of the two blasts was chosen so that the geology was as consistent as possible. Blast design parameters, including initiation timing, were determined by engineering to suit the geology and kept constant for both shots.

The results of the blasts showed:

- Muck pile profile and swell
  - The electronic blast increased the fragmentation on the surface of the blast.
  - The electronic blast achieved a much more consistent heave.
- Productivity—A 16 per cent increase in dig rate was achieved with the electronically initiated blast in comparison to the shock tube-initiated blast.
- Fragmentation—The electronically initiated blast achieved an improvement in overall fragmentation.
- Crusher—The electronically initiated blast achieved higher average throughput and maximum throughput than the shock tube-initiated blast.
- Vibration analysis—The vibration readings achieved from the electronically initiated blast were more uniform though not significantly lower.

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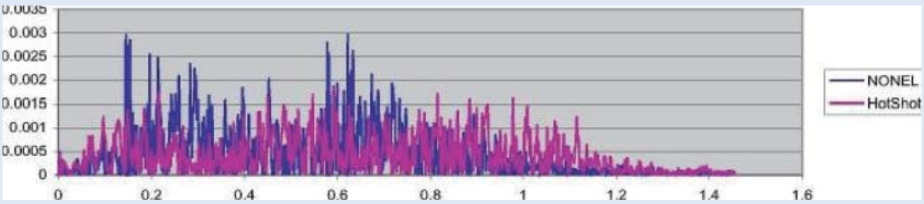
Electronic blast muck pile.

Shock tube blast muck pile.



Shock tube (NONEL©) and electronic (HotShot©) geophone vibration comparison.

Full details of this case study can be found in the technical paper: Vaughan, M, Hall, E, Varga, D, Billing, G & McSweeney, K 2007, 'Blast improvements with electronics at Sunrise Dam Gold Mine', paper presented at the EXPLO Conference, Wollongong, NSW, 3–4 September 2007.

CASE STUDY: Ventilation shaft in a residential area

Sinking a 315 metre ventilation shaft is challenging enough—when you place that project in a residential area of a regional city, you really need to do your homework.

Planning and consultation

LGL Ballarat started planning for the ventilation shaft in 2006, well before the planned construction commencement date of July 2006.

With some residents as close as 60 metres from the worksite, significant effort was put into planning to minimise the impact on the neighbours. Extensive consultation with the community was undertaken prior to, during and after each phase of construction.

Initial consultation (letter drop) was followed up by personal contact with the closest residents and those with particular concerns. One-on-one consultation with the immediate neighbours, using diagrams of each phase, took place during the early planning stage. Each neighbour was asked whether they had any concerns; most were concerned about potential blast vibration, noise, work hours and dust.

The company has a long history of good community engagement, so many members of the community were interested in and supportive of the project. The information gathered from community surveys was incorporated into the final plans. For example, the site layout was changed to accommodate two neighbours, moving parking bays, installing visual screens to ensure car lights did not shine into the neighbour's property and moving a tipping bay to reduce dust and noise impacts.

Letter drops and community newsletters were produced throughout the duration of the construction of the shaft. The site was also incorporated into the company's public open day. Information supplied focused on describing current and upcoming activities and ensuring the community had an open line of communication with the company.

LGL Ballarat strives to minimise the impact on the community, rather than simply achieve the compliance limits set by regulators. For the shaft project, the company set internal targets well below compliance levels for blast vibration. For example, the internal limit for peak particle velocity was 3 millimetres per second, which was less than a third of the regulatory compliance limit of 10 millimetres per second.

Once the site preparation was completed and shaft works had begun, the community realised that the company was doing its utmost to ensure that all impacts were minimised. The company took all complaints seriously and modified practices to ensure constant improvement. The biggest reward for the project team came when the initial objectors became supporters of the project and acknowledged the consultation efforts undertaken. One comment from a regulator was 'going beyond compliance is gold.'

(continued)

Bird's-eye view of the worksite in Ballarat. Source: LGL – Ballarat Goldfields.

Dust

Collected stormwater and recycled mine water were used as temporary dust suppressants and, although acceptable, did not deliver satisfactory results. Other technologies were trialled but, given the tight turning circles of heavy vehicles and a need for constant reapplication, they also failed to deliver satisfactory results. The only means of effectively reducing dust emissions was to lay asphalt in the car park, which the company did. In addition, sprinklers were engaged to reduce dust rising out of the shaft during blasting.

Noise

Research identified a locally produced recycled paper and concrete noise attenuation product that was ideal for the 6 metre-high compound walls. The compound housed activities such as the use of shaft winders and air compressors, rock dumping, truck loading and equipment handling. To ensure that there was no interruption to the neighbours' power supply, noise-attenuated diesel power generators (like those used on film sets and at public events) were used. These generators were placed within a smaller compound with additional attenuation barriers, on the side of the project site furthest from neighbours. All vehicle-reversing alarm beepers were changed to low-frequency 'squawkers'.

(continued)

A noise monitoring officer visits a neighbour's residence, with the sound wall visible in the background.

Vibration

Several of the neighbours had concerns regarding the potential for cracking of their houses from the blast vibration. To provide assurance to these neighbours the company commissioned house inspections by a qualified independent building inspector, during the planning phase. Four investigations were undertaken prior to commencement and two during the project. These inspections and additional monitoring undertaken by the company gave residents peace of mind that there was minimal chance of damage occurring to their properties.

Consultation with the explosive manufacturers and peer review by independent blast experts ensured a high level of control over the blast design process. A decision to free dig the shaft with a small excavator to a depth of 70 metres, rather than blast, reduced the impact of near-surface blasting.

During times of blasting, electronic detonators were used to provide reliable timing of blast delays and a larger range of delays compared to the more commonly used initiation methods. This enabled blast vibration to be minimised and eliminated the use of blasting cord, which can be a source of blast noise. Three blast monitors with geophones and linear microphones were used during the project; two remained stationary while the third was used for reactive investigations at properties where the residents had blasting concerns.

One of the key learnings from the project involved the benefit of providing a spoken telephone text message service to warn residents immediately prior to blasting. Many of the residents were startled by the blast vibration and noise, and simply alerting them five minutes prior to firing alleviated this issue.

5.0 CONCLUSION

The life cycle approach, through planning and exploration to development and operations and, finally, to closure and rehabilitation, is central to leading practice management of airborne contaminants, noise and vibration arising from mining operations. Different risks and issues arise in each phase of the mine's life, and have to be managed systematically. From the earliest stages, management strategies should be integrated into systems and plans, as a tool for operational staff and a basis for ensuring compliance and improving performance.

The handbook adopts a risk management approach to the three issues. This involves identifying the dust, noise or vibration hazard, assessing the risk and implementing controls. The need for monitoring and management to ensure the controls are working effectively is a common message throughout the booklet.

Even though the handbook necessarily focuses on the hard engineering controls required to eliminate or mitigate the risks, the significance of working with the community is also stressed throughout. Without community involvement and engagement in all aspects of the mine's life cycle, the 'social licence to operate' will be quickly withdrawn and the operation will close, leaving a negative impression on community attitudes that can affect not just the operator but the whole industry.

Leading practice is all about integrating sustainable development into a mining operation. By way of text, photos, figures, tables and selected case studies, this handbook provides a toolkit for implementing leading practice in the management of airborne contaminants, noise and vibration.

GLOSSARY

CFD	computational fluid dynamics
dBA	Sound is measured in decibels (dB). When measuring environmental noise, a weighting network is used which filters the frequency of the sound so that it better corresponds to the response of the human ear. In this handbook, noise measurements made using such a weighting network are expressed as dBA.
dB(linear)	A measure of sound that relates to effects on structures rather than human hearing, dB(linear) peak is the maximum reading in decibels (obtained using the 'P' time-weighting characteristic as specified in AS 1259.1—1990 Sound level meters, with all frequency weighted networks inoperative
DEM	dust extinction moisture
$L(A)_{eq}$	In noise monitoring, the equivalent to the level of a constant noise which contains the same energy as the varying noise environment.
$L(A)_{10}$	In noise monitoring, the noise level which is exceeded for 10 per cent of the sample period.
$L(A)_{90}$	In noise monitoring, the noise level which is exceeded for 90 per cent of the sample period—commonly known as the 'background noise level'.
MHM	materials handling moisture
NEPM	National Environment Protection Measure
NPI	National Pollutant Inventory
PLC	programmable logic controller
PM_{10}	particulate matter less than 10 microns in diameter
$PM_{2.5}$	particulate matter less than 2.5 microns in diameter
TEOM	tapered element oscillating microbalance
TSP	total suspended particulate matter
RASS	Radar Acoustic Sounding System
SO_2	sulphur dioxide
SODAR	Sonic Detection and Ranging
TEOM	Tapered Element Oscillating Microbalance
TSP	Total Suspended Particulate Matter

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