SINCLAIR KNIGHT MERZ
SKM

Improvement of NPI Fugitive Particulate Matter Emission Estimation Techniques

- Final
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Executive Summary

The NPI is a program designed to provide the community, industry and government with information on the types and amounts of certain substances being emitted to the air, land and water.

The NPI program published the Mining Emission Estimation Technique Manual (hereafter referred to as the NPI Mining Manual) in June 1999, after its development by consultants and many mining industry representatives. This manual contains emission estimation techniques (EET) and emission factors for particulate matter with a diameter of less than 10 µm (PM_{10}) and Total Suspended Particulate (TSP) based on a variety of sources, including many from the United States Environmental Protection Agency (USEPA) and the Australian coal mining industry.

There has been significant feedback from the wider non-coal mining industry to the NPI program expressing concerns over the calculation methods and emission factors included in the NPI Mining Manual for fugitive PM_{10} and metal and compounds emissions from mining activities such as stockpiles, open areas and windblown dust. In many instances facilities have been directed to use coal emission factors in the absence of emission factors for their specific ore or waste types.

The emission of "toxic" metals in particulate matter is a potentially highly contentious issue. Particulate emissions are an environmental issue in towns such as Port Hedland and Esperance, and in other locations in Australia where large quantities of mining material are handled. NPI reporters from mining, quarrying, mineral sands and other industries have expressed strong interest in improving estimates of PM_{10}.

As a result, a study was conducted to review the status of, and identify and recommend ways to improve, emission estimation methodologies for fugitive (non-combustion) $PM_{2.5}$, PM_{10}, TSP and metals/metal compounds in particulate matter from mining (non-coal) and other industrial activities for NPI reporting. The first phase of the review was a consultation with mining companies and consultancies covering a broad range of non-coal mining industries. This report presents the second phase of the project and contains a review of the status of techniques listed in USEPA AP-42 and the USA's Toxic Release Inventory (US TRI), as well as the Canadian National Pollutant Release Inventory (NPRI). The report also develops recommendations on potential improvements to the current methods, further test work that can be conducted to improve the techniques to Australian non-coal mining conditions and the potential costs that such work may incur.

With respect to general comments, the review concludes that particulate matter emission sections included in the NPI Mining Manual and the current draft of the NPI Fugitive Emissions Emission Estimation Technique Manual (NPI Fugitive Emissions Manual) are not well written or documented, with many of the emission factors in need of revision.

Other general recommendations include:

1) As a priority, the draft NPI Fugitive Emissions Manual should be rewritten to incorporate the changes recommended in this report. This will involve incorporating the newer USEPA AP-42 emission factors;
2) Individual default factors should be removed where possible with only the emission equation supplied, or the equation and a range of default factors; and
3) A number of actions and studies be undertaken to obtain/collate data to improve the factors for the Australian situation. It is recommended that, if funding permits, these studies be conducted with any resultant improvements to estimation techniques being added to future versions of relevant EET Manuals.

Specific recommendations of the report comprise:

Vehicle Emissions - Unpaved Roads

R1 Incorporate the recent December 2003 USEPA AP-42 unpaved road equations into the NPI Fugitive Emissions Manual. It is noted that the draft version of the NPI Fugitive Emissions Manual has a number of errors that require correction, such as deletion of the soil moisture table.

R2 Single default emission factors should not be provided as there can be large variations between the vehicle fleets and road characteristics at different sites. If defaults are to be provided they should be given for the various combinations of typical vehicle fleets (for example vehicle usage on haul roads at a mine site and a typical light vehicle fleet) and for typical uncontrolled and controlled roads. To assist companies in estimating the appropriate emission factor for their site, it is recommended that the NPI Fugitive Emissions Manual include a compilation of typical silt contents, as well as moisture contents for various Australian industry groups, as per the USEPA guides.

R3 Update the unpaved road control factor with separate methods for:

- Fresh water, using either:
  - The equation of Cowherd et al (1988). This will require mines to estimate the number of vehicle passes and watering rates on the various roads. Estimates of the hourly evaporation rate could be undertaken using annual evaporation estimates and converting these to a maximum hourly value using a multiplier as in Cowherd et al (1988); or
  - The current USEPA approach where moisture contents for the road in a controlled and uncontrolled state under typical traffic conditions are measured.
- Use of organic chemical suppressants, using for example the US AP-42 methodology; and

- Use of salts including the use of hyper-saline water. It is considered that test work, estimated at $20,000, is required to develop appropriate control factors.

R4 Though not strictly applicable to the NPI Mining Manual, it is considered that the Aggregated Emissions from Paved and Unpaved Roads EET Manual should be updated to include the new AP-42 equations, including a default moisture content of 1% (following the US NEI) and typical Australian data for road silt contents. This may involve a desktop study or in-field sampling.

Wind Erosion

R5 The current default factor should be deleted. It is considered that emission estimates can be readily obtained with the current NPI equation and this should be used to take into account climate variations across Australia. This will result in some areas having emission factors that are twice as high as the current default with some areas having considerably lower emissions;

R6 Though the current NPI equation is considered indicative only, there appears to be no ready replacement, with the existing AP-42 equation considered to be based on little data for non-coal mines and difficult to implement (eg. estimation of threshold friction velocities). Therefore it is recommended that:

- The current NPI equation should be retained in the interim.
- The NPI coordinate with the US groups (USEPA and WRAPAIR) to determine and progress toward a new equation with more supporting studies for this.
- The NPI liaise with the wind erosion community within Australia to see if a more suitable equation or simple model for mines could be developed. Such work may include undertaking a single case study to verify the methodology or the development of portable wind tunnel methodology to determine relative erodibility potential of materials.

R7 The NPI develops or commissions estimates for all fugitive particulate matter sources within Australia, such that the mining fugitive emissions can be placed in context, as is provided in the US NEI. At present in most regions of Australia, fugitive particulate matter from mining is presented as the only large source, with other larger sources of PM_{10} and "metals" such as from wind erosion of non mine areas, from agricultural activities and bush fires omitted. For wind erosion estimates it is recommended that the NPI liaise with those in the Australian Air Quality Forecasting System (AAQFS) who are currently evaluating a system that predicts PM_{10} wind erosion emissions and the resultant PM_{10} concentrations for Australia. Alternatively, a system using the CARB approach as used in the Pilbara and Bunbury airsheds (SKM, 2003 and SKM, 2003b) and recently undertaken for Victoria (Ng, 2004) could be used. The use of a national approach would also have the advantage of providing consistency across Australia. Other sources of particulate matter from agricultural practices and fires could also be coordinated at a national or at least state level. PM_{10} estimates from fires could be obtained in conjunction with the national greenhouse gas emission estimates as they both require fuel loading and the area burned**.** The development of estimates for all fugitive particulate matter sources within Australia has the potential to cost around $100,000.

R8 Alternative methods, such as using validated particulate matter dispersion models, should be highlighted as an acceptable alternative to the AP-42 equation. Such a method can consist of well-sited ambient monitors that are free from confounding sources, along with the use of back-calculation techniques involving dispersion models. It is recommended that all such studies have an independent technical review to ensure that the estimates are acceptable. This method would initially require a statement in the manual indicating that is an acceptable option, though requiring agreement on a case by case basis with the relevant State NPI department.

R9 Wind erosion control factors need to be improved to provide more detail on how to classify surface types. A possible method may be to supply photographic examples of bare areas as per the method used in RWEQ. This is recommended as greater than a factor of two variation can occur due to the subjective interpretation involved in classifying the amount of erodible area and the relevant control factors for a particular site.

R10 A wider range of control factors is needed for water cannon control to give credit to facilities with well designed and maintained systems. To undertake this, a review of water cannon control is recommended as a first step. The authors are aware of one study currently underway to determine control factors for water cannon.

Material Handling

R11 For loading/unloading trucks it is recommended that, as a first step, an in-depth review of the derivation of the USEPA AP-42 load-in/load-out emission equation is required to resolve the apparent large underestimation in emissions when using this equation, compared to that measured at Australian mines.

R12 For transfers, reclaimers and stackers, it is recommended that, as per loading/unloading trucks a review of the derivation of the USEPA load-in/load-out equations be undertaken to resolve the apparent underestimation of emissions. As an interim measure it is recommended that the defaults be retained but usage of the equation be dissuaded.

R13 When considering the moisture content of ores, as a second higher level of complexity to using the default 4% cut off between high and low moisture content ores, mines should be encouraged to use the rotating drum test to classify the dustiness of the ore as either high or low moisture. In general, the available data supports the default 4% cut off but the limited test work presented in this report indicates that thresholds may vary between at least 3 to 5.5%.

R14 As a low priority task, it is recommended that dustiness tests be used to account for the dustiness of the ores as a function of moisture. It is considered that this captures the true dustiness of the ore rather than trying to fit a simple universal moisture and silt particulate matter relationship to the ore as is used for moisture in the current and both moisture and silt in the older AP-42 material handling equations.

R15 For crushing emissions, the new AP-42 stone crushing and quarrying factors be included as the defaults for the stone crushing and quarrying industry.

R16 For screening emissions, the emission factors should be updated with those in the new AP-42 crushed stone processing and pulverised minerals guide. For primary, secondary and tertiary screening at stone processing and quarrying operations the AP-42 "screening" factors are applicable, whilst for iron ore re-screening the "fines screening" factor is considered applicable.

Blasting

R17 Though there is little support for the application of the current AP-42 blasting equation, and despite it being dropped from AP-42 Crushed Stone Processing and Pulverized Mineral Processing guide, it is recommended that:

- The new AP-42 equation be retained in the interim;
- NPI liaise with the USEPA to investigate further work planned to improve this factor; and
- NPI investigate the feasibility of conducting Australian testing using aircraft to profile the particulate matter plume to derive estimates. Such methods have been used for other aerosols such as smoke plumes from fires and industrial sources using the Flinders University aircraft and CSIRO.

Issue of Particulate Removal

R18 It is recommended that the NPI review the issue of particulate removal, noting that depletion for pit retention is incorporated but other removal mechanisms, such as vegetation belts, are not. In the case of mines, it is considered that the pit retentions are very indicative and that guidance should be provided so mines can develop site-specific factors using a model such as ISC3.

Particulate Size Issues

R19 Fugitive particulate matter $PM_{2.5}$ emissions should not be included in NPI reporting at this stage. There is a need to resolve the various issues with estimating $PM_{2.5}$ from fugitive crustal sources, with the $PM_{2.5}$ emission factors likely to be revised substantially in the next few years. Secondly, fugitive $PM_{2.5}$ from crustal sources are a small component of overall $PM_{2.5}$ emissions, based on US work, with the majority of $PM_{2.5}$ originating from gas to particle conversion or from sources not covered in the current NPI reporting. Additionally, there are a number of issues in the TSP and PM_{10} emission estimation methods that should be resolved as a higher priority.

R20 With the large amount of knowledge available on wind erosion (from wind erosion scientists) it is recommended that their work and models be utilised to develop more realistic particle size distributions at emission. It is considered that particle size distributions may have some wind speed dependence, and should not be a constant factor as in the current AP-42.

Metal Speciation

R21 Collate and review available metal speciation undertaken by different mining sectors to determine if sector based default factors can be developed. The speciations should preferably be for the silt fraction or even dust fraction and not the bulk ore;

R22 If insufficient quality data is available from *R21*, it is recommended that the NPI coordinate a study to obtain particulate matter speciation for fugitive particulate matter sources from mining activities within Australia. Such a study should involve:

- Coordinating particulate matter samples taken from representative mining sectors with the samples sent to a central laboratory for analysis. It is considered that coordinating one laboratory with the samples processed in a batch should achieve cost reductions and ensure consistency and quality of the data;
- Sampling sources from the surfaces of unpaved roads, wind erosion of stockpile areas and “tailings areas” using standard sampling techniques for roads and other areas. Unpaved and paved road areas should be composites of a facility’s roads weighted by their contribution to particulate matter emissions or split into areas adjacent to stockpiles and elsewhere. This would provide representative road surfaces where there is deposition of ore and therefore potential enhancement of metals derived from the ore body. It is also suggested that analysis be conducted on the parent material to determine the potential enrichment for the metals;
- Conducting the analysis in a laboratory through sieving, re-suspension of the particulate matter and then sampling with the selected particle size sampler as described by Watson et al (1998). This procedure is recommended as this method is considered easier, subject to less interference from other particulate matter sources and more cost effective than sampling with a high volume air sampler immediately downwind of such sources.
- Sampling of mining sectors should include, but not be limited to iron ore, gold, quarrying, mineral sand and bauxite (including refineries). It is suggested that the size fraction for sampling should be PM_{10} to be consistent with CARB. Additionally, as this is between the $PM_{2.5}$ and TSP fractions, the speciation should not be too dissimilar to either of these size fractions; and
- Analysis of the full range of metals in the NPI list, and any others recorded by standard analytical methods as detailed in Chow and Watson (1998), with method detection limits below 0.01 ppm.

R23 The NPI program consider undertaking testing for public unpaved roads at the same time as the testing in *R22*. Such testing could involve sampling up to five representative unpaved road surfaces in each State. In Western Australia, this could include a typical Pilbara road, a coastal limestone-based road, a typical Wheatbelt road etc. This would significantly improve unpaved road metal speciation and would also provide data for comparison to mining road speciation. It is noted that in the Bunbury airshed study (SKM, 2003) unpaved/paved roads were estimated to contribute 85% of the PM_{10} emissions and over 73% of the emission for the 11 metals provided with default speciations.

Table 1 has been compiled to assist in determining the costs associated with the recommendations listed above. This table also suggests wether the necessary work can be conducted as a desktop review or if fieldwork is required. The costs presented in this table are an approximate estimate only as more accurate costings can only be determined with a comprehensive scope of work.

- **Table 1 Possible testwork and estimated costs of completing recommendations**

Recommendation No.	Possible Testwork	Estimated Cost
R1	Incorporate the recent 2003 USEPA unpaved road equation into the NPI Fugitive Emission Manual. Correct errors in the NPI Fugitive Emission Manual.	$4,000
R2	Compilation of default emission factors Compile a list of typical silt and moisture contents for various industry groups. Collaboration between mines in similar areas has the potential to decrease the costs associated and increase the accuracy of the results.	$5,000 $30,000
R3	Update the unpaved road control factor for: - Fresh water using either Cowherd et al (1988) or the current USEPA approach - Chemical suppressants (including AP-42 methodology) (desktop study) - Applicable reductions for use of saline/hyper-saline water (field work)	 $1,500 $2,000 $20,000
R4	Update the Aggregated Emissions from Paved and Unpaved Roads EET Manual to include the new AP-42 equations with a default moisture content and typical road silt content for Australian roads - Desktop study - Field work (could potentially be conducted in-conjunction with R2)	 $5,000 $30,000
R6	Development of a suitable wind erosion equation for mines. - Case study to verify methodology of an existing equation - Development of portable wind tunnel methodology	 $10,000 $40,000
R7	Develop estimates for all fugitive particulate matter sources within Australia.	$100,000
R9	Provide further detail on how to classify surface types. A request to NPI reporters to submit photographs should be sufficient. Various photographs can then be incorporated into the NPI Mining Manual as examples.	$1,000
R10	Development of control factors for the use of water cannons. As the authors are aware of at least one study the first step would be to obtain the results of this study and determine its applicability. The second step would be to determine what other studies have been conducted in Australia. This recommendation would primarily be a desktop study.	$5,000

R11	In-depth review of how the USEPA derived the equation for loading/unloading trucks.	$6,000
R12	In-depth review of how the USEPA derived the equations for load in/load out.	$7,000
R17	Using airborne monitoring equipment to profile the particulate plumes derived from blasting.	$60,000
R18	The review of particulate removal (green belts and pit retention) would initially be a desktop study into its applicability to the mining industry and the potential use of models.	$7,000
R20	Develop realistic particle size distributions at the emission source by collating currently available information.	$10,000
R21	To determine if industry specific metal speciation is required a review of the current speciation from various mines/industries would need to be conducted.	$15,000
R22	If required, further investigations into metal speciation would require Coordinating samples from representative industries to a central laboratory. The samples would be obtained from unpaved roads, tailing dams, stockpiles and erodible open areas using a standard sampling technique. Laboratory analysis	$20,000 $50,000
R23	Conduct testing of unpaved public roads at the same time as the sampling in R22	$80,000

1. Introduction

The Western Australian Department of Environment (DoE) has commissioned Sinclair Knight Merz to review the status of, and identify and recommend ways to improve, the current emission estimation methodologies used to calculate fugitive (non-combustion) particulate matter. The review is to cover all components of fugitive emissions including $PM_{2.5}$, PM_{10}, TSP and metals/metal compounds from non-coal mining industries (gold, base metals, iron ore, bauxite, quarries).

The first phase of this review was a summary response document compiled from a questionnaire sent to various mining companies and consultancies covering a broad range of non-coal mining industries. The summary document contains the responses to the questionnaire as well as including all the comments and concerns that various companies have regarding fugitive particulate matter emission estimation.

This report covers the second phase of the project and contains a review of current emission estimation techniques used in the NPI Mining Manual and Aggregated Emissions from Paved and Unpaved Roads EET Manual. The report also presents a review of the status of techniques listed in the USEPA AP-42, US NEI and the US TRI, as well as the NPRI. The report provides recommendations on potential improvements to the current EETs, further test work that can be conducted to improve the techniques for Australian non-coal mining conditions and the potential costs that such work may incur.

2. Particulate Matter

2.1 Introduction

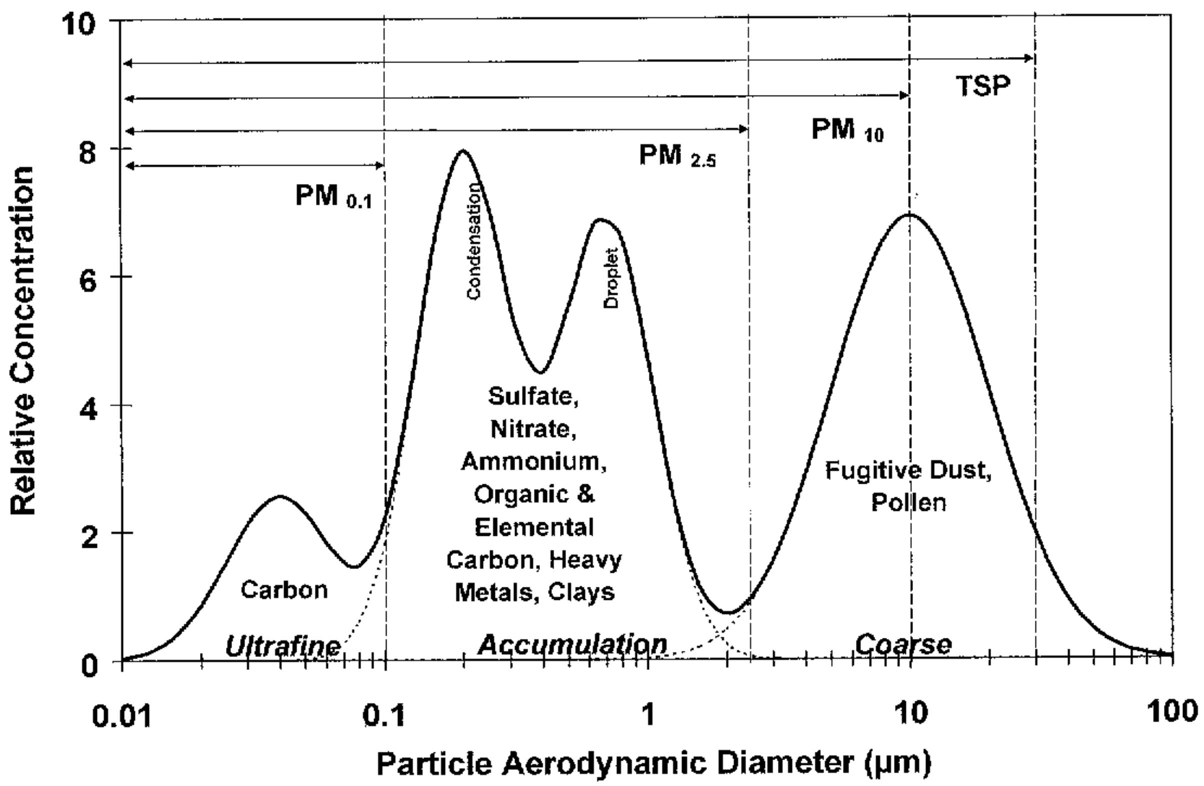
Suspended particulate matter can be defined by its size, chemical composition and source. Particles can also be defined by whether they are primary particles, such as pollens, sea salt from evaporating sea spray, a suspension of the fine fraction of soil by wind erosion or soot particles from incomplete combustion; or secondary particles, such as those formed from gas by particle conversion of sulphate or nitrate particles from sulphur dioxide and oxides of nitrogen. In this report, only particulate matter and the emission factors applying to (non-combustion) fugitive and crustal sources are discussed. Fugitive particulate matter is particulate matter that cannot be reasonably collected by passing through a stack, chimney or vent. Sources of such particulate matter include wind erosion, wheel generated dust, road repairs, blasting, storage or transportation of particulate matter, sandblasting, tilling, feedlots and metallic fumes from many industrial processes such as welding.

For simplicity in this report, fugitive dust will be referred to as particulate matter. It is noted that there are other types of particulate matter, however these are beyond the scope of this report.

2.2 Terminology

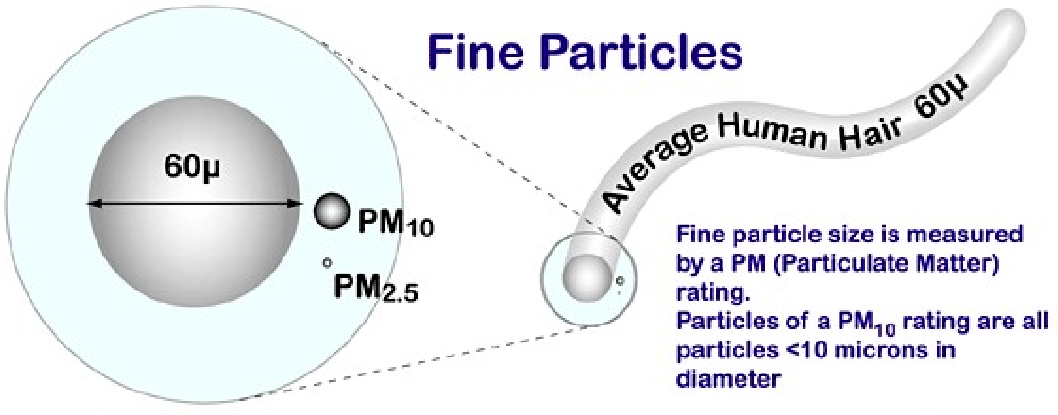
Typically, particulate matter is characterised by its size as measured by collection devices specified by regulatory agencies. The particulate size ranges specified in ambient air criteria are total suspended particulate (TSP), particulate matter below 10 microns (PM_{10}) and particulate matter below 2.5 microns ($PM_{2.5}$) (see **Figure 1**).

TSP refers to particulate that can remain suspended in the air or can be measured though a TSP sampler (see **Section 2.3**). This particle size does not correspond to a fixed physical size, but varies, as the size of particle that can remain suspended in the air is a function of air turbulence. Under strong winds and over rough surfaces, particles with aerodynamic diameters up to 100 microns can remain suspended, whilst under lighter wind conditions these particles will typically fall out within several minutes. The aerodynamic diameter is the diameter of a sphere of density 1 gm/cm^3 that has the same settling velocity as the particle of concern. Aerodynamic diameters are used to standardise particle sizes because particle settling velocity, and the ability to penetrate into the respiratory tract (or be separated by a sampling head), are dependent on the size, shape and density of the particle. For example, an iron ore particle of physical size of 4.5 microns with density 5.2 g/cm^3 will behave as an aerodynamic particle of approximately 10 microns.



- **Figure 1 Typical particle size distributions from Watson and Chow. Fugitive particulate matter dominates the coarse mode.**

PM_{10} and $PM_{2.5}$ particles are those that are sampled with PM_{10} and $PM_{2.5}$ samplers, which have a 50% cut point at 10 and 2.5 microns respectively. An illustration of the size of a particle of 10 and 2.5 microns diameter in relation to a human hair is presented in **Figure 2**.



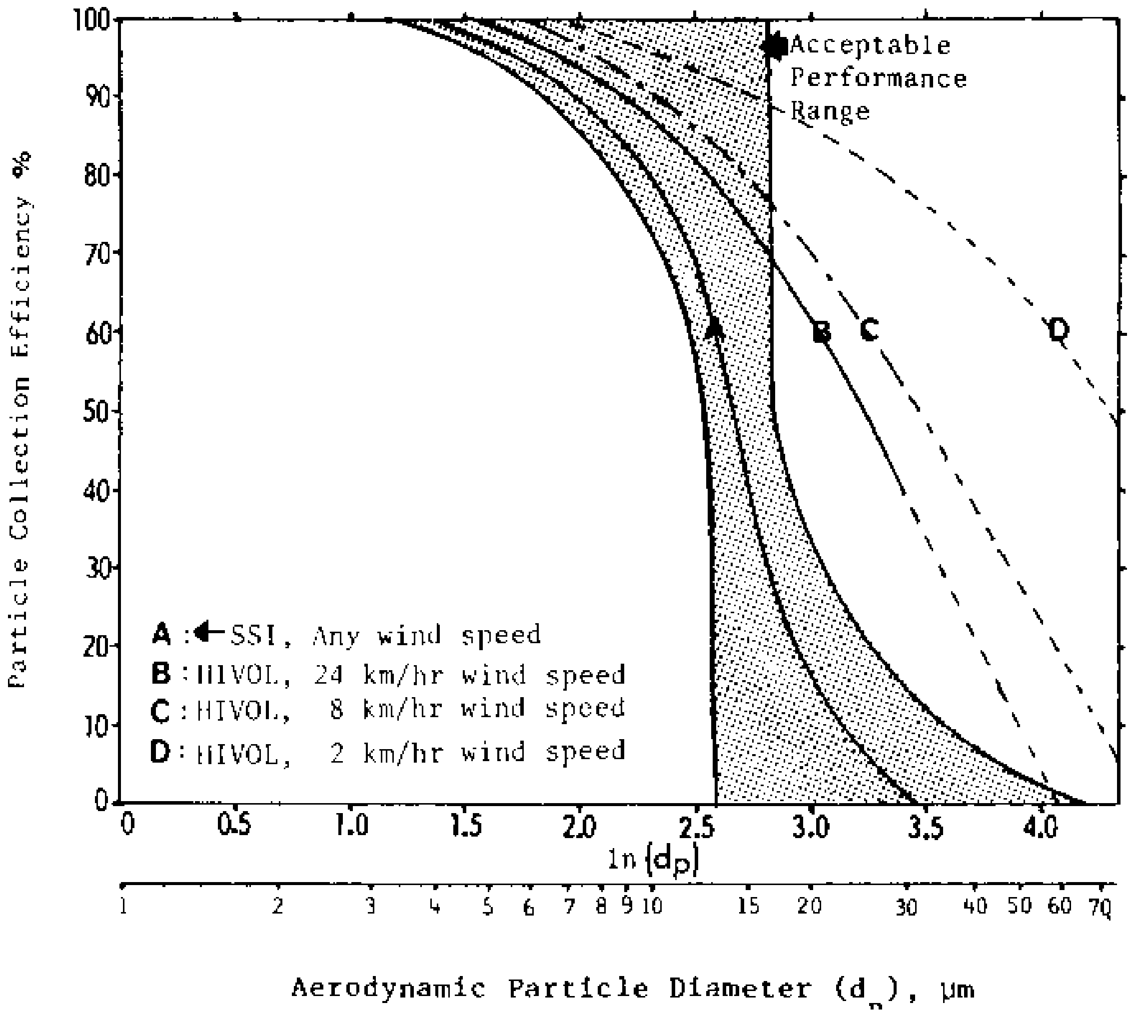
- **Figure 2 Example of particle sizes (From Qld EPA, 2005)**

Note: 1,000 microns (µm) = 1 millimeter

2.3 Sampling Methodology

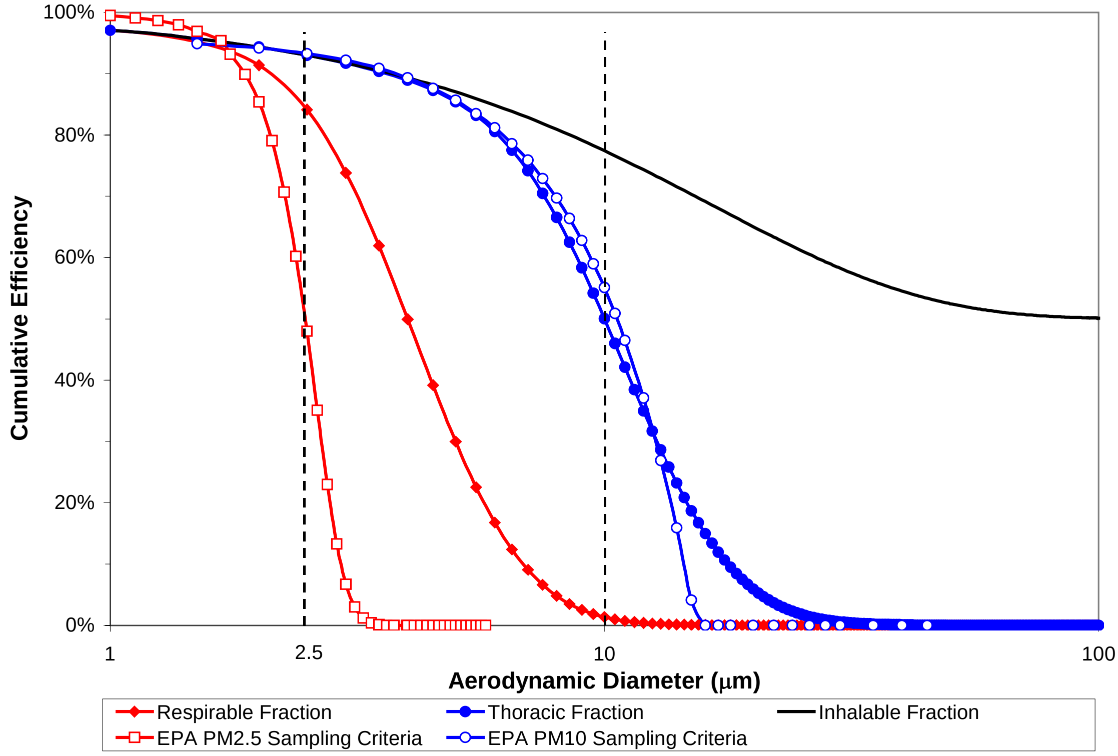
For TSP measurements, high volume air samplers are the reference sampler used in the US. In Australia there is an Australian standard (AS/NZS 3580.9.3:2003) covering their operation. High volume TSP samplers typically have a simple tent shaped covering, which is designed to keep the rain off the filter paper. Due in part to the simple tent shaped head, the collection efficiency of a TSP sampler is very dependent on the ambient wind speed and the orientation of the sampler to the wind. Generally the lower the wind speed, the higher the collection efficiency. This is illustrated in **Figure 3**. Being dependent on the wind speed and orientation, the 50% cut off for the sampler will vary between 30 and 80 microns. Additionally, even at a given wind speed and direction *"the efficiency curve of the sampler is very broad, extending from 100 percent capture of particles smaller than 10 µm to a few percent capture of particles as large as 100 µm*" (MRI, 1998). In the US an effective cut off point of 30 µm aerodynamic diameter is frequently assigned to the standard high volume air sampler with this termed suspended particulate (SP). SP, also be denoted as PM_{30} is often used as a surrogate for TSP. (MRI, 1998).

The above collection efficiency variation of TSP samplers is important as the concentrations and the emission factors determined are a function of the wind conditions at the time the measurements were taken. Therefore, in some cases PM_{30} emission factors (as often reported in the US AP-42) may significantly under-represent the actual TSP emissions as a significant proportion of larger particles may not be accounted for.



- **Figure 3 Collection efficiency of TSP samplers (from Aerosols, Ess and Schneider, et al, 1986, p. 27). Note SSI is Size Selective Inlet**

Ambient air PM_{10} and $PM_{2.5}$ samplers are defined by their 50% cut off point and the slope of the collection efficiency at their cut point. The collection efficiency is independent of the wind speed, unlike the older TSP samplers. Plots of the collection efficiency curves for PM_{10} and $PM_{2.5}$ and their comparison to respirable, thoracic and inhalable size fractions are presented in **Figure 4**. This indicates that for PM_{10} samplers, particles up to around 15 µm aerodynamic size can be measured, though at a low probability. Therefore, greater than 50% of the particulate measured by a PM_{10} sampler may be in fact greater than 10 micron if the ambient particulate has the majority of its mass larger than 10 microns, as occurs for most crustal particulate matter (see **Figure 4**). This is a result of the broad PM_{10} sampler cut point and has large implications on the comparability of emission factors and estimates for different sources of PM_{10} (see **Section 4.5**).



- **Figure 4 Sampling Efficiency Curves for Particulate Samplers from Shaw et al (2004). Note cumulative efficiency should read collection efficiency**

2.4 Sources of Particulate Matter from Crustal Sources

Particulate matter from crustal sources is generated by the suspension of the fine fraction of crustal materials through either wind or mechanical processes.

Wind generated particulate matter occurs when the wind speed exceeds the "threshold" velocity for erosion of the underlying surface. Under these conditions, particles greater than 100 microns that protrude above the surface are dislodged by shear forces and bounce and creep across the surface. These particles by their bouncing, skipping motion can dislodge smaller particles, which then remain suspended in the air. The amount of particulate matter generated is therefore highly dependent upon the wind speed. Below the wind speed threshold, (normally in the range of 5 to 10 m/s measured at 10 m above ground level), no particulate matter is generated, whilst above the threshold, particulate matter generation tends to increase with the cube of the wind speed. The amount of particulate matter generated is also dependent on the surface properties; including whether the material is crusted, the amount of non-erodible particles present (particles greater than several millimetres that tend to protect the smaller particles) and the size distribution of the material.

Mechanical processes that generate and potentially release particulate matter include material movement (such as grinding operations, dropping at conveyor transfer points, stacking, reclaiming and ship loading), blasting and vehicular movement. The amount of particulate matter generated from these processes does not have as high a wind speed dependency as that from wind erosion, and is dependent on the moisture properties of the material being transferred, size distribution of the material, drop heights and the particulate matter controls in place.

Particulate from crustal sources y generally have a median diameter in the range of 10 to 20 micron with the majority of the particulate greater than 10 micron. **Figure 1** for example indicates that crustal fugitive particulate matter from mining operations and wind erosion have a mode around 10 microns with minimal particulate matter below one micron. TSP samplers and even PM_{10} samplers will therefore measure a significant fraction of the coarse mode, whilst $PM_{2.5}$ samplers will only sample the very tail of fugitive crustal particulate matter. $PM_{2.5}$ samplers will instead contain a relatively greater fraction of particulate matter from non-crustal sources such as particulate from gas to particle conversion.

2.5 Particulate Removal

Particulate matter below one micron is removed through processes such as coagulation to form larger particles; by acting as condensation nuclei for the formation of cloud droplets; and through precipitation scavenging by falling water droplets. Particulate matter below one micron has negligible settling velocity and is not removed appreciably by sedimentation or impaction onto surfaces such as vegetation. For particulate matter greater than several microns, gravitational and inertia effects are important with the particles removed reasonably efficiently by vegetation and other obstacles. In addition to removal by settling and capture, removal can occur through “filtering” of the air by vegetation, as commonly occurs with trees along the sides of unpaved roads. Recently in the US there has been much work on defining the removal of $PM_{2.5}$. The studies showed that capture rates of up to 80% can occur in areas where buildings or dense vegetation surround the emission sources, which is much higher than has been considered in the past for these small particles (Pace, 2004). Large particles greater than tens of microns are removed primarily through gravitational settling.

3. Review of Overseas Reporting Requirements

This section provides a review of the requirements for reporting $PM_{2.5}$, PM_{10}, TSP and metals or metal compounds in particulate matter in use or planned by the US TRI and the NPRI.

3.1 US Toxics Release Inventory (TRI)

The TRI was developed from community requests for the right to know what was emitted from industry and is legislated under the *Emergency Planning and the Community Right-to-Know-Act* (EPRCA). The goal of TRI is to empower citizens, through information, to hold companies and local governments accountable in terms of how toxic chemicals are managed. The USEPA compiles the TRI data each year and makes it available through several data access tools, including the TRI Explorer and Envirofacts.

The TRI program commenced in 1987 with the first reporting year being 1988. Since its inception the number of chemicals and chemical categories has roughly doubled to approximately 650. The TRI program does not cover all industry groups in the US, but was expanded in 1999 to cover seven additional industry sectors beyond the original manufacturing industries. Included amongst these were the majority of the mining industry. Recently, the reporting thresholds for certain persistent, bio-accumulative, and toxic (PBT) chemicals have been reduced in order to be able to provide additional information to the public on these chemicals.

Reporting by a facility is required if the facility meets all the following points:

1) It is covered under an industry category. Industry categories included are Metal Mining and Coal Mining. Sub categories under Metal Mining include:

   - 1021 - Copper ores
   - 1031 - Lead and zinc ores
   - 1041 - Gold ores
   - 1044 - Silver ores
   - 1016 - Ferroalloy ores, except vanadium
   - 1099 - Miscellaneous ores, not elsewhere classified, including bauxite, ilmenite, rare earths mining, tin and titanium mining.

   It is noted however that mining of iron ore, uranium-radium-vanadium ores and metal mining services are exempt as well as non-metals mining, such as quarrying for aggregate, sand and clays.

2) The number of employees exceed 10 or more full time employees (20,000 hours) per year;
3) The facility manufactures (which includes importation), processes, or otherwise uses the listed chemicals; and

4) Thresholds are exceeded for the listed chemicals. The thresholds are 25,000 pounds for non-persistent bio-accumulative toxic from manufacturing or processing (applicable to mining), and 10,000 pounds for otherwise use.

If the reporting threshold listed above is exceeded and the "use" of that chemical exceeds the de minimus amount of 1% (or 0.1% for certain air toxics), then reporting is required for the various pathways of the chemical including emissions to air. A de minimus amount is an amount considered so minor that it can be disregarded.

For metal mining facilities, the industry guidance in the Metal Mining Facilities (Handbook) (USEPA, 1999) provides little guidance on the exact procedures to be followed. The guidance indicates that direct monitoring (eg a point source such as the exhaust from a scrubber), mass balance, emission factors such as from AP-42 or engineering calculations (eg Raoult's law etc for vapour emissions) are applicable. For crushing and grinding the USEPA does provide default values per tonne of ore for a low and high moisture content case which have been adopted into the NPI Mining Manual.

For metal mining there are no requirements for reporting PM_{10} or $PM_{2.5}$ emissions, only the metals that exceed the thresholds. This is a result of the TRI being focussed on chemicals. Furthermore, emissions from the transport of the ore itself and emissions of road particulate matter that may be low in the TRI-listed chemicals are apparently omitted. The sources required to be considered in reporting are transfer activities, crushing and screening of the ore itself.

In response to facility concerns, the USEPA is currently conducting a stakeholder dialogue process to identify improvements to the TRI and to develop opportunities to reduce the burden on reporting facilities.

Of particular relevance to NPI reporting requirements for mining facilities:

- Not all mining sectors (and hence facilities) are covered.
- The application of a de minimus exemption (except for wastes) for elements with concentrations in materials less than 1%, except for OHSA defined carcinogens which is 0.1%. Therefore most contaminants in ores do not need to be considered when determining whether the facility has processed or used that element.
- Emissions of $PM_{2.5}$ and PM_{10} are not required.
- Emissions from wind erosion or from the road particulate matter itself are not to be included. Sources to be included comprise; transport, (eg haulage, conveying), crushing, loading and unloading.
- TRI provides little guidance on EETs, referring to AP-42 and associated software.

3.2 US - National Emission Inventory (NEI)

The National Emissions Inventory (NEI) is a US inventory of criteria and hazardous air pollutants (HAP) emissions from point area and mobile sources (see http://www.epa.gov/ttn/chief/trends/). It is similar to the diffuse emissions (e.g. motor vehicles) included in the NPI. The NEI is not presented in conjunction with the TRI. Currently there are six criteria pollutants of which four are reported in the NEI (carbon monoxide, sulphur dioxide, PM (PM_{10} and $PM_{2.5}$) and NO_X) and 188 hazardous air pollutants. The first NEI inventory was conducted for 1999 and was finalised in 2003, with the current 2002 inventory scheduled for completion in 2005/2006. Prior to the 1999 inventory, criteria pollutant emission estimates were undertaken in the National Emission Trends (NET) inventory (1996 and 1999), whilst HAP emission estimates were maintained in the National Toxics Inventory (NTI) database. The NEI is therefore a more integrated approach to the previous inventories, combining both the NTI and NET data. The NEI is jointly developed by the USEPA, state and tribal agencies.

The NEI database provides estimates of annual emissions by source of air pollutants in all 50 States, the District of Colombia, Puerto Rico, and the Virgin Islands. Emission estimates for individual point or major sources (facilities), as well as county level estimates for area, mobile and other sources, are available currently for years 1985 through 1999 for criteria pollutants, and for years 1996 and 1999 for HAPs. Note that prior to 1999, the estimates are from the earlier programs.

Of note to the mining industry is that:

- The NEI is not estimated by industry but by government agencies, using gross “production” statistics by state and, if possible, county levels. It does not provide emissions on a facility basis.
- The NEI inventory includes PM_{10} and $PM_{2.5}$ from mining and rock quarrying that is the sum of emissions from metallic and non-metallic ore mines, and surface coalmines. These include four specific operations; overburden removal, drilling and blasting, loading and unloading, and overburden replacement. Not included are any conveyor operations, crushing and screening operations and storage. $PM_{2.5}$ emissions were estimated as 0.2 of the PM_{10} emissions. (http://www.epa.gov/ttn/chief/eiip/pm25inventory/areasource.html).
- The NEI provides an inventory of all sources of metals allowing, a more accurate picture of the relative contribution from mining to be assessed, unlike the situation in Australia where there are a number of large sources of PM and metals, such as unpaved roads, wildfires etc which are not generally reported. Within Australia, emissions from the “full” range of non-industry diffuse sources have been determined only for select locations (ie. Perth, Pilbara and Bunbury regions). Australia’s NPI would be improved if diffuse emissions were considered for the entire nation.
- By providing the total emission inventory, the emission estimates can be used to effectively target sources that require control, as is undertaken for the areas out of compliance with the US PM_{10} and the new $PM_{2.5}$ standards. This has been one of the major drivers for the development of emission inventories in the US, unlike that in Australia.

- There are guidance documents for average silt and default dry moisture contents for sources such as unpaved roads.

An example of a inventory for the US is presented in **Figure 5,** which highlights the overall low contribution to fugitive particulate from mining activities. It is noted that later inventories such as the 2001 NEI, use updated emission factors, particularly for unpaved roads, and now estimate an even smaller percentage of particulate matter from fugitive sources for the US.

3.2.1 Canadian National Pollutant Release Inventory (NPRI).

The NPRI is similar to the US TRI in that it has an employee facility threshold of 20,000 hours. It also uses mass and general concentration thresholds to eliminate ores and overburden with minor or insignificant metal concentrations.

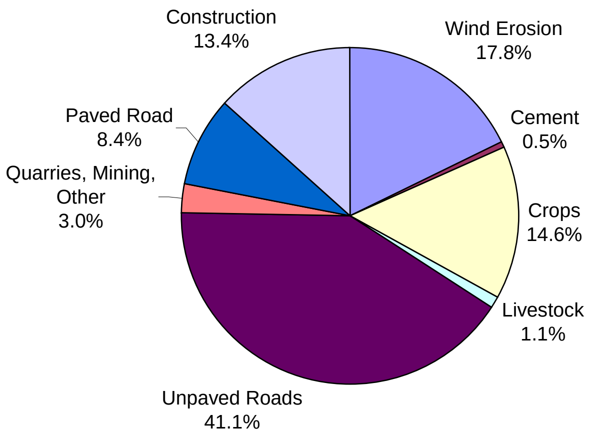
The NPRI determines substances that are manufactured, processed or otherwise used (MPO), or incidentally manufactured and released to the environment, trigger the reporting threshold if the mass of the MPO substance:

1) at a concentration above the applicable threshold; and
2) released as a product, at any concentration, on site to the environment, offsite or disposed of (including treatment)

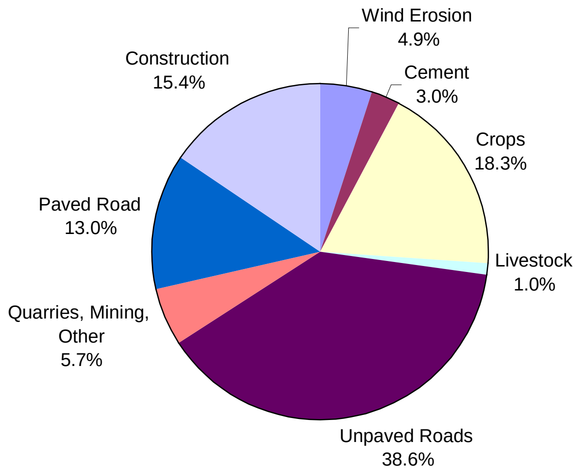
is greater than the mass threshold. Note that no threshold is applied for release of the substance, though a 1% exemption was applied before 2002.

The mass thresholds and the concentration thresholds are listed in **Table 2**.

Once it is determined that a substance has triggered the reporting threshold, all on site releases, and all off site transfers for disposal or recycling of that substance, are reportable regardless of their concentration or quantity (including zero releases and transfers).



PM_{10} Fugitive Particulate matter = 29,778 of 33,574 thousand tpy of PM_{10}



$PM_{2.5}$ Fugitive Particulate matter = 5,511 of 8,288 thousand tpy of $PM_{2.5}$

Fraction of PM_{10} and $PM_{2.5}$ fugitive emissions for unpaved roads, paved roads, construction, wind erosion, crops, livestock and industrial sources. Fugitive particulate matter constitutes 88% of total PM_{10} and 66% of $PM_{2.5}$ emissions

- **Figure 5 Percentage contribution to fugitive particulate matter from Watson and Chow (2000)**

- **Table 2 Canadian NPRI**

Part	Substance	Mass Threshold	Concentration Threshold	Substances Reported by Mining in Canada
Part 1 Group 1	241 substances	10 tonnes	1%	Antimony, Chromium, Cobalt, Copper, Cyanides (ionic), Manganese, Nickel, Selenium, Silver, Vanadium, Zinc
Part 1 Group 2	Mercury Cadmium Arsenic, Chromium VI compounds, lead, tetraethyl lead	5 kg 5kg 50kg	n/a 0.1% 0.1%	Mercury Cadmium Arsenic, Chromium VI compounds, Lead
Part 2	17 Individual PAHs		n/a	Generally not applicable though one facility reported all
Part 3	Dioxins and Furans and HCB	Activity based	n/a	
Part 4	Criteria Air Contaminants CO NO_X SO_2 TPM VOC PM_{10} $PM_{2.5}$	 20 tonnes 10 tonnes 0.5 tonnes 0.3 tonnes	 n/a n/a n/a n/a	

Prior to 2003, mining facilities involving activities up to and including the primary crushing of ores (stand-alone mines with no mill) were wholly exempt from all provisions of the NPRI and the associated reporting requirements. Beginning in 2003 however, all mining facilities, including those previously exempt, became subject to at least some provisions of the NPRI as outlined in the Canada Gazette Notice (MAC, 2004). Exemptions from reporting must now be determined on a facility-by-facility basis. The current exemption for mining is for activities related to the actual removal of ore, rock or overburden, up to and including primary crushing. This exemption, however, does not apply to Part 4 substances (Criteria Air Contaminants) and the facility would have to report if the mining operation ran a stationary combustion unit with capacity greater than certain criteria. As such, mines that only process the ore up to primary crushing may be exempt, which may apply to stockpiling and ship-loading facilities provided no further crushing occurs.

For Part 4 substances, total particulate matter (TPM), PM_{10} and $PM_{2.5}$ originating from road particulate matter are not included in the reporting, nor are pollutants released from motor vehicle exhausts (NO_X, SO_2, particulate matter etc).

The Canadian NPRI, like the US TRI, does not attempt to provide detailed guidance for the methodologies to be used in estimating emissions. As for the TRI, the NPRI guidance specifies that a range of methodologies can be used. The guidance also provides links to other sites and software, notably the US AP-42 documentation and associated software (FIRE, Speciate and PM_{10} calc), and references to the Ontario Ministry of Environment (MOE) methodology and to the Australian NPI EETs. Possibly in response to difficulties found in using the methodology, the Mining Association of Canada also has a comprehensive web site to assist mining companies and to simplify the NPRI process. (http://www.mining.ca/english/).

The Canadian NPRI also requires estimated releases for the next three years into the future. These forecasts are not binding but "*you should make your best effort to honour the commitment to the reductions in releases of NPRI substances that you release*" (MAC, 2004).

Currently a working group is reviewing speciation, which primarily includes speciation of VOCs but also $PM_{2.5}$.

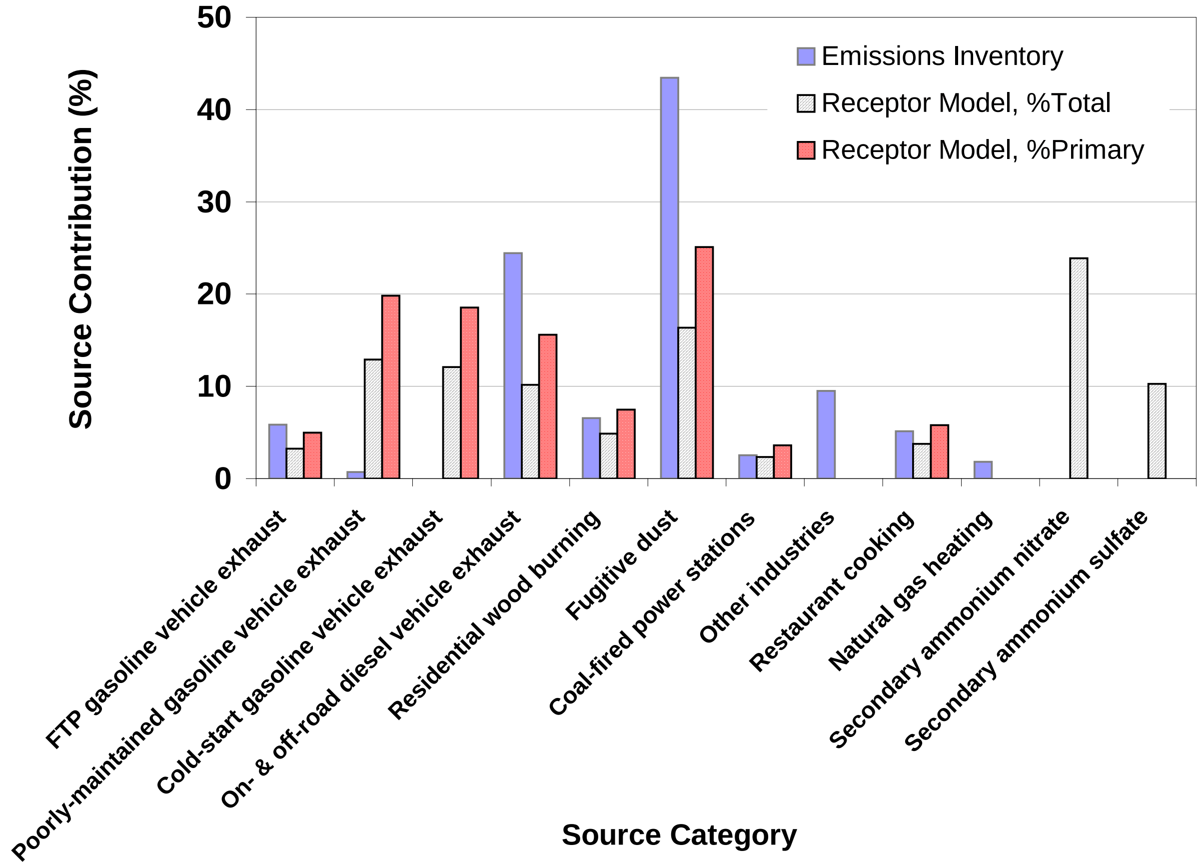
4. Emission Factor Developments in the US

4.1 Overview of US Developments

As the Australian NPI EETs are primarily based on USEPA AP-42 guidance, a brief review of developments in the US is provided.

4.2 Overestimation of $PM_{2.5}$ Emissions

In the late nineties it became apparent that there was a discrepancy in particulate matter emissions estimated using the USEPA AP-42 guidance and emissions determined from source attribution from analysis of ambient filter samples. **Figure 6** from Watson and Chow (2000) provides a typical example of the differences between the two methods.



- **Figure 6 Comparison between fractional source $PM_{2.5}$ contributions estimated by the CMB receptor model and the emissions inventory for Denver during 1996 (Watson and Chow, 2000).**

This large apparent over-prediction in the fugitive particulate matter emissions led some to argue that the emission factors were incorrect and that a reduction of up to a factor of four was necessary in the emission estimates.

Research into this issue has indicated that a major component of the apparent over-prediction was due to near source removal by particle settling and filtration by vegetation (Etyemexian et al, 2003). Emission factors are typically derived at or near the source (tens of metres) before significant depletion occurs and therefore essentially comprise the total particulate emitted. However, ambient monitoring may be several kilometres from the major sources at which a significant proportion of even the $PM_{2.5}$ may have been removed.

The particle capture fraction is a function of the underlying roughness of the surface including the vegetation, buildings, terrain etc. For emissions from vehicles on unpaved roads, the deposition of particulate matter is potentially large as the release height is generally low, with many roads being tree lined which act to filter the low lying particulate matter plume as it is swept past.

Another potential reason for the over-prediction is that the unpaved road emission factors used in the USEPA's AP-42 had no vehicle speed dependence. As particulate matter from vehicles on unpaved roads is generally considered to be wind speed dependent, the emissions at lower speeds were overestimated.

Another hypothesis being currently tested is that the $PM_{2.5}$ emission estimates are overstated due to the measurement method employed. Generally the $PM_{2.5}$ emission factors used in the USEPA's AP-42 guidance for fugitive particulate matter sources were determined by using hi-volume samplers fitted with a PM_{10} head and a subsequent cascade impactor for the sizing below PM_{10}. With the use of the cascade heads, it is hypothesised that particle bounce on the cascade impactor stages may have resulted in higher $PM_{2.5}$ concentrations than actually occurred. That is, larger particles that should have been retained at higher size fractions passed through the impactor stages and were recorded at the lower size fractions. *"If so, this may help to explain why the AP-42 emission factors for fugitive dust sources appear to overestimate $PM_{2.5}$ emissions". (WRAPAIR, 2004)*

4.3 USEPA Review of AP-42

Recently the USEPA has conducted a review of the use of the AP-42 factors (USEPA, 2004a). The review entailed a survey of industry and government departments. Major recommendations from the survey were that:

- A more open and less cumbersome approach needs to be established that allows interested parties to assist in the improvement and development of emissions factors;
- The format of AP-42 should be updated along with the methods for accessing the factors and associated documentation;

- Guidance is needed to help users select the most appropriate factor; understand how to consider uncertainties when using factors; and gather data to estimate emissions when a factor is not available. Guidance is also needed with respect to applying factors in permitting and enforcement applications; and
- Existing emission factors should be updated and more factors are needed where gaps currently exist. In many cases, the new factors requested were related to more speciation (particle size for PM, specific chemicals for air toxics and VOCs). Attention also needs to be given to the development of regional factors and factors for unique events and circumstances (USEPA 2004a).

For the fugitive sources comments were particularly directed towards the paved and unpaved roads.

4.4 WRAPAIR

The Western Regional Air Partnership (WRAP), covering roughly the western half of continental USA, has set up a number of studies that are attempting to improve fugitive particulate emission estimates. Relevant studies include work on developing improved wind erosion estimates (ENVIRON, 2004), and the quantification of the particle depletion work. As such, revisions and improvements to fugitive particulate matter emissions should occur over the next few years. Under the WRAP, a contract has been let to develop a fugitive particulate matter handbook and website. This will compile emission estimation methods and control techniques on paved roads, unpaved roads, materials handling, wind erosion from material storage piles, construction and demolition, open area wind erosion, agricultural tilling and agricultural wind erosion (WRAPAIR, 2004). This is scheduled to be ready in early 2005.

4.5 CAAQES

The Centre for Agricultural and Air Quality Engineering and Science (CAAQES) at the Texas A & M University is undertaking numerous studies related to emission estimates of particulate matter from agricultural activities and the representativeness of PM_{10} and $PM_{2.5}$ samplers for agricultural particulate matter (website http://caaqes.tamu.edu/). The research indicates that over-sampling of PM_{10} occurs for particulate matter with mass mean diameters (MMD) greater than the sampler 50% cut off point. Wang et al (2003) argue that the cut off point of the sampler increases with high MMD particles and that over-sampling of the particulate matter occurs. CAAQES therefore has been arguing that the performance of the PM_{10} and $PM_{2.5}$ samplers has not been clearly ascertained for particle sizes larger than 10 microns.

The acceptance of the CAAQES work by the USEPA is not known at this stage. However, notwithstanding the issue of the cut off point increasing with high MMD particles, it does highlight that when sampling particulate matter from agricultural or mining operations with a broad cut point PM_{10} sampler, the majority of the PM_{10} sampled will in fact be greater than 10 µm. It is likely to be in the range of 10 to 15 µm. (see **Figure 4**). To correct this overestimation, the use of samplers with very sharp cut off points are required, which would result in much lower emission estimates for PM_{10} and $PM_{2.5}$ emissions from mining and agriculture.

This issue is important due to the perception that a PM_{10} sampler only samples particulate below 10 µm, the public perception that all PM_{10} has the same health effects and the usage of NPI data to compare and rank sources of PM_{10}. Use of a PM_{10} sampler with a sharper cut off point could decrease the concentrations and derived emissions from mining operations by up to a factor of two, but would make negligible difference to most particulate measured from combustion sources.

5. Emission Factor Review

The following sections provide details of the emission factors and past development of the factors/equations used in the NPI EET Manuals.

5.1 Unpaved Roads

5.1.1 USEPA Factors/Equations

The following equations have been used in emission estimation from vehicles and are of relevance to those used in NPI Mining Manuals.

5.1.1.1 USEPA AP-42 (1985 4th Edition and 1988 4th Edition Supplement B)

The fourth edition of AP-42 (USEPA, 1985, ***Section 13.2.2 Unpaved Roads***) recommended particulate matter emissions from unpaved roads (including industrial roads), be estimated by:

$$E\ (kg/VKT) = 1.7\ k\ (s/12)\ (S/48)\ (W/2.7)^{0.7}\ (w/4)^{0.5}\ (365-p)/365 \qquad \textbf{Eq 5.1}$$

Where k = the aerodynamic particle size multiplier for the given particle size, such as for PM_{30}, PM_{10} etc. For PM_{10} k is equal to 0.36. Note, that the emission equations are specified with a subscript if they are specific to a particle size and without, if they are generic with the emissions for particle size determined by the appropriate k.

s = silt content of the road (%)

S = average vehicle speed (km/hr)

W = mean vehicle weight (tonne)

w =mean number of wheels

p = number of days with greater than 0.25mm precipitation

VKT = Vehicle kilometre travelled

For surface coal mining, ***Section 8.2.4 "Western Surface Coal Mining"*** a separate equation for haul trucks and light duty vehicles was provided with PM_{30} emissions estimated as:

$$E_{30}\ (kg/VKT) = 0.0019\ w^{3.4}\ L^{0.2} \qquad \textbf{Eq 5.2}$$

Where w = number of wheels

L = silt loading (g/m^2)

In the 4th edition, Supplement B (September 1988), a PM_{10} factor was added with:

$$E_{10}\ (kg/VKT) = 0.00087\ w^{3.5} \qquad \textbf{Eq 5.3}$$

This equation and the PM_{30} equation were derived from test data on haul trucks (Axetel and Cowherd, 1981), with the number of wheels in the range of 6 to 10 and with silt loadings between 3.8 and 254 g/m^2

(USEPA, 1988). Gross weights are not stated in the AP-42 documentation, but these are supplied in the review by MRI (1998), indicating that gross tonnages were typically in the range of 50 to 100 ton (US short ton), with a maximum value tested of 125 ton. These emission factors were for "uncontrolled" sources with no reduction provided for watering or other particulate matter suppressants.

Particulate matter emissions from light medium duty vehicles at Western Surface Coal Mines were also specified as:

$$E_{10}\ (kg/VKT) = 0.63 / M^{4.3} \qquad \textbf{Eq 5.4}$$

Where M = Material moisture content (%)

This equation was derived from limited surface moistures in the range of 0.9 to 1.7%.

5.1.1.2 USEPA AP-42 (1998) 5th Edition, Supplement E

The vehicle emission factors for industrial unpaved roads and Western Surface Coal Mining were both substantially revised in the AP-42 5th edition Supplement E (1998). These revisions were due primarily to concerns with the accuracy of the haul truck factors. As detailed in the Supplement E (footnote to Table 11.9-1), *"Section 234 of the Clean Air Act of 1990 required EPA to review and revise the emission factors in this Section (and models used to evaluate air quality impact), to ensure that they did not overestimate emissions from western surface coal mines. Due to resources and technical limitations, the haul road emission factors were isolated to receive the most attention during these studies, as the largest contributor to emissions"*.

This review is summarised in MRI (1998), and found that **equation 5.1** for independent haul truck data for western surface coal mines,

*"severely under-predicted the emission factors. On average, equation 3.2 (*note the equation numbers refer to those in the MRI document*) under-predicted the independent test data by a factor greater than 5. In contrast equation 3.1 for the light vehicles tended to over-predict the independent test data, but by a factor of less than 2 on average. Equation 3.1 also performed reasonably well (within 20 percent on average) when applied to independent tests on light-duty traffic emissions. Although the AP-42 light/medium duty factor provided reasonably accurate (within a factor of 2) estimates in two of three cases, the industry specific factor over-predicted a third independent test result by a factor of 20"* (MRI, 1998).

Based on the findings of this report, the haul trucks and light/medium duty vehicles predictive emission factors were removed from the Western Surface Coal Mines section (October 1998) and replaced with a footnote referring users to the recently revised unpaved road section in the Miscellaneous Sources chapter. It was noted that the emission factors for PM_{10} still tended to over-predict impacts with regulatory modelling and users were cautioned as to the limitation of this factor. See **Section 4** for more detail.

The new unpaved road emission equation (Section 13.2.2 - Unpaved Roads, 1998) removed the parameters of speed and the number of wheels in **equation 5.1**, whilst introducing a road surface moisture content parameter as follows:

$$E\ (kg/VKT) = k\ (s/12)^{0.8}\ (W/2.7)^{0.4}\ (M/0.2)^{-0.3} \qquad \textbf{Eq 5.5}$$

Note, this equation has been converted using a conversion of 1 US short ton = 0.907 tonnes and 1 lb/VMT (vehicle miles travelled) = 0.282 kg/VKT. The 1998 unpaved road equation was developed empirically from a wide range of mean vehicle weights (1.4 to 260 tonnes), mean vehicle speeds (8 to 88 km/hr), surface moisture contents (0.03 to 20%) and mean number of wheels (4 to 7).

It was noted that the new equation, without the vehicle speed dependency, over-predicted emissions for average vehicle speeds less than 15 mph. As such, for cases for vehicle speeds less than 15 mph, AP-42 recommended multiplying the emission factor by S/15 where S is the mean vehicle speed in mph.

To account for precipitation in annual inventories, AP-42 recommended:

$$E\ (kg/VKT) = k\ (s/12)^{0.8}\ (W/2.7)^{0.4}\ (M_{dry}/0.2)^{-0.3}\ (365\text{-}p)/365 \qquad \textbf{Eq 5.6}$$

In this equation M_{dry} represents the surface moisture under dry worst case conditions, as the equation assumes that emissions are at the dry uncontrolled road emissions for days without rain and are negligible for days with measurable precipitation (MRI, 1998, page 2-1). In the absence of appropriate site-specific information, the default value for M_{dry} of 0.2% was recommended.

For roads with particulate matter controlled by watering or the addition of chemical dust suppressants, **equation 3.5** was recommended with the moisture to be the average value during periods of traffic for different periods of the year. If only one set of samples was to be collected, then these must be collected during worst case, hot summertime conditions.

For roads with chemical dust suppressant added, AP-42 provides a simple chart for determining the control efficiency that can occur, dependent on the accumulated inventory of product applied to the road surface, with up to a 80% control factor achievable.

5.1.1.3 USEPA AP-42 (2003) 5th Update 2003

In October 2001, the USEPA published a new draft section 13.2.2 "Unpaved roads" for AP-42 and requested comments. This draft:

- proposed two separate emission factor models for public and industrial roads;

- incorporated speed as an input parameter for public roads to overcome the shortcoming of the previous model which over-predicted emissions for low vehicle speeds; and
- revised the watering control effectiveness discussion (MRI 2001).

In December 2003 the USEPA finalised this revision with slight changes. The current AP-42 equation for vehicles travelling on unpaved surfaces at industrial sites is:

$$E_{10}\ (kg/VKT) = 0.423\ (s/12)^{0.9}\ (W/2.7)^{0.45} \qquad \textbf{Eq 5.7}$$

And, for vehicles travelling on publicly accessible roads, dominated by light duty vehicles:

$$E_{10}\ (kg/VKT) = 0.508\ (s/12)\ (S/30)^{0.5}\ (M/0.5)^{-0.2} - C \qquad \textbf{Eq 5.8}$$

Where C = emission factor for 1980's vehicle fleet exhaust, brake wear and tyre wear equal to 0.00047 lb/VMT (0.000133kg/VKT)

For estimating the various parameters, AP-42 recommends the use of site-specific silt content information and where this is absent provides mean values for industrial roads. For surface moisture, AP-42 strongly recommends site-specific measurements be undertaken due to the significant variation that can occur between different types of road surfaces and discourages the use of the default moisture content of 0.5%. (Note, this was 0.2% in the 1998 version).

The effect of rainfall can be estimated simply by the following equation:

$$E_{xt} = E\ (365-p)/365 \qquad \textbf{Eq 5.9}$$

Where E_{xt} = annual size-specific emission factor extrapolated for natural mitigation.

With road watering, the degree of control is determined based on the ratio of the "controlled" to "uncontrolled" road moistures. These are to be measured for periods with typical traffic with the uncontrolled moisture content measured at least 24-hours after watering or rain, with the average controlled value measured *"either as a series of samples between water applications or a single sample at the midpoint"* (USEPA, 2003, 13.2.2.-11). This ratio will vary with season and vehicle frequency such that representative sampling, particularly of hot summer time conditions, is required.

By doubling the surface moisture content of the road the AP-42 estimates that a 70% control is achieved with greater than 90% control achieved by increasing the moisture five times. For chemical dust suppressants, the same control factors as supplied in the 1998 AP-42 are recommended with up to 80% controls achieved for PM_{10}.

That the equation for industrial sites does not have speed dependence is surprising. Anecdotal evidence suggests that for many of the larger pits in WA with long inclines, vehicle speeds are very low (<15 km/hr) with particulate matter emissions that appear to be minimal. Under these conditions it may be appropriate to have a speed dependent factor such as in the 1998 AP-42 guide for very low wind speeds.

5.1.2 Application in US Inventories

In estimating emissions from unpaved public roads, the NEI recommends use of the AP-42 emission factors, whilst providing State average silt values which vary between an average of 3.8% and a maximum of 7.9% (current file http://www.epa.gov/ttn/chief/ap42/ch13/related/r13s0202_decv03.xls). The NEI also provides State representative rain days and specifies a dry uncontrolled moisture of 1%. For California, the Californian Air Resources Board (CARB) have developed their own State specific emission factor of 2.27 lb PM_{10} VMT (0.64 kg/VKT) (Gaffney, 2004) from their own measurement program.

5.1.3 NERRDC Coal Mining Fugitive Particulate Matter Studies - Hunter Valley

The National Energy Research Development and Demonstration Council (NERDDC) funded a study to determine emission factors for fugitive particulate matter from coal mines in Australia using data collected from the Hunter Valley in NSW. This study used an array of five high volume samplers fitted with vane-orientated heads that sampled in an iso-kinetic fashion. These samplers were located in a line extending approximately 10 to 200 m from the sources except for draglines. The emission factors were calculated using a simple gaussian dispersion model and by taking into account particulate matter depletion. A comparison was made to US PM_{30} factors as reported by Axetell and Cowherd (1981), by converting the iso-kinetic sampled particles to a PM_{30} fraction using particle sizing data and taking into account particle density and shape as presented in SPCC (1986). The comparison indicated good agreement between the values excepting that the NERDDC study was for mines with typical particulate matter controls at the time, whereas the US factors were for uncontrolled emissions. Therefore, the NERDDC uncontrolled factors would be higher than the USEPA factors.

5.1.4 NPI EETs

5.1.4.1 Mining EET Manual - March 1999

The original NPI Mining Manual (NPI, 1999a) recommended the USEPA (1988a) Surface Coal Mining factors for coal mines as per **equation 5.2** and **5.3** for “wheel generated dust”. **Equation 5.3** was used as a first choice for PM_{10} with a default value of 0.42 kg/VKT (rounded to 0.4 in the summary table), for modern mines with large trucks travelling at low speeds (<30 km/h). Note, the default factor should actually be 0.46 kg/VKT for a mean number of six wheels. For mines that used smaller trucks (<100 t) that travel at higher speeds, a default PM_{10} factor of 0.9 kg/VKT was recommended based on the 1980’s NERDDC study.

This derivation of the default value of 0.42 kg/VKT for PM_{10} in the original NPI Mining Manual is not clear since the NERDDC value is for a “watered” haul road and as such is not actually uncontrolled or comparable to the USEPA uncontrolled factor. The NERDDC report states that TSP emissions of

2.2 kg/VKT *"were for normal operating mines practising normal dust control measures as applied in the Hunter Valley. The Axetall and Cowherd emission rates apply before the application of control measures"* (NERDDC, 1988, page 27).

Additionally, the Axetell and Cowherd (1981) study is based on 1979 and 1980 testing with mean gross truck weights in the range of 50 to 100 ton (US short ton), whilst the NERDDC study is based on 1986 and 1987 tests in the Hunter Valley and an assumed weight of 100 tonnes (NERDDC, 1988, page 24). Therefore, the USEPA emission equation relates to older trucks and lower weights and not vice versa as argued in the NPI Mining Manual (NPI, 1999a, page 41). As such, the Australian data for coal mines did not support the default uncontrolled factor of 0.42 kg/VKT in the 1999 NPI Mining Manual.

5.1.4.2 Mining EET Manual Versions 2.0 (2000) and 2.3 (2001)

Version 2.0 (2000) of the NPI Mining Manual (NPI, 2000) revised the wheel generated particulate matter equation following concern that it could over-predict particulate matter emissions, as concluded from the Kalgoorlie NPI trial (see **Section 5.1.4.5**). This revised equation remains the current equation recommended in the NPI Mining Manual (NPI, 2001, version 2.3).

The equation used in version 2.0 to 2.3 was adopted from the AP-42 general unpaved road equation (USEPA, 1998) (**equation 5.8**) that was current at the time that version 2 was drafted. With this equation a new default uncontrolled PM_{10} emission factor of 0.96 kg/VKT was developed based on an assumed surface silt content of 10%, vehicle gross mass of 48 tonnes and a moisture content of 2% (see Section A1.1.11, NPI, 2001). This default is 4.8 times higher than the 1999 default. It is noted, however, that the use of 2% moisture for an uncontrolled moisture value is considered high given that:

- Values of 0.2% and 0.5% were given in the USEPA unpaved road manuals;
- A value of 1%, is given for unpaved roads in the NEI;
- A default value of 0.2% is given in Aggregated Emissions from Paved and Unpaved Roads EET Manual (NPI, 1999b); and
- A value of around 1% is typical of much of the uncontrolled road tests summarised in MRI (1998).

As such, the resultant NPI default uncontrolled emission factor is considered to be on the low side.

5.1.4.3 Draft Fugitive Emissions (Version 1.1 - September 2002)

The current draft emission factor in the unpublished NPI Fugitive Emissions Manual (NPI, 2002, version 1.1) has incorporated the current NPI Mining Manual sections, though also including the earlier 1988 Western Surface Mining equation back into the manual with no recommendation as to which equation should be used. The default uncontrolled emission factors given are 2 kg/VKT for TSP and 0.4 kg/VKT for PM_{10}.

The draft also provides a table for default moisture contents (Table 8) for various soils with values ranging from 8 to 66% which are intended to supply guidance for road surface moistures. These values are for soils and are totally irrelevant to road surface values which will be much lower and therefore the draft Table 8 should be deleted.

In general the draft version has a number of errors and should be substantially revised before release.

5.1.4.4 EET for Aggregated Emissions from Paved and Unpaved Roads – September 1999

The Aggregated Emissions from Paved and Unpaved Roads EET Manual adopts the 1998 USEPA unpaved road emission (**equation 5.5**). For the required parameters, the average vehicle weight can be calculated by supplied weight for typical class of vehicles which is not problematic. Silt contents are provided for two road types with values of 6.4% and 11% as provided in AP-42 (USEPA, 1998). For comparison to these defaults, the NEI now provide default values for the various States that range from 1.5% to 7.2% with an average of 3.8%, with a value of 2.6% for California (USEPA, 2004b). These were derived from approximately 200 tests conducted around the US, with States having no testwork data assigned the mean value. Countess (1999) reported for the South Coast Air Quality Management District (Los Angelas, San Bernadino etc) an average silt content of 10.8%, which was less than the CARB State value of 15%. These variations indicate that there is a quite a large degree of scatter in the results, with a tendency for lower values in the more recent studies. This highlights the need for actual measurements.

5.1.4.5 Kalgoorlie NPI Trial

The Kalgoorlie NPI trial estimated emissions from aggregated sources defined in Coffey (1999), with point sources estimated by the WA Department of Environmental Protection (WA DEP) and the overall work summarised (WA DEP, 1999). Coffey (1999) estimated the unpaved road particulate emissions using the AP-42 equation (**equation 5.6**) along with estimates of the silt content, average vehicle weight and measurements of the number of rain days. In summarising the results of fugitive particulate, WA DEP (1999) undertook a brief comparison of the estimates obtained using the equation used by Coffey (1999) and the NPI Mining Manual equation and default factor at that time (NPI, 1999a, version 1). Using a range of vehicles, including a 60 wheel 120 tonne road train, the study estimated emissions that varied by up to several orders of magnitude. With such a large variation, WA DEP (1999) recommended that the NPI *"consider estimating particulate emissions only at this stage or report them separately to fugitive dust generated* PM_{10} *emissions. Further direct monitoring studies are required to determine the validity of fugitive dust* PM_{10} *emission factors"*. (page xiv, WA DEP, 1999). Based on this apparent uncertainty and difficulties encountered in estimating wind blown dust, the report concluded that *"it is impossible to estimate with a reasonable degree of accuracy the total* PM_{10} *emissions from a regional centre, without conducting a long term monitoring program",… "the results are likely to be order of magnitude estimates only".*

This conclusion, however, is considered to be overstated in that:

- The NPI Mining Manual equation used was derived from a narrow range of number of wheels (6 to 10), with the equation in the Kalgoorlie trial applied significantly outside its range of applicability;
- The default factor specified in the NPI Mining Manual is for a specific situation only. The above example for the Kalgoorlie trial demonstrates that one default factor cannot be applicable for the range of vehicle fleets that can be encountered; and
- The equations were applied to individual vehicles and not to the weighted average weight and number of wheels as required.

As such, the conclusions in the NPI trial for fugitive PM_{10} estimates were based on the misapplication of certain techniques, which unfortunately have increased the perception that fugitive particulate matter emission estimates have little credibility.

5.1.5 Other Australian Research

Pitts (2000) reported results from using an upwind downwind method using a portable DustTrak monitor. It is noted that the methodology has a number of uncertainties including:

- The need to estimate a vertical profile of the plume. This was undertaken using standard Gaussian plume dispersion curves;
- The need to account for particle depletion. This was undertaken using the models ISC3 and the assumed initial particle distribution from AP-42 for wind erosion; and
- Calibration of the DustTrak particulate matter monitor for that particulate and the collection efficiency of the sampler. An attempt was made to calibrate the DustTrak sampler for the particle as a function of wind speed with limited success.

Estimated PM_{10} emission values from haul trucks (average 80 tonne gross weight and speeds of 40 to 60 km/hr) ranged from 3.5 kg/VKT for a reasonably uncontrolled road to 0.5 kg/VKT for a controlled road with approximately hourly watering. Notwithstanding the uncertainty in the absolute values, it does indicate that uncontrolled emissions are much greater than version 1 of the NPI Mining Manual and that controls of 85% can be achieved.

Using a wind tunnel, Air Noise Environment (2003) found an average control efficiency of 70% (range of 55 to 89%) in the particulate matter emissions for the watered haul roads tested which had less than 1 m^2/hr applied. These results, however, are for wind blown dust, and are not considered readily applicable to vehicle emissions due to the different particulate matter emission processes involved.

Leys et al (1998) determined emissions from tractor cultivation on a cotton farm and a light vehicle on farm roads using a vertical array of sampling inlets from a following vehicle. Lateral plume width was measured on successive runs with the vertical array profile offset. They estimated relatively high TSP emissions of 3.7 kg/VKT. Of note is that, estimated from their figures, less than 1% of the TSP was below 2.5 microns.

5.1.6 Particulate Matter Controls

The various versions of the NPI Mining Manual have all specified the controls for watering of unpaved road as:

- 50% control for level 1 watering (1 $L/m^2/hr$); and
- 75% for level 2 watering (>2 $L/m^2/hr$).

The basis for these factors is not clear as it is not referenced. It appears that control factors were based on estimates of the watering rates and typical Hunter Valley haul road usage using the equation of Cowherd et al (1988) (Holmes, per comm., 2004). The equation of Cowherd et al (1988) specifies

$$C = 100 - (0.8\ P\ d\ t)/\ I \qquad \textbf{Eq 5.10}$$

Where C - average control efficiency percent (%);

P = potential average daytime evaporation rate mm/hr;

d = average hourly traffic rate (hr^{-1});

I = application intensity L/m^2; and

t = time between applications.

Based on what may have been the values of 30 truck passes per hour (Holmes, pers comm., 2004), and a maximum extreme hourly evaporation rate of 2 mm/hr (for a hot windy day), application of 1 and 2 $L/m^2/hr$ gives 50% and 75% control. This equation was listed in Cowherd et al (1988) along with another method (which is currently used in US AP-42 for unpaved roads) which Cowherd et al (1988), commented may be more suitable for regulatory applications. The equation has been used by the USEPA to develop a spreadsheet to predict control factors using hourly rainfall rates (USEPA, 2004b).

Therefore, the control factors given for watering are very site-specific in terms of vehicle usage and the assumed evaporation rate. Areas with lower evaporation rates and lower vehicle usage could have much larger controls than provided in the NPI Mining Manual. Other problems with the control factors provided in the NPI Mining Manual are:

- No advice is given for low watering rates (between 0 and 1 $L/m^2/hr$). That is, what should be done for a watering rate of 0.5 $L/m^2/hr$ which is considered typical (see Air Noise Environment, 2003);
- For low vehicle rates the control tends to 100% even for very low watering rates. That is, evaporation due to solar radiation and wind has little effect in comparison, which appears unrealistic;

- Chemical suppressants are not considered. These should be incorporated by using the AP-42 methods;
- The use of salts, such as magnesium chloride or the effects of hyper-saline water, is not accounted for. In WA mines, hyper-saline water is often used due to lack of available fresh water. This water (up to 250,000 mg/L of total dissolved salts, McDougall, 2004), is noted to have improved particulate matter control properties compared to fresh water. As this effect is not currently considered, more investigation is recommended. This can easily be achieved in a relative sense by using a DustTrak to determine the percent control, or a more rigorous quantitative study could be adopted using the USEPA methodology.

Therefore, it is recommended that the current NPI control factors be modified as follows:

- For watering controls with fresh water, either
  - The equation of Cowherd et al (1988) should be provided such that the control efficiency is estimated. It is considered that this has been the basis of the current factors but now site-specific factors will be used. This will require mines to estimate the number of vehicle passes and watering rate on the various roads. Estimates of the hourly evaporation rate could be undertaken using annual evaporation estimates and converting these to a maximum hourly value using a multiplier as in Cowherd et al (1988).
  - The current USEPA approach should be provided for mines if they choose to measure typical moisture contents for controlled and uncontrolled roads to determine the moisture increase.
- For chemical suppressants the US methodology should be included;
- For addition of salts, including hyper-saline water, it is considered that test work is required to develop factors. A study to undertake this could be undertaken for a ballpark figure of $20,000.

5.1.6.1 Comparison of Equations and defaults used in the NPI EETs

To illustrate the range of emissions in the various equations and to determine how the new US AP-42 equations compare, the emission for haul trucks and light vehicles have been estimated and presented in **Table 3** and **Figure 7**.

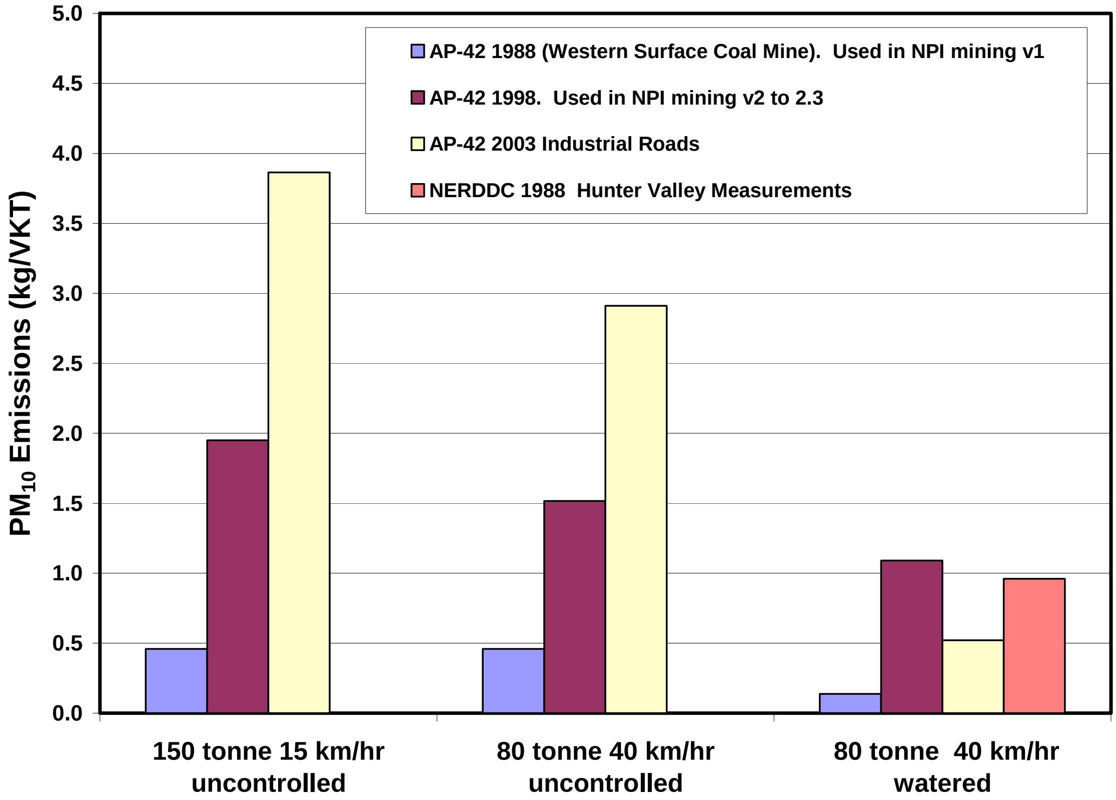
Table 3 Comparison of unpaved road emissions

Source	Eq No.	Haul Truck (kg/VKT)				Light Vehicles (kg/VKT)		
		Dry	Dry	Dry	Watered	Dry	Watered	Dry
Variables								
Surface Moisture Content (%)		1.0	1.0	1.0	3.0	1.0	3.0	1.0
Silt Content (%)		10	10	10	10	10	10	10
Average Weight (tonne)		150	150	80	80	2.5	2.5	2.5
Speed (km/hr)		15	40	40	40	50	50	25
Number of Wheels		6	6	6	6	4	4	4
Equations								
USEPA (1988), Western Coal. Used in NPI Mining Manual v1	5.3	0.46	0.46	0.46	0.23			
USEPA (1998) Used in NPI Mining Manual v2 to v2.3	5.6	1.95	1.95	1.52	1.09	0.38	0.27	0.38
USEPA (2003) Industrial	5.7	2.23	2.23	1.68	0.30	0.35	0.06	0.35
USEPA (1983 - 95) Unpaved roads	5.1	3.9	10.4	6.70	1.20	0.60	0.11	0.30
USEPA (2003) Public roads (weight 1 - 2.7 tonne only)	5.8	N/A	N/A	N/A	N/A	0.48	0.38	0.34
Defaults								
NPI Mining Manual v2.0 to 2.3 based on NERDDC (1986)		0.96	0.96	0.96	0.96	0.96	0.96	0.96
NPI Mining Manual v1		0.2	0.2	0.2	0.2	0.46	0.46	0.46
NPI Fugitive Emissions Manual draft v1.1		0.4	0.4	0.4	0.2	0.4	0.4	0.4

Notes:

1) N/A is not applicable as the vehicle weight is above the weight range for which the equation was developed

2) Watered particulate matter estimates are based on assuming 50% control for eq 5.3 based on the NPI recommendations, using the 3% moisture content in equations 5.6 and 5.8, whilst in equations 5.1 and 5.7 the current USEPA equation using Cowherd et al (1988) assumes the moisture increase is three times, giving a control efficiency of 82%.



- **Figure 7 Particulate matter emissions from haul trucks**

Table 3 and **Figure 7** indicate that:

- The 1988 equation used for the NPI Mining Manual predicts much lower emission factors than the other equations and the current equation. This is consistent with the NERDDC study which found that the PM_{10} emissions for haul trucks at the time (100 tonnes) with typical controls (watering) was 0.96 kg/VKT. Likewise, the NPI default uncontrolled factors are lower than estimated with the newer equations. For the 2001 default, this is due to the estimate being based on 2% surface moisture which has some degree of control;
- The 1998 equation has no dependence on factors such as weight, speed and moisture;
- The 2003 equation has a much greater dependency on watering than previously given; and
- For light vehicles on uncontrolled surfaces, the emissions are all very similar for vehicle speeds of 50 km/hr at around 0.5 kg/VKT. This in line with the Californian uncontrolled unpaved road value of 0.64 kg/VKT.

5.1.7 Recommendations for Unpaved Roads

The following are recommended:

R5.1 Incorporate the recent December 2003 USEPA AP-42 unpaved road equations into the NPI Fugitive Emissions Manual. It is noted that the draft version of the NPI Fugitive Emissions Manual has a number of errors that require correction, such as deletion of the soil moisture table.

R 5.2 Single default emission factors should not be provided as there can be large variations between the vehicle fleets and road characteristics at different sites. If defaults are to be provided they should be given for the various combinations of typical vehicle fleets (for example vehicle usage on haul roads at a mine site and a typical light vehicle fleet) and for typical uncontrolled and controlled roads. To assist companies in estimating the appropriate emission factor for their site, it is recommended that the NPI Fugitive Emissions Manual include a compilation of typical silt contents, as well as moisture contents for various Australian industry groups, as per the USEPA guides.

R 5.3 Update the unpaved road control factor with separate methods for:

- Fresh water, using either:
  - The equation of Cowherd et al (1988). This will require mines to estimate the number of vehicle passes and watering rates on the various roads. Estimates of the hourly evaporation rate could be undertaken using annual evaporation estimates and converting these to a maximum hourly value using a multiplier as in Cowherd et al (1988); or
  - The current USEPA approach where moisture contents for the road in a controlled and uncontrolled state under typical traffic conditions are measured.
- Use of organic chemical suppressants, using for example the US AP-42 methodology; and
- Use of salts including the use of hyper-saline water. It is considered that test work, estimated at $20,000, is required to develop appropriate control factors.

R 5.4 Though not strictly applicable to the NPI Mining Manual, it is considered that the Aggregated Emissions from Paved and Unpaved Roads EET Manual should be updated to include the new AP-42 equations, including a default moisture content of 1% (following the US NEI) and typical Australian data for road silt contents. This may involve a desktop study or in-field sampling.

It is noted that the adoption of the above will result in higher uncontrolled particulate matter emission estimates, but higher control factors should result in comparable emission estimates for vehicles.

5.2 Wind erosion from Industrial Areas and Mine Sites

5.2.1 USEPA methods

5.2.1.1 Industrial Wind Erosion

Wind erosion for active storage piles was specified from the Third Edition, Supplement 14 (USEPA, 1983) up to the Fourth Edition, Supplement B (USEPA, 1988a) as:

$$E_{TSP} = 1.9\ (s/1.5)\ \ (365\text{-}p)/235\ (f/15)\ \ (\text{kg/ha/day}) \qquad \textbf{Eq 5.11}$$

Where: p = the number of days with less than or equal to 0.25mm (0.01 in) precipitation

f = the percentage of time the unobstructed wind at the mean pile height exceeds 5.4 m/s

This equation is based on a study of particulate matter emissions from a sand and gravel storage pile area as reported by Cowherd (1974). It is rated C for application in the sand and gravel industry and D for other industries using the US EPA quality rating for emission factors. This rating system is as follows:

- A: Excellent;
- B: Above average;
- C: Average;
- D: Below average; and
- E: Poor.

It is important to note that the storage pile is active, that is either the surface is being disturbed frequently enough such that fresh material is available for wind erosion, or the surface is not depleted or crusted.

In the Fourth Edition, Supplement B (USEPA, 1988a) this equation was replaced in the new section "Industrial Wind Erosion" with a more detailed procedure for "wind erosion of open aggregate storage piles and other exposed areas within an industrial facility" (USEPA, 1988a). This procedure is still the current method within AP-42. (Note that within USEPA, 1988b, both equations are given with the current equation to apply to surfaces which are limited in the amount of erodible material and the former equation to unlimited or active surfaces).

The current AP-42 method was developed by Cowherd (1983) for coal stockpiles based on wind tunnel testing of coal storage piles and other areas such as overburden. Critical to this method is that it is based on wind tunnel tests showing that particulate emissions decay rapidly, with a half life of a few minutes during an erosion event, because there is limited availability of erodible material. This is unlike the active sand stockpiles on which the previous equation was developed. Based on the wind tunnel observations, the method assumes that because the erosion potential increases rapidly with wind speed, the particulate matter emissions between times when the surface area is disturbed can be approximated by the particulate matter emitted only during the peak one minute wind. That is, no particulate matter is assumed emitted for lower wind gusts which exceed the threshold velocity, or the method allows for particulate matter from these events by calibrating the coefficients in the equation.

In the method of Cowherd (1983), the erosion potential (P) of each particulate matter event is defined as:

$$P\ (g/m^2) = 58(u_* - u_{*t})^2 + 25(u_* - u_{*t}) \quad \text{for } u_* \geq u_{*t}. \qquad \textbf{Eq 5.12}$$

$$P\ (g/m^2) = 0 \qquad \text{for } u_* \leq u_{*t}.$$

Where u_* = the friction velocity (m/s)

u_{*t} = the threshold friction velocity (m/s)

This method is conceptually sounder than the previous method in that it takes into account:

- That the threshold friction velocity will vary with the material and that this is the appropriate measure of the erodibility of the material;
- The variation in wind speed over a stockpile by using wind tunnel test work from scale models for two simple stockpile shapes; and
- That the erosion potential of most surfaces is limited with a finite reservoir of particles and will not be replenished until the surface is disturbed.

This method, however, does have limitations in that:

- The equation is based on a small amount of wind tunnel testing, with limitations on determining the particulate matter flux for larger areas as detailed in **Section 5.2.1.3**.
- There appears to be little validation data to support the method apart from the wind tunnel tests;
- There is no apparent supporting data for non-coal mine material;
- It does not take into account that the friction velocity will vary with the angle of the surface material, which for stockpiles is the angle of repose (typically 30 to 40 degrees). As such, material should be easier to dislodge when sitting on the side of a stockpile, especially when the wind is across the slope of the stockpile;
- Only approximate methods are provided for the estimation of threshold friction velocity (eg using the mode of the dry aggregate size distribution of samples according to a sieving procedure), though the results are very sensitive to this estimate; and
- Difficulties from an Australian context are that the fastest mile of wind is not recorded routinely. The Bureau of Meteorology (BoM) routinely records wind every 10 minutes on the hour. Most other monitoring sites measure 10-minute or 1-hour averages and some may record peak gusts (eg gusts lasting two or three seconds) within that period. Therefore for Australian sites, fastest mile data is not available and must be estimated. A possible method that could be used is the use of gust factor theory to estimate a fastest mile “gust”. Assuming a gust wind speed of 15 m/s, the time taken to

travel one mile is 107 seconds. Therefore assuming a 107-second "gust" and data or relationships such as in presented in Krayer and Marshall (1992), the fastest mile wind speed would be approximately 1.18 to 1.27.times the hourly wind speed.

The uncertainty in the current USEPA method is also detailed in USEPA (1984) with the following concluding comments indicating its preliminary nature and inherent uncertainty: *"Taking all the sources of uncertainty into account, it is thought that the wind erosion emission factors for surfaces similar to those tested are accurate to within a factor of about three"*; and *"Until further research is accomplished, it is recommended that wind erosion factors be used with full consideration of their uncertainty and preliminary nature. It is recommended that their use be restricted to estimates of emissions relative to other mines sources and that they not be used for estimating the ambient air impact of wind erosion at surface coal mines"*.

5.2.1.2 Western Surface Coal Mining

The AP-42 Fourth Edition Supplement 14 (USEPA, 1983) for Western Surface Coal Mining specifies a default TSP factor of 0.85 tonne/ha/year (0.1 kg/ha/hr) for seeded land, stripped overburden and graded overburden. This was derived using upwind downwind sampling using high volume air samplers for the coal mines listed in Table 8.24-5, which are all in reasonably dry areas (rainfall 280 to 430 mm/year) and have relatively high wind speeds (four sites with average wind speeds of 4.8 to 6 m/s and one with 2.3 m/s). Therefore, the equation appears to be based on reasonably dry and windy sites. As PM_{10} will be less than 50% of TSP, the PM_{10} emissions will be less than 0.05 kg/ha/hr.

For active storage piles, the fourth edition specifies that wind erosion (and maintenance) for PM_{30} is given as 1.8u (kg/ha/hr) where "u" is the wind speed (m/s). This equation is obtained from the study of Axetel (1978) and is implied to be for annual estimates even though it is given on an hourly basis. In the footnote to Table 11-9-2, it is noted that to estimate shorter times (eg, a worst case day) the procedure referenced in Section 13.2.5 should be adopted. Using this equation and an annual average wind speed of 3 m/s (such as for Kurri Kurri in the Hunter Valley, NSW), this equation estimates PM_{30} emissions of 5.4 kg/ha/hr. Assuming that PM_{10} is 50% of this gives a value of 2.7 kg/ha/hr. These equations are still listed in the current version of AP-42 for Western Surface Coal Mining..

5.2.1.3 Other Models Considered Relevant

A good summary of available particulate matter models for regional scales is provided in Countess et al (2001a). This review was conducted for WRAPAIR which is estimating particulate matter emissions from wind erosion for the western States of the US (ENVIRON, 2004) and is undertaking a number of studies to improve emission estimates from fugitive particulate matter sources. The following is abbreviated from this review for models considered relevant.

Wind Erosion Equation (WEQ)

The WEQ is an empirical wind erosion equation developed by Woodruff and Siddoway (1965) and used by the U.S. Soil Conservation Service to inventory the potential of soils for wind erosion. The WEQ estimates the average annual mass of soil lost off the downwind edge of the field (not particulate matter loss) as:

$$E = I\ C\ K\ L'\ V' \qquad \textbf{Eq 5.13}$$

where E = the potential average annual soil loss

I = the soil erodibility index

K = the soil ridge roughness factor

C = the climate factor

L’ = the unsheltered distance across a field

V’ = the equivalent vegetative cover

For estimating TSP emissions, the USEPA estimated that 0.025 and 0.038 kg/ha of the soil transported off agricultural land or a road will remain as TSP (USEPA, 1974 and USEPA, 1988b). To estimate PM_{10} emissions, the CARB (1997) assumed that 50% of the TSP was PM_{10}.

The CARB has modified the WEQ to improve the emission estimate for California, to better reflect seasonal changes in the climate, winds and rainfall and crop conditions (fraction of bare soil etc). Monthly values of climatic factors are used to better resolve the variation in climate, rather than an annual factor which may not capture variations in wind and rainfall regimes. The CARB (1997) methodology has been used to estimate particulate matter emissions for the Pilbara Airshed Study (SKM, 2003a), the Bunbury Airshed study (SKM, 2003b) and for Victoria (Ng, 2004). One limitation of this approach is that the climate factor does not adequately capture the upper extreme of wind distribution, which has the greatest bearing on annual particulate matter emissions. For example, in Australia studies have shown that it is the infrequent dust storms which contribute the majority of particulate matter emissions from an area. Another limitation is that the percentage of the saltation flux assumed to be TSP and PM_{10} is very approximate and neglects how this percentage may vary with soil type and wind speed.

Revised Wind Erosion Equation (RWEQ)

The revised wind erosion equation (RWEQ) (Fryrear et. al, 1998) improved the original WEQ, and was validated with field data. A significant modification included in the RWEQ is the assumption that the maximum transport capacity occurs a short distance downwind from the field boundary, beyond which no net soil loss occurs. Though this is in an improvement on the WEQ, its major limitation (like WEQ) is that it only predicts the soil loss from an area and does not predict the vertical particulate matter flux.

NAPAP Model - Gillette and Passi (1988)

Gillette and Passi (1988) developed a model to estimate total particulate matter production by wind erosion for the US, for the National Acid Precipitation Assessment Program (NAPAP). The particulate matter model estimates particulate matter emission from soils based on the threshold friction velocity of that soil which takes into account the effects of soil type, soil moisture, soil texture and vegetative cover, with the threshold friction velocities for soil type based on a large number of wind tunnel tests. The NAPAP methodology was modified for the purpose of assessing annual PM_{10} emissions for EPA's emissions trends report (Barnard and Stewart, 1992).

Wind Erosion Prediction System (WEPS)

The Wind Erosion Prediction System (WEPS) developed by Hagen and others (eg, Hagen, 1995) is intended to replace the WEQ and RWEQ. Unlike the previous wind erosion models, WEPS is a process-based, continuous, daily time-step model that simulates weather, field conditions, and erosion. WEPS simulates complex field shapes and topography, and takes into account spatial and temporal variability of field conditions and soil loss or deposition. WEPS is by far the most complex of the above models and is not considered applicable for use in the mining area or larger regional areas because of its complexity.

Wind erosion models based on the Sand Saltation Scheme of Shao et al (1996) and Lu and Shao (2001)

The particulate matter emissions scheme initially developed by Shao et al (1996), Shao and Leslie (1997) and modified by Lu and Shao (2001), estimates the particulate matter flux based on a physically based model of the saltation process. The particulate matter flux is determined from discrete saltation particle sizes using the particle size distribution of the actual soil. The saltation flux for each particle size is based on the friction velocity for that particle size which is determined from particle diameter, soil moisture, non-erodible surface roughness elements and effects of surface aggregation and crusting. The particulate matter scheme has been utilised in different modelling systems with land use classification systems and regional wind models to provide winds to estimate particulate matter emission and to then estimate the transport and dispersion of the dust.

This wind erosion scheme has been incorporated into models for Australia by Shao et al (1996), Shao and Leslie (1997) and Leys et al (2002) and recently into the Australian Air Quality Forecasting System (AAQFS) by Lu et al (2003 and 2004). The scheme was also used in the Integrated Wind Erosion Modelling System (IWEMS) for the northeast Asian dust storms as detailed by Shao et al (2003) where it was shown to provide a good quantitative comparison between observed and predicted TSP, PM_{10} and $PM_{2.5}$ concentrations.

The particulate matter model for the AAQFS is currently under trial with predictions in real time being made of particulate matter emissions and concentrations over Australia for the summer of 2004/2005.

WRAPAIR

WRAPAIR is a collaborative effort of tribal governments, state governments and various federal agencies to implement the Grand Canyon Visibility Transport Commission's recommendations, and to develop the technical and policy tools needed by the western States and tribes to comply with the USEPA's regional haze regulations. As part of the plans, WRAPAIR is developing an emission inventory for the western half of the US of wind-generated particulate matter using an empirical scheme as detailed in MacDougall and Uhl (2002). This method estimates the particulate matter fluxes based on wind tunnel derived tests that are a function of wind speed, soil group and whether the soil is stable or unstable.

Stable land or soils are assumed to emit particulate matter only during the first hour of a wind event and as such have only a limited reservoir available for wind erosion. For unstable, disturbed lands the reservoir of particulate matter is much greater with the particulate matter depleted within 10 hours of any wind event. Particulate matter reservoirs are recharged within 24 hours of a wind event, with a wind event defined as any time period for which the winds exceed the threshold wind velocity (taken as 20 mph, approximately 9 m/s at 10 m) separated by at least 24 hours. Precipitation was considered simplistically within the first phase modelling, with any rain considered to suppress particulate matter for 72 hours after the event. Winds and precipitation for the estimates were derived from hourly values predicted by the model MM5 on a 36 km grid. MM5 (Mesoscale Model) is a non-hydrostatic, terrain following model that is designed to simulate or predict atmospheric circulation. The results gave spatially and temporally variable particulate matter fluxes across the western half of the US. For the trial year of 1996, 5.4 Mtpa of PM_{10} was predicted to be emitted with major sources in Texas and New Mexico and the major land use category being desert barren land (ENVIRON, 2004). $PM_{2.5}$ emissions were estimated as 22% of PM_{10} from an analysis by CARB, though the details of the derivation were not provided.

This model is sensitive to a number of assumptions and simplifications, including definition of the wind speed threshold, the reservoir recharge time and the effect of rainfall. These are subject to further studies.

In a review of the WRAPAIR approach, Countess et al (2002) argued that particulate matter fluxes based directly on wind tunnel measurements as used in the "MacDougall" method (MacDougall and Uhl, 2002) have the following shortcomings:

1. *Limited fetch length: Fugitive particulate matter emissions often have a very significant fetch length dependence;*
2. *Limitation of loose material in the surface: Using a wind tunnel causes a rapid depletion of all the surface material contained within the tunnel. However, in natural situations loose material from upwind continues to be resuspended. Thus, wind tunnels will underestimate the amount of particulate matter emissions;*
3. *Feeding of sand into the tunnel from outside does not duplicate nature: That is, inserting saltating sand into the tunnel does not necessarily fix the problem of (2) above. One must refer emission factors to the amount of sand fed into the tunnel. In other words, this technique is only good for some*

problems like measuring the ratio of vertical particulate matter flux to horizontal sand flux (and then only with great caution);

4. *Wind tunnels limit the size of natural roughness that can be measured (i.e., wind tunnels must be much larger than the roughness); and*
5. *An efficiently run wind tunnel investigation will measure parameters that are important in a general sense (eg, quantifying variables in a computer model) but not in matching a large number of real-world erosion scenarios.*

Countess et al (2002) also noted that models of particulate matter fluxes generally had the following problems, which limit the accuracy that can be achieved:

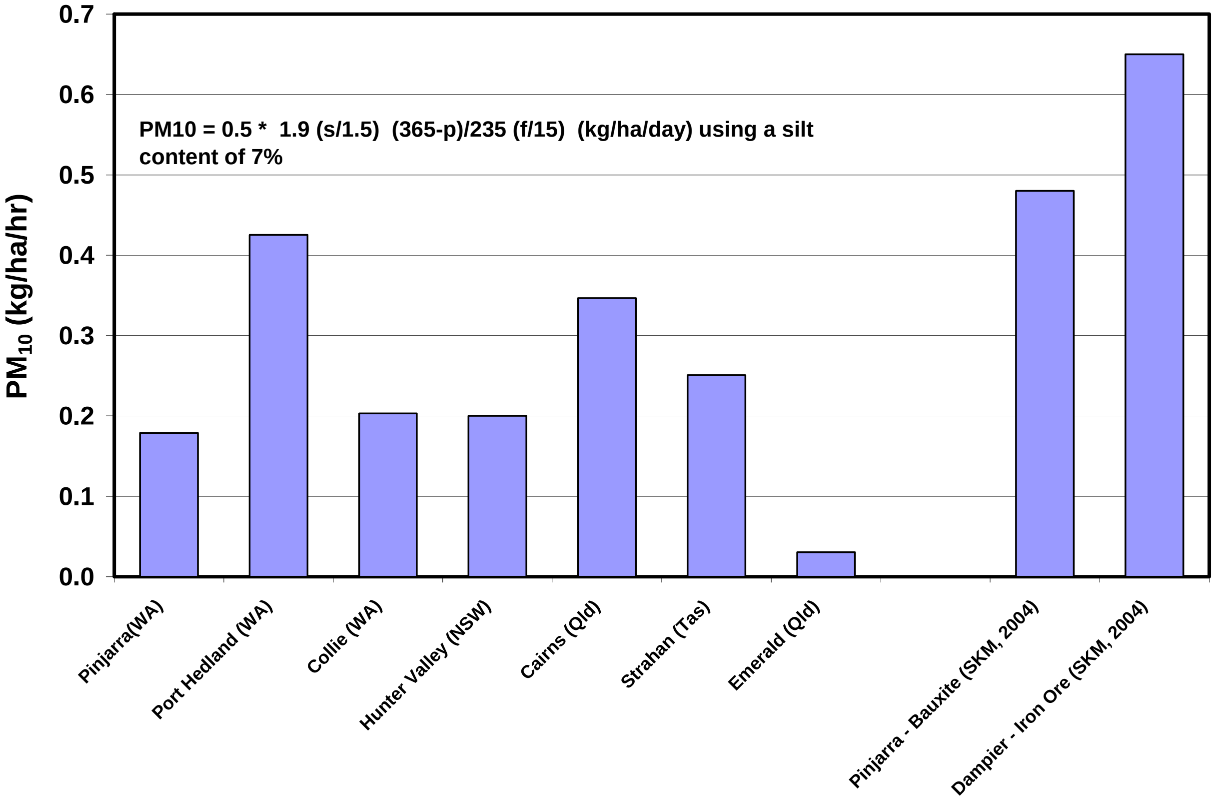
- Difficulty in determining the threshold friction velocity: As the particulate matter predictions are usually determined using equations where the particulate matter flux is estimated as the difference between the friction velocity and the threshold friction velocity, the specification of these is critical.
- Use of average wind velocities: Average wind speeds, (in time and in space) smooth out the extremes of the wind speeds, which can lead to a significant under-prediction of particulate matter emissions.
- Neglect of small-scale topographic features, such as small hills, embankments, buildings, trees and shelter belts affect both the threshold friction velocity and the local wind speed and, therefore, friction velocity. These are generally not included in modelling.

5.2.1.4 NPI Methods

Methods in the NPI have remained constant since the first version in 1999. The NPI Mining Manual suggests the use of **equation 5.11**, which is recommended in the third and fourth editions of AP-42 (USEPA, 1983 and 1988). That is, the NPI did not adopt the US EPA method current at the time as introduced in "wind erosion of open aggregate storage piles and other exposed areas within an industrial facility" (USEPA, 1988a). Using **equation 5.11**, the NPI Mining Manual derives a TSP emission of 1.82 kg/ha/hr using values of p=80 days/year, s=15% and f=30%. The rationale behind these estimates, however, is not provided. The manual then quotes the value given in SPCC (1983) for wind erosion of 0.4 kg/ha/hr of TSP, which it suggests should be adopted as the default in the absence of other information. Assuming 50% of the TSP is PM_{10} (from USEPA, 1998) a PM_{10} emission factor of 0.2 kg/ha/hr is obtained. This value is provided as the default factor and as no equation is provided in the summary table, is implied to be the preferred method. For other exposed areas the same default factor is recommended.

Review of the derivation of the SPCC (1983) factor indicates that this was not based on measurements, but is likely an estimate using **equation 5.11** and typical Hunter Valley values with a silt content of 7% (for coal and overburden, NERDDC, 1986 Table 8), number of rain days (80) and with 13.4% of the wind greater than 5.4 m/s (as taken from the Bureau of Meteorology site at Kurri Kurri). Therefore, the default value is highly specific to a location and ore type. Additionally, it is for a surface that is continually active, does not crust or is continually disturbed and, as such, is likely to be an overestimate for many Australian mines.

As a comparison, emissions derived using the NPI Equation (**equation 5.11)**, for the climates at various Australian localities, using a silt content of 7% are provided in **Figure 8**. These indicate that, using the equation, PM_{10} estimates may range from 0.03 to 0.43 kg/ha/hr. The major reason for this variation is the variation in the wind speed. For comparison, two estimates from SKM (2004) are also presented which indicate higher emissions, though the silt content of these areas is not exactly known. The higher emissions may be due to higher silt contents or may just reflect the inaccuracies in the measurements and/or in the approximate nature of the AP-42 equation.



- **Figure 8 PM_{10} emissions estimated using the NPI equation and a silt content of 7% and two measurements from SKM (2004)**

5.2.1.5 Control factors

In the NPI Mining Manual, control factors for wind erosion are provided for wind breaks (30%), water sprays (50%) and re-vegetation or total enclosure (99%). The water spray control factor (as per most of the control factors) is considered to be very indicative. Particulate matter control through water cannon is very dependent on both the design (spacing and coverage) of the water cannon, the maintenance of the system (fixing broken cannon, pumps etc) and the operation of the system. In some newer systems, weather forecasts are used to enable the cannon to cycle and pre-wet areas before the strong winds eventuate when the cannon has less coverage. In properly designed and maintained automatic systems which are based on wind, evaporation rates and weather forecasts to determine wetting cycles, control higher than 90% may be achieved.

In determining the control factors and areas subject to each control it is considered that the NPI currently provides minimal guidance. For most mines in the more arid parts of Australia there are generally large bare areas that are non-erodible, with a high proportion of gravel sized or larger "rocks", or with the surface crusted due to rain or water application, with vehicle access restricted. At the other end of the spectrum there are lay-down areas and areas around stockpiles that may have frequent vehicle usage and infrequent watering that can be very erodible. In deriving PM_{10} estimates, such areas must be quantified as to the level of particulate matter control. It is considered that more guidance, primarily pictorially such as used in RWEQ, should be provided to lessen the subjective interpretation of control factors.

5.2.1.6 Other Australian Studies

Small portable wind tunnels have been used to characterise relative particulate matter emissions on tailings dams and material at mines, for example work by Carras et al (1999) on tailings dams and Leys et al (2002) at iron ore ship loading facilities. These studies have been used to determine the relative dustiness potential of the surfaces (to highlight areas for improved particulate matter controls) and to assess particulate matter control measures.

Air Noise Environment conducted a study for the Australian Coal Association Research Programme to validate existing particulate emission estimation techniques for open area sources at coal mines (Air Noise Environment, 2003). The study used a large portable wind tunnel 1 m wide, 1.2 m high with a 5 m long working section. The wind tunnel was run for an initial 60 seconds where the "spike" in initial particulate matter was removed. The tunnel was then run for a period of 90 minutes with saltation material introduced at the beginning of the working section, with TSP and PM_{10} measured 1 m before the end of the tunnel at 0.3 and 0.75 m above the surface, and with the wind speed measured at 1 m.

The major conclusions from the study were:

- *The particulate emission data from the wind tunnel testing suggests that PM_{10} may comprise a significantly higher proportion of TSP, more than the 50% assumed by the NPI;*
- *The open area emission factor (for TSP) of 0.4 kg/ha/hr may overestimate by a significant margin actual particulate emissions from tested open area surfaces for some open cut mines; and*
- *The NPI emission equation (see* **equation 5.11***) may overestimate the actual emissions from active coal stockpiles.*

The conclusions from this report however are considered indicative only due to problems with wind tunnel derived emissions as discussed by Countess et al (2002) (see **Section 5.2.1.3**). Also, there appear to be a number of other issues with the study including:

- Particulate matter emissions appeared to be derived using average concentrations measured at 0.3 and 0.75 m above the surface and then multiplied by the flow rate. The particulate matter flux however should be determined using the profile of wind speed and the particulate matter concentrations as detailed in ENVIRON (2004) and Countess et al (2001).
- The particulate matter emissions appear not to have been corrected to a standard wind speed at 10 m; and
- The particulate matter flux from the first 60 seconds was not included in the measurements, but was only used to estimate the natural saltation rate. This exclusion, along with the long sampling time of 90 minutes at a constant wind speed, may result in armouring of the surface, (where the larger non-erodible elements protect the surface), and as such, the average concentrations may be lower than that measured over a shorter period.

Other large wind tunnel studies that have been conducted in Australia for mining applications that the authors are aware of include:

- Portable wind tunnel studies to investigate the wind erosion potential of various residue surfaces at the Pinjarra alumina refinery, as reported in Bell (1984) and later in Scott (1994); and
- Use of Agwest wind tunnel on a variety of surfaces bauxite refinery surfaces (SKM, 1997).

SKM (2004) provides a summary of two studies of open stockpile areas and two of drying areas using portable samplers to profile the particulate matter plumes in the horizontal. These studies used the horizontal particulate matter profiles and an estimated vertical Gaussian plume spread, mean wind speed at plume height and particle depletion to back-calculate the particulate matter emissions. These studies have limitation in the absolute accuracy as detailed in **Section 5.1.5**.

The results were fitted to the form of particulate matter flux proposed by Shao et al (1996) of:

$$PM_{10}\ (g/m^2/s) = k\ [WS^{3}\ _{x}\ (1 - (WS_o^{2})/WS^{2})], \qquad WS > WS_0 \qquad \textbf{(Eq. 5.14)}$$

$$PM_{10}\ (g/m^2/s) = 0, \qquad WS < WS_0$$

Where: WS is the wind speed (m/s)

WS_o is the threshold for particulate matter lift-off (m/s)

k is a constant.

Using these equations and annual hourly wind records, estimates of the annual PM_{10} emissions were made.

Table 4 Particulate Matter emission fluxes as presented in SKM(2004)

Surface	Controls in Area	K ($g/m^2/s$)	WS_o at $10m_o$ (m/s)	Annual Average PM_{10} (kg/ha/hr)
Bauxite Stockpile Area	Uncontrolled	$3.39e^{-7}$	8.5	0.48
Residue Area Wind Erosion - Area 1	Well Controlled	$1.32e^{-7}$	9.8	0.05
Residue Area Wind Erosion - Area 2	Well Controlled	$5.7e^{-7}$	6.5	0.04
Iron Ore Stockpiles - Main Live stockpile area	Uncontrolled	$5.2e^{-7}$	7.5	0.65

Note: Iron Ore data from Environmental Alliances (2003).

The results indicate that:

- Wind speed thresholds (hourly average at 10 m) were in the range of 6.25 to 9.8 m/s;
- Estimates for the controlled sites, using water cannons to increase the cloddiness of the site, were 25% of the default NPI emission rate for PM_{10} of 0.2 kg/ha/hr; and
- Annual PM_{10} emissions for the uncontrolled surfaces were 0.48 and 0.65 kg/ha/hr. This is higher than the default NPI PM_{10} value, but could be due to the windy nature of the sites, uncertainty in silt content, potential errors in the measurements and the approximate nature of **equation 5.11**.

Coffey and Evans (2000) present a variation on the above method whereby a network of 24 hour samplers surrounding a large residue drying area was used to back-calculate the particulate matter emissions. An uncertainty with this method is the need to assume the sampler 24 hour concentrations are representative of a large wind sector and as such the method requires good coverage around the particulate matter source. Another uncertainty arises from the concentrations being averaged over 24 hours, which requires the particulate matter contribution at each monitor to be apportioned over the period when the wind was from the source to the monitor. This can cause ambiguity as the particulate matter emission estimates are dependent on the wind speed and the correct apportionment for the various wind conditions. This problem can be overcome if hourly average data is used. This method has acceptance by the NPI in Western Australia as an approved alternative for the three surfaces in **Table 4**.

Another alternative to this method is the use of dispersion models such as ISC3 or AUSPLUME that model the dispersion and the depletion of the plume. It is considered that such a method with suitable well-sited monitors (free from other local sources), appropriate choice of wind erosion function such as **equation 5.14** and a reasonably accurate wind speed threshold will provide a better estimate of the particulate matter emissions than the use of equations such as **equation 5.11**. Therefore, given the uncertainty in the current method, it is recommended that these methods be proposed as alternative methods, provided they are subject to an independent review by suitably qualified practitioners to evaluate the accuracy and adequacy of the estimates.

5.2.2 Summary and Recommendations

The current NPI recommendation for wind erosion is the PM_{10} default factor of 0.2 kg/ha/hr. This is based on the older AP-42 equation (pre 1988, **equation 5.11**) for active storage piles with a continual supply of fresh material, use of Hunter valley coal and overburden characteristics, and Hunter Valley wind and rainfall values. It is therefore unlikely to be representative of conditions for all Australian mines, as it does not take into account the differences in climate and ore types and, since it was developed for an active storage pile, tends to overestimate emissions.

Furthermore, both the original and the current AP-42 equations appear to be based on limited data for coal mines. The current method in particular, is based on a small number of wind tunnel measurements which are subject to uncertainties, especially when extrapolating to larger areas.

As such, the following are recommended:

R 5.5 The current default factor should be deleted. It is considered that emission estimates can be readily obtained with the current NPI equation and this should be used to take into account climate variations across Australia. This will result in some areas having emission factors that are twice as high as the current default with some areas having considerably lower emissions;

R 5.6 Though the current NPI equation is considered indicative only, there appears to be no ready replacement, with the existing AP-42 equation considered to be based on little data for non-coal mines and difficult to implement (eg. estimation of threshold friction velocities). Therefore it is recommended that:

- The current NPI equation should be retained in the interim.
- The NPI coordinate with the US groups (USEPA and WRAPAIR) to determine and progress toward a new equation with more supporting studies for this.
- The NPI liaise with the wind erosion community within Australia to see if a more suitable equation or simple model for mines could be developed. Such work may include undertaking a single case study to verify the methodology or the development of portable wind tunnel methodology to determine relative erodibility potential of materials.

R 5.7 The NPI develops or commissions estimates for all fugitive particulate matter sources within Australia, such that the mining fugitive emissions can be placed in context, as is provided in the US NEI. At present in most regions of Australia, fugitive particulate matter from mining is presented as the only large source, with other larger sources of PM_{10} and "metals" such as from wind erosion of non mine areas, from agricultural activities and bush fires omitted. For wind erosion estimates it is recommended that the NPI liaise with those in the Australian Air Quality Forecasting System (AAQFS) who are currently evaluating a system that predicts PM_{10} wind erosion emissions and the resultant PM_{10} concentrations for Australia. Alternatively, a system using the CARB approach as used in the Pilbara and Bunbury airsheds (SKM, 2003 and

SKM, 2003b) and recently undertaken for Victoria (Ng, 2004) could be used. The use of a national approach would also have the advantage of providing consistency across Australia. Other sources of particulate matter from agricultural practices and fires could also be coordinated at a national or at least state level. PM_{10} estimates from fires could be obtained in conjunction with the national greenhouse gas emission estimates as they both require fuel loading and the area burned**.** The development of estimates for all fugitive particulate matter sources within Australia has the potential to cost around $100,000.

R 5.8 Alternative methods, such as using validated particulate matter dispersion models, should be highlighted as an acceptable alternative to the AP-42 equation. Such a method can consist of well-sited ambient monitors that are free from confounding sources, along with the use of back-calculation techniques involving dispersion models. It is recommended that all such studies have an independent technical review to ensure that the estimates are acceptable. This method would initially require a statement in the manual indicating that is an acceptable option, though requiring agreement on a case by case basis with the relevant State NPI department.

R 5.9 Wind erosion control factors need to be improved to provide more detail on how to classify surface types. A possible method may be to supply photographic examples of bare areas as per the method used in RWEQ. This is recommended as greater than a factor of two variation can occur due to the subjective interpretation involved in classifying the amount of erodible area and the relevant control factors for a particular site.

R 5.10 A wider range of control factors is needed for water cannon control to give credit to facilities with well designed and maintained systems. To undertake this, a review of water cannon control is recommended as a first step. The authors are aware of one study currently underway to determine control factors for water cannon.

5.3 Material Handling Load-in/Load-out

5.3.1 USEPA AP-42

Emission factors from AP-42 of relevance are those under:

- Aggregate handling and storage piles (AP-42 Section 13.2.4, 1995). This contains general equations for continuous or batch drop operations:

$$E\ (kg/tonne) = k\,(0.0016)\,(U/2.2)^{1.3}\ (M/2)^{-1.4} \qquad \textbf{(Eq 5.15)}$$

Where k = particle size multiplier

U = mean wind speed (m/s)

M = material moisture content (%)

This equation is specified for loading in (truck dumping to pile, stacking into pile) and loading out from the pile (e.g. a front-end loader loading a truck).

- Western Surface Coal Mining (Section 11.9, 1998) contains truck loading and truck dumping factors for coal.
- Crushed Stone Processing and Pulverised Mineral Processing (Section 11.19.2, August 2004) contains emission factors for tertiary crushing, screening, conveyor transfers and truck unloading
- Taconite Ore Processing (Section 11.23.1, February 1997) contains emission factors for primary, secondary and tertiary crushing.
- Sand and Gravel Processing (Section 11.19, November 1995) contains a factor for sand handling and storage with a wet scrubber.
- Metallic Minerals Processing (Section 11.24, 1982, reformatted January 1995) provides factors for low and high moisture ores (the cut off defined as 4%) for primary, secondary and tertiary crushing and material handling and transfer for uncontrolled sources. It is noted that the factors for crushing and drying operations are for the process as a whole and cover all the separate particulate matter sources such as hoppers, surge bins or transfer points that are integral with these facilities. This definition of crushing needs to be clearly spelt out to ensure that no double counting of transfers etc occurs.

In AP-42 material aggregate handling (AP-42 4th edition), the equations were:

$$E\ (kg/tonne) = k\ (0.0009)\ (s/5)\ (U/2.2)\ (H/1.5)\ (M/2)^{-2}\ (Y/4.6)^{0.33}\ \text{(batch drop)} \quad \textbf{(Eq 5.16)}$$

$$E\ (kg/tonne) = k\ (0.0009)\ (s/5)\ (U/2.2)\ (H/3.0)\ (M/2)^{-2}\ \text{(continuous drop)} \quad \textbf{(Eq 5.17)}$$

These were replaced with the current equations in 1995, which have removed the silt content and drop distance dependence.

5.3.2 NPI and Australian Studies

5.3.2.1 Truck Loading and Dumping

The NERDDC study on Australian coal mine operations (NERDDC, 1986) found very similar emission factors for truck and shovel loading of coal and overburden to that reported by Axetall and Cowherd (1981). However, in the comparison of the NERDDC emission factors to the present AP-42 batch loading equation, Holmes Air Sciences (1998) found that the equations give much lower particulate matter emissions for operations such as overburden and coal dumping and load-in to haul trucks. In reviewing the applicability of the AP-42 equations Holmes Air Sciences (1998) state that the AP-42 equation,

"gives much lower dust emissions than the Australian research (NERDCC, 1988 and SPCC, 1983), or indeed than earlier US research. It is likely that the reason for this is that the earlier equations treat the

entire loading operation as a single operation. The entire operation involves using a shovel/excavator or front end loader to scoop up a load, move to a loading position, dump material into a truck, reload and repeat the process. After the new loading operation is completed the loaded vehicle moves off and is replaced by a new vehicle. If the newer equation simply considers a pure batch or continuous load-out operation, for example as might be found in a facility using a clamshell, or loading from a conveyor to a stockpile then many of the dust producing actions will not be included. It would seem that the (NERDCC, 1988), (SPCC 1983) and earlier US equations would be more appropriate, for both coal and metalliferous mines, than the newer equation proposed by the EPA (NSW)."

In the original NPI Mining Manual (version 1), a comparison was presented of the estimates from the AP-42 for aggregate handling and measurements of loading overburden to trucks at a coal mine. The AP-42 values were up to 90 times lower than those obtained from the NERDDC study (see Section A1.1.3). Therefore, the NPI Mining Manual recommended the NERDDC values. Similarly, for dumping coal and overburden the NPI Mining Manual again recommended the NERDDC values. For loading coal a comparison was made to the available equation in AP-42 Western Surface Coal Mining which compared well with the NERDDC measurements. As such, the equation was recommended. For metalliferous mines, as there was no Australian data the AP-42 equation was recommended as the only available option, though it was considered that this equation may underestimate actual emissions by a factor of 5 to 10.

Therefore, for metalliferous mines the available Australian data indicates that these sources may be underestimated by use of the current AP-42 equations.

R 5.11 For loading/unloading trucks it is recommended that, as a first step, an in-depth review of the derivation of the USEPA AP-42 load-in/load-out emission equation is required to resolve the apparent large underestimation in emissions when using this equation, compared to that measured at Australian mines.

5.3.2.2 Transfer Points, Stacking and Reclaiming

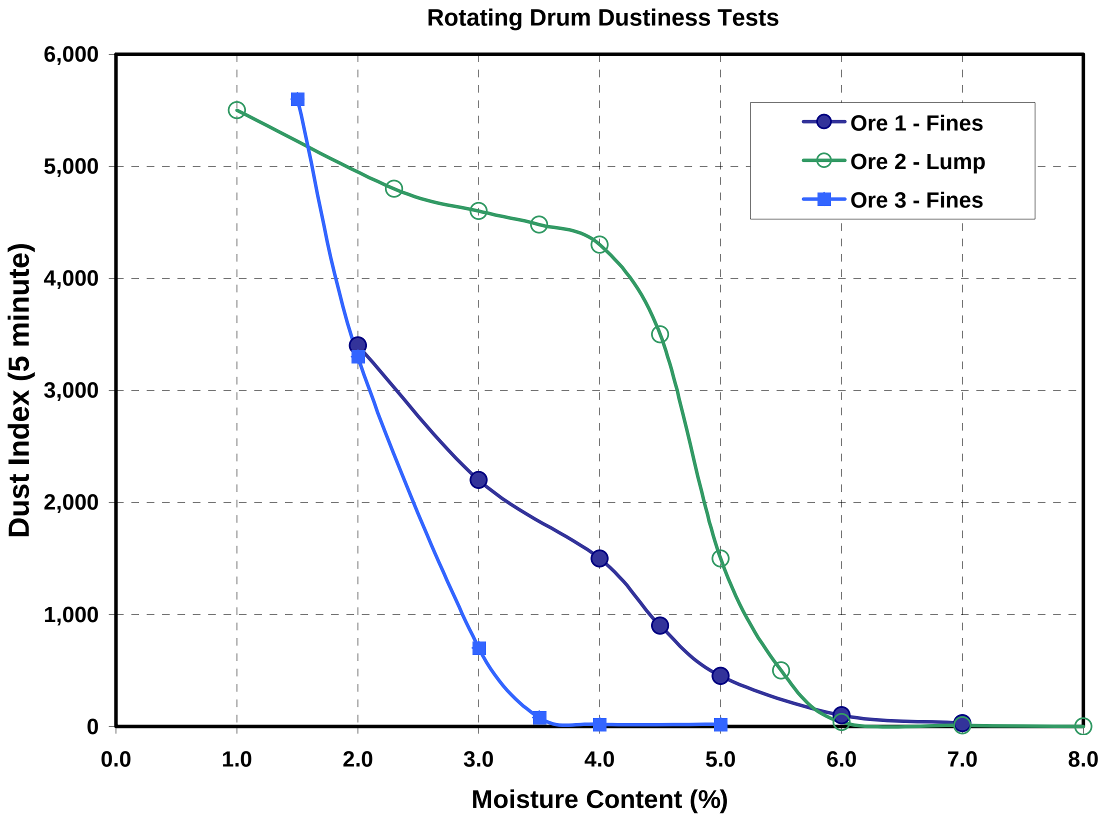
Particulate matter emission factors in the NPI Mining Manual for coal mining transfer stations were given by the AP-42 load-in/load-out equation. No Australian data were available for comparison of these values. The AP-42 equation and a default based on "typical" conditions" are provided in a summary table in the NPI Mining Manual (version 2.3). For metalliferous mines, emission factor defaults are provided for both low moisture content ores (below 4%) and high moisture content ores (greater than 4%) obtained from the AP-42 metallic minerals processing handbook. The source of these factors in the AP-42 guide is not clear and, due to the approximate step change cut off, are considered to have a high degree of uncertainty. The AP-42 classifies these with a rating of C.

In practice, the mining industry generally uses the AP-42 load-in/load-out equation given in the coal mining section, though this is not provided in the metalliferous section of the NPI Mining Manual.

Apart from the metallic minerals processing factors, and aggregate handling equation, the new crushed stone processing and pulverised minerals processing guide (USEPA, 2004c) contains emission factors for conveyor transfer points as well as crushing and screening. These factors are all generally well below the metallic minerals factors. It is considered that for some of the hard rock mines these factors may be more applicable than those from the metallic minerals processing guide (USEPA, 1982).

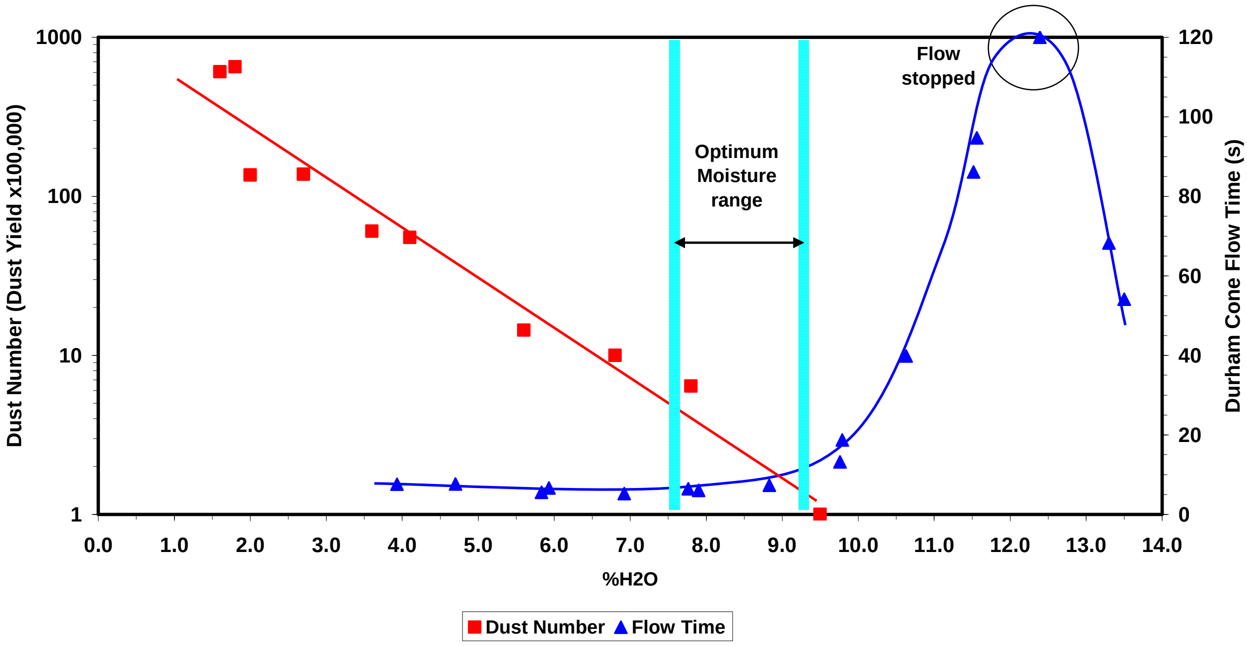
With the current NPI defaults, the division of ores into either low or high moisture is approximate and reduces the dustiness of ores into two states only, instead of the continuum of dustiness that can occur over several orders of magnitude. The change in dustiness with moisture can be determined in the laboratory by the rotating drum test used in defining coal dustiness (AS4156.6-2000). These tests have been used in a modified format in Western Australian iron ore operations to account for the density of iron ore when defining the relative dustiness and the moisture content needed to suppress dust. Indicative results for three ore types are presented in **Figure 9**. This figure shows that:

- Different iron ores can exhibit differences of about 2% in the moisture cut off between high and low dusting ores. The actual value is dependent on the definition of the level of "no" dust, but it is likely to be in the range of 3% to 5.5 % moisture content for the ores tested. This is in approximate agreement with the metallic minerals processing guide of 4%.
- Ores with low silt contents, such as lump ores, have the potential to be dustier than fines with higher silt contents. Lump ores are the premium product from the screened mined ore with an approximate 6 to 32 mm size, whilst fines are product smaller than 6 mm. The lumps can be more dusty at a given moisture content because the small fraction of fines can be in loose adherence to the larger lump material and can be easily dislodged and winnowed during material handling.
- There is a much greater variation in particulate matter emissions than is indicated in the metallic minerals guide (USEPA, 1982) where moist ores are specified to have particulate matter emissions of between 10 to 20% of the low moisture ores. Conversely very dry ores can have much higher particulate matter emissions. It is noted that the magnitude of the difference from the rotating drum test is overstated as the particulate matter is drawn out of the sample for a period of five minutes with continual tumbling, unlike in a conveyor transfer point in which the ore is passed through only once.



- **Figure 9 Typical variation in particulate matter test results from iron ore**

Figure 9 also highlights that the current binary system of particulate matter factors does not recognise that a wider range of particulate matter emissions can occur and the ore can be conditioned with water to achieve optimum moisture content with negligible particulate matter emissions. This conditioning is now a primary method used in the iron ore industry to control particulate matter from material handling, where the optimum moisture from a particulate matter emission and material handling viewpoint is maintained. This is illustrated in **Figure 10** using the rotating drum test and a Durham flow test to determine the optimum moisture range for lessening particulate matter emissions and material handling problems such as blocked chutes.



▪ **Figure 10 Particulate matter number and Durham cone flow time as a function of moisture content for an iron ore**

The rotating drum tests also indicate that the current material handling dependence on moisture content and silt content are very simplistic and do not hold for all ore types. Instead, it would be preferable to develop a method whereby the dustiness of an ore was determined as a function of moisture by a test such as the rotating drum. The test results could then be incorporated into a predictive factor that took into account the operating dependent emissions.

Another important issue with the application of appropriate moisture content is that this is relevant to unbound moisture only. AP-42 for Western Surface Coal Mining states the unbound sorbed moisture is to be used in the equations and not bound moisture. This is supported by Smithman and Nicol (1990), who tested Australian coals using wind tunnels, and Lu (1997) for Chinese coals. Lu (1997) uses definitions of inherent moisture (moisture that is preserved in air-dried coal and that which is held in the internal pores etc); free moisture (that which can be air-dried), and the total moisture. Lu (1997) found that some coal, with moisture contents in the 6 to 8% range could be very dusty as all the moisture was held internally as inherent moisture. Lu found that free moisture was a much better predictor of the dustiness of the coal. For most metallic ores it is considered that inherent moisture will be low, though for some ores with high internal pores this may be an issue. As such, this definition needs to be better highlighted in the NPI Mining manual.

Pitts (2000) provides a comparison of the emissions from iron ore operations for transfers, stacking and reclaiming. The study indicated reasonable agreement with the default NPI factors taken from the AP-42 metalliferous default factor. However, a comparison of the emissions estimated by the AP-42 aggregate handling equation, assuming typical wind speeds of 4 m/s and moisture contents of 3 and 5% for the low and high moisture content ores, indicates that the AP-42 derived values are generally 5 to 25 times lower than the default NPI factors or as presented by Pitts (2000). As such, and as also found by Holmes Air Sciences (1988), it appears that the AP-42 equation under-predicts the particulate matter emissions.

The following are recommended for transfer stations, stackers and reclaimers:

R 5.12 For transfers, reclaimers and stackers, it is recommended that, as per loading/unloading trucks a review of the derivation of the USEPA load-in/load-out equations be undertaken to resolve the apparent underestimation of emissions. As an interim measure it is recommended that the defaults be retained but usage of the equation be dissuaded.

R 5.13 When considering the moisture content of ores, as a second higher level of complexity to using the default 4% cut off between high and low moisture content ores, mines should be encouraged to use the rotating drum test to classify the dustiness of the ore as either high or low moisture. In general, the available data supports the default 4% cut off but the limited test work presented in this report indicates that thresholds may vary between at least 3 to 5.5%.

R 5.14 As a low priority task, it is recommended that dustiness tests be used to account for the dustiness of the ores as a function of moisture. It is considered that this captures the true dustiness of the ore rather than trying to fit a simple universal moisture and silt particulate matter relationship to the ore as is used for moisture in the current and both moisture and silt in the older AP-42 material handling equations.

5.3.2.3 Crushing

The current NPI Mining Manual has adopted the AP-42 values from Metallic Minerals Processing (Chapter 11.24) (USEPA, 1982). As noted in **Section 5.3.1**, the Crushed Stone Processing and Pulverised Minerals Processing (USEPA, 2004c) also provides a value for tertiary crushing which is substantially below that from metallic minerals. As such, it is recommended that:

R 5.15 For crushing emissions, the new AP-42 stone crushing and quarrying factors be included as the defaults for the stone crushing and quarrying industry.

5.3.2.4 Screening

Screening generally occurs in combination with crushing operations to size the crushed product. The NPI Mining Manual provides emission factors for screening for one all encompassing ore type at a “low” moisture content, with TSP and PM_{10} emissions of 0.08 and 0.06 kg/tonne respectively. The source of these factors is not given in the NPI Mining Manual, with the derivation not clear. The values are similar to those provided in the Crushed Stone Processing and Pulverised Minerals Processing section of AP-42 (USEPA, 2004c) for uncontrolled fines screening of 0.15 and 0.036 kg/tonne. Fines screening takes place after tertiary screening to produce manufactured sand with a maximum screen size of 50 mm. Uncontrolled screening factors for use with screening in primary to tertiary crushing are quoted at 0.0125 and 0.0043 kg/tonne for TSP and PM_{10} respectively, with a PM_{10} controlled factor of 0.00037 kg/tonne (controlled) which gives a control efficiency of 91.6%.

In practice, screening emissions for most sites will be covered under the crushing factors as this factor includes the system of crushers, screens, hoppers and transfers. However, iron ore port operations often have separate re-screening facilities to screen the lump ore before shipment and remove the fines for return to the fines product stockpiles. This re-screening is required due to "degradation" of the ore through handling, primarily through the many conveyor transfers which can break off fine particles, therefore producing a sizeable proportion of fines in the lump ore.

Pitts (2000) measured the emissions from these screening plants, (including all sources, hoppers and conveyor transfers) at an average 0.004 kg/tonne. The screens themselves were controlled with particulate matter extraction to scrubbers with the hoppers (bins) mainly enclosed. If control efficiencies of 93.5% and 89% are assumed for the entire plant, which appears reasonable, the measurements of Pitts (2000) imply uncontrolled values of 0.06 and 0.036 kg/tonne respectively, which are in agreement with the values used by the NPI EET and that for fines screening in stone quarrying as reported in AP-42. As such, for the iron ore industry, the fines screening value in the new crushed stone processing and pulverised minerals appear appropriate, with a typical overall control factor of 90% based on operations in a partially enclosed building with dust extraction from the screens and partial enclosure of hoppers.

Therefore, it is recommended that:

R 5.16 For screening emissions, the emission factors should be updated with those in the new AP-42 crushed stone processing and pulverised minerals guide. For primary, secondary and tertiary screening at stone processing and quarrying operations the AP-42 "screening" factors are applicable, whilst for iron ore re-screening the "fines screening" factor is considered applicable.

5.4 Blasting

5.4.1 USEPA AP-42

Until 1998, the USEPA AP-42 recommended the following equation for coal and overburden blasting:

$$E_{TSP}\text{ (kg/blast)} = 344\ (A^{0.8})\ (M^{-1.9})\ (D^{-1.8}) \qquad \textbf{(Eq 5.18)}$$

Where A = the area of the blast (m^2)

M = the moisture content (unbound moisture content) (%)

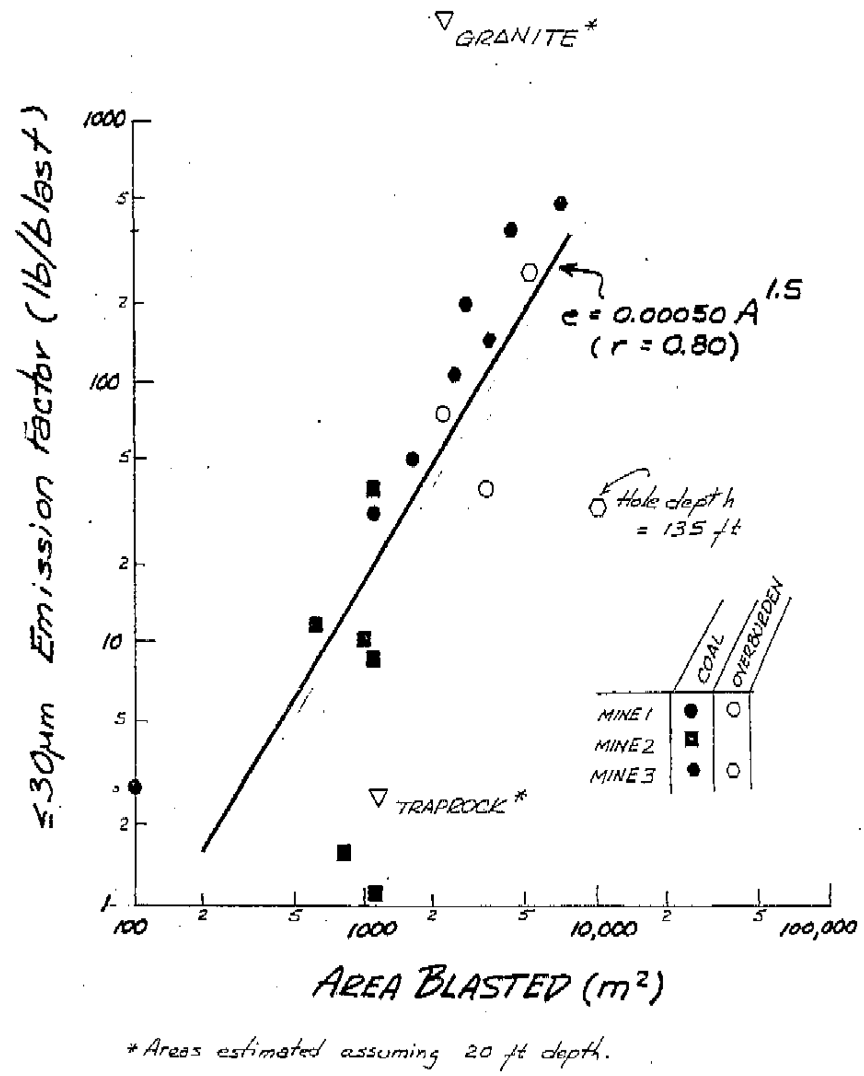
D =the blast depth (m)

This area dependent equation was recommended for all blasting from coal, overburden and other un-fractured rock blasting with quality ratings for TSP of C and D for both PM_{10} and $PM_{2.5}$.

This equation was developed from 14 coal and four overburden blasts at three western surface coalmines. This equation was included in the Crushed Stone Processing guideline in 1985, but was considered by industry to overestimate the emissions due to the strong moisture dependence of the equation and the much lower moistures in the stone processing industry (MEPA review, 1998). In response, the USEPA developed a new equation for use in the crushed stone industry based on the original surface coal data that only included the area blasted. The data used and the equation developed are presented below and in **Figure 11**:

$$EF_{30}\ (kg/blast) = 0.00022\ A^{1.5} \qquad \textbf{(Eq 5.19)}$$

Note, this equation is as presented in the 1998 Western Surface Coal Mining which is all in metric units, though at various times a mixed unit equation has been given with emissions in lb/blast and area in square metres as per **Figure 11**.



- **Figure 11 Particulate matter emissions from blasting versus area blasted from Cowherd (1986).**

As well as the coal mining data, two inferred estimates on granite and traprock were also presented which were commented to have "bracketed" the coal/overburden tests and the equation. The inferred granite test result however, as indicated in **Figure 11**, is around 30 times greater than that estimated from the equation and does not appear to support the use of this equation outside the coal mining industry. Also, of note is that the blast area ranges from approximately 700 m^2 up to 8,000 m^2, whilst blasting in Australian mining can be up to 45,000 m^2 (McDougall, 2004). Currently there are no other equations available to estimate particulate emissions from blasting.

Values of PM_{10} from blasting are then estimated at 52% of TSP, based on material handing PM_{10}/TSP ratios. $PM_{2.5}$ values were originally estimated as 0.03 of TSP based on ratios from material handling. It is noted that MRI (1998) removed the $PM_{2.5}$ factor, whilst this is still in the 1998 AP-42 manual.

The recently updated Crushed Stone Processing and Pulverised Mineral Processing (August 2004) now states that *"Emission factor estimates for stone quarry blasting operations are not presented because of the sparsity and unreliability of available tests. While a procedure for estimating blasting emissions is presented in Section 11.9, Western Surface Coal Mining, that procedure should not be applied to stone quarries because of dissimilarities in blasting techniques, material blasted and size of blast areas"* (USEPA 2004).

5.4.2 NPI

The 1999 NPI Mining Manual and current 2002 NPI Mining Manual (version 2.3) provided the two AP-42 equations, but recommended the first equation with no default provided. This recommendation was based on the comparison in Holmes Air Sciences (1998) which considered **equation 5.18** to "*give more reasonable estimates of particulate matter emissions*" as well incorporating the intuitively dependent variables such as moisture content and blast depth. The current draft NPI Fugitive Emissions Manual (NPI, 2002), set to replace the NPI Mining Manual, has adopted the new equation although no text is provided to explain the changes.

A comparison of the estimates for a range of moisture contents, areas blasted and blast depths is given in **Table 5**.

- **Table 5 Blasting PM_{10} emissions for a range of conditions**

Moisture Content (%)	Area Blasted (m^2)	Blast Depth (m)	PM_{10} Emissions AP-42 (1988) (kg/blast)	PM_{10} Emissions AP-42 (1998) (kg/blast)	Ratio Old/New Estimate
3	2,000	4	800	10	78.2
3	2,000	6	386	10	37.7
10	2,000	6	39	10	3.8
10	15,000	6	196	210	0.9
3	15,000	6	1,933	210	9.2
3	15,000	8	1,152	210	5.5

This shows that, for moisture contents below 10%, there can be an appreciable difference between the two methods. For moisture contents around 3%, which typically occur in arid areas when mining above the water table, the new equation predicts 5 to 10 times lower concentrations for large blast areas. For small blast areas (2,000 m^2) the equation predicts 35 to 80 times lower emissions.

As such, replacing the existing equation with the new equation will lead to a generally very large reduction in blasting particulate matter emissions for reporters that have used the recommended equation. It is noted that, though not recommended, some reporters have been using the area-based equation due to its simplicity, requiring only the area blasted and not estimates of the moisture content, which at some mines are not undertaken. In fact, for the evaluation of the relative contribution of particulate matter sources at various mines presented in **Section 8.1** and **Figure 11,** the relatively high contributions of up to 11% from blasting were from mines which used the older equation, whilst the lower contributions were predicted for mines that have used the current equation.

Of note in the NPI Mining Manual and NPI Fugitive Emissions Manual is that the area blasted (in m^2) is not clearly identified as area per blast. As a result, it is known that some NPI estimates have been undertaken using the area from the total 12-month period. Use of the area from 12 months and the older equation will result in lower than intended emissions whilst use of the new equation (in particular using the total area) will give an erroneously high particulate matter emission.

Based on the above review and the recent recommendation in the Crushed Stone Processing and Pulverized Mineral Processing guide (USEPA, 2004c) it is seen that there is little if any justification for the equations for the non-coal mining industry. Additionally, mines in Australia can have blast areas substantially larger than that for which the current AP-42 equation in coal mining was developed (max value of 9,600 m^2) with two mining groups contacted having blast areas in the range of 11,000 to 15,000 m^2 and up to 45,000 m^2. As such, it is recommended that:

R 5.17 Though there is little support for the application of the current AP-42 blasting equation, and despite it being dropped from AP-42 Crushed Stone Processing and Pulverized Mineral Processing guide, it is recommended that:

- The new AP-42 equation be retained in the interim;
- NPI liaise with the USEPA to investigate further work planned to improve this factor; and
- NPI investigate the feasibility of conducting Australian testing using aircraft to profile the particulate matter plume to derive estimates. Such methods have been used for other aerosols such as smoke plumes from fires and industrial sources using the Flinders University aircraft and CSIRO.

5.5 General Comments on Control Factors

The control factors listed in the NPI Mining Manual are generally limited and quite dated. It is considered that a review of the control factors should be conducted with more categories of control options provided.

5.6 Particulate Removal

In general, the NPI requires particulate matter emissions to be estimated at the source and does not take into account deposition rates, which would allow estimation of the quantity of particulate matter that is transported beyond a site's boundary (see Holmes Air Sciences, 1998 and NSWMC, 2000). This neglect of particulate removal does not recognise that many mines are planned such that have a good buffer zone around the operations to ensure that the majority of the particulate matter is deposited before it leaves the site. Such a buffer may be due to the "natural" revegetation or the land may be intentionally revegetated to assist in removing particulate matter. Additionally, the NPI methodology does not distinguish between the use of shelter belts and vegetation grown adjacent to sources (such as along road sides and around stockpiles) that reduce the wind speed (therefore reducing particulate matter emissions) and between the use of vegetation downwind to trap the particulate matter once emitted. In the first case, the reduction of wind speed to reduce particulate matter emissions can be incorporated into the applicable EET, whilst the use of shelter belts to trap particulate matter cannot. Also, for particulate matter sources, fogger sprays to capture particulate matter are counted as a dust control measure, whilst shelter belts immediately downwind are not. As detailed by Pace (2004), vegetation immediately downwind of sources can remove an appreciable proportion of even the fine $PM_{2.5}$ particulate.

Whilst not allowing for use of vegetation belt to remove particulate matter, the NPI Mining Manual allows for the capture or removal of particulate matter from mining activities within a pit to be used, and provides a value of 50% and 5% retention for TSP and PM_{10}. The source quoted for these factors in the NPI Mining Manual is Holmes Air Sciences (1998), but it would appear to be based on data presented in NSWMC (2000) using the model ISC3-ST, an assumed source particle size distribution and particular pit dimensions. Therefore it is specific to a particular mine and may under-predict that which occurs from some of the larger, deeper open cut mines.

From the US perspective, it is understood that emission inventories are to be at the source, with Pace (2004) recommending against incorporating near source particulate removal to derive emission inventories.

R 5.18 It is recommended that the NPI review the issue of particulate removal, noting that depletion for pit retention is incorporated but other removal mechanisms, such as vegetation belts, are not. In the case of mines, it is considered that the pit retentions are very indicative and that guidance should be provided so mines can develop site-specific factors using a model such as ISC3.

6. Particulate Size Distributions

As detailed in **Sections 3** and **4**, emission factors have principally been developed from sampling immediately downwind of the sources using TSP samplers and PM_{10} samplers with cascade impactors to determine the particle size distribution below 10 µm. Little work has been done with $PM_{2.5}$ samplers, particularly those that meet Federal Reference Method requirements with a sharp cut point head. As a result, fugitive particulate matter emission factors are relatively more uncertain for the smaller size particulates.

In the US, the issue of the accuracy of the particle distribution, especially for $PM_{2.5}$ fractions has been of concern due to the over-prediction of crustal material $PM_{2.5}$ compared to its presence in ambient monitoring (see **Section 4.2**). This has lead to WRAPAIR undertaking a study to evaluate the USEPA's Fugitive Particulate Matter Emission Factor Test Methods for $PM_{2.5}$. One of the outcomes of the study is that it highlighted the significance of particle capture near the source in removing even fine $PM_{2.5}$ particulate. Though this can result in a large fraction of the $PM_{2.5}$ captured, there remains concern that the $PM_{2.5}$ emission factors may be overstated.

Other reasons for the uncertainty and possible over-prediction are:

- Sampling methodology using high volume samplers fitted with a PM_{10} cyclone and cascade impactor may over-sample the lower size ranges due to particle bounce in the cascade impactor. This is important for high filter loads where the particles may bounce off the particles already captured on the surface of the impactor plates, and therefore be collected in the next lower size fraction. This may help to explain why the AP-42 emission factors for fugitive particulate matter sources appear to overestimate $PM_{2.5}$ emissions (WRAPAIR, 2004).
- The uncertainty in TSP measurements recorded with a high volume sampler. These, as detailed in **Section 2**, are very dependent on the wind orientation and speed during sampling. AP-42 factors are normally presented as PM_{30}, but it is not always clear whether the PM_{30} has been derived by assuming that the size distribution measured by a TSP sampler is approximately PM_{30}, or by specifying the particles collected by the TSP sampler as a PM_{30} subcategory.
- Accounting for depletion of the particles between source and sampler. The size distributions are typically determined from samplers tens to hundreds of metres downwind. At this distance appreciable depletion of the larger particles can occur. In the AP-42 studies, simple depletion models have been used to account for the depletion (see MRI, 1998). In Australia, the method of Slinn (1982) has been used for the SPCC (1986) study.
- $PM_{2.5}$ sampling has used older broader cut points than those now specified for ambient samplers which have sharp cut points. Broader cut points will result in an over-sampling of crustal material with the potential that the majority of the sample is actually greater than 2.5 micron.

A comparison of available particle size distributions in the literature and within Australia is summarised in **Table 6**. These have been derived from:

- Current AP-42 factors;
- The work of SPCC (1986), which is considered to be the only comprehensive study of source particle size distribution data within Australian to date. This work was conducted on coal mining activities in the mid-eighties to determine the particle size distribution of particulate matter from haul trucks and load-in and load-out operations. The study used:
  - High volume samplers with iso-kinetic sampling heads mounted on wind vane heads, with the sampling velocity matched to the wind speed by using an adjacent wind sensor. Velocity was obtained by the average of the last five seconds of wind run.
  - Particle sizing obtained by washing and sonication of the papers in ethanol, with the particulate matter passed through a Malvern particle sizer. Physical particle sizes were converted to aerodynamic sizes by then correcting for the shape and density of the particles.
  - Corrections for depletion, with a maximum of 10% to 30% correction for the larger particles and the results presented as percentage of particles less than 30 µm (i.e. SP or PM_{30} and not TSP).

  This data has been recently summarised in NSW Mineral Council (2000) with, on average, 4.7% and 39.1% of the PM_{30} being $PM_{2.5}$ and PM_{10};
- The work of Leys et al (1998) on agricultural machinery and unpaved road dust in northern NSW. This indicates that of the PM_{30}, 1% was $PM_{2.5}$, 15% was PM_{10} and only 5.6% of the PM_{10} was $PM_{2.5}$;
- The $PM_{2.5}/PM_{10}$ ratio of 22% for wind blown particulate matter used in WRAPAIR. This ratio is based on work by CARB though its exact origins are not detailed (ENVIRON, 2004);
- Wind erosion data as presented in Shao et al (2003) for Asian dust storms; and
- Data as summarised by Watson and Chow (2000) of Ahuja et al (1989) and Houck et al (1989, 1990).

- **Table 6 Particulate Matter Size Distributions from the Literature**

Size	Load-in/Load-out			Wheel Generated Industrial			Wind Erosion		
Percentage below	$PM_{2.5}$	PM_{10}	PM_{15}	$PM_{2.5}$	PM_{10}	PM_{15}	$PM_{2.5}$	PM_{10}	PM_{15}
AP-42	15	47	65	4.7 4.5	31 30	- -	20	50	60
SPCC (1986)	4	-	48-63	6	-	59	-	-	-
Watson and Chow	5.8	35	-	10.7	52.3	-	-	-	-
Ratio	$PM_{2.5}$ / PM_{30}	$PM_{2.5}$ / PM_{10}	PM_{10} / PM_{30}	$PM_{2.5}$ / PM_{30}	$PM_{2.5}$ / PM_{10}	PM_{10} / PM_{30}	$PM_{2.5}$ / PM_{30}	$PM_{2.5}$ / PM_{10}	PM_{10} / PM_{30}
AP-42	15	32	47	4.6	15	31	20	40	50
SPCC (1986)	4	-	-	6	-	-	-	-	-
Watson and Chow	5.8	17	-	10.7	20	-	-	-	-
Shao et al (obs)	-	-	-	-	-	-	-	16 range 18-29	-
CARB/WRAPAIR	-	-	-	-	-	-	-	22	-

Notes:

1) Shao et al (2003) are observations at distances hundreds to thousands of kilometres downwind. As such, the $PM_{2.5}$ to PM_{10} fraction should be greater than at the source.

Table 6 indicates the following:

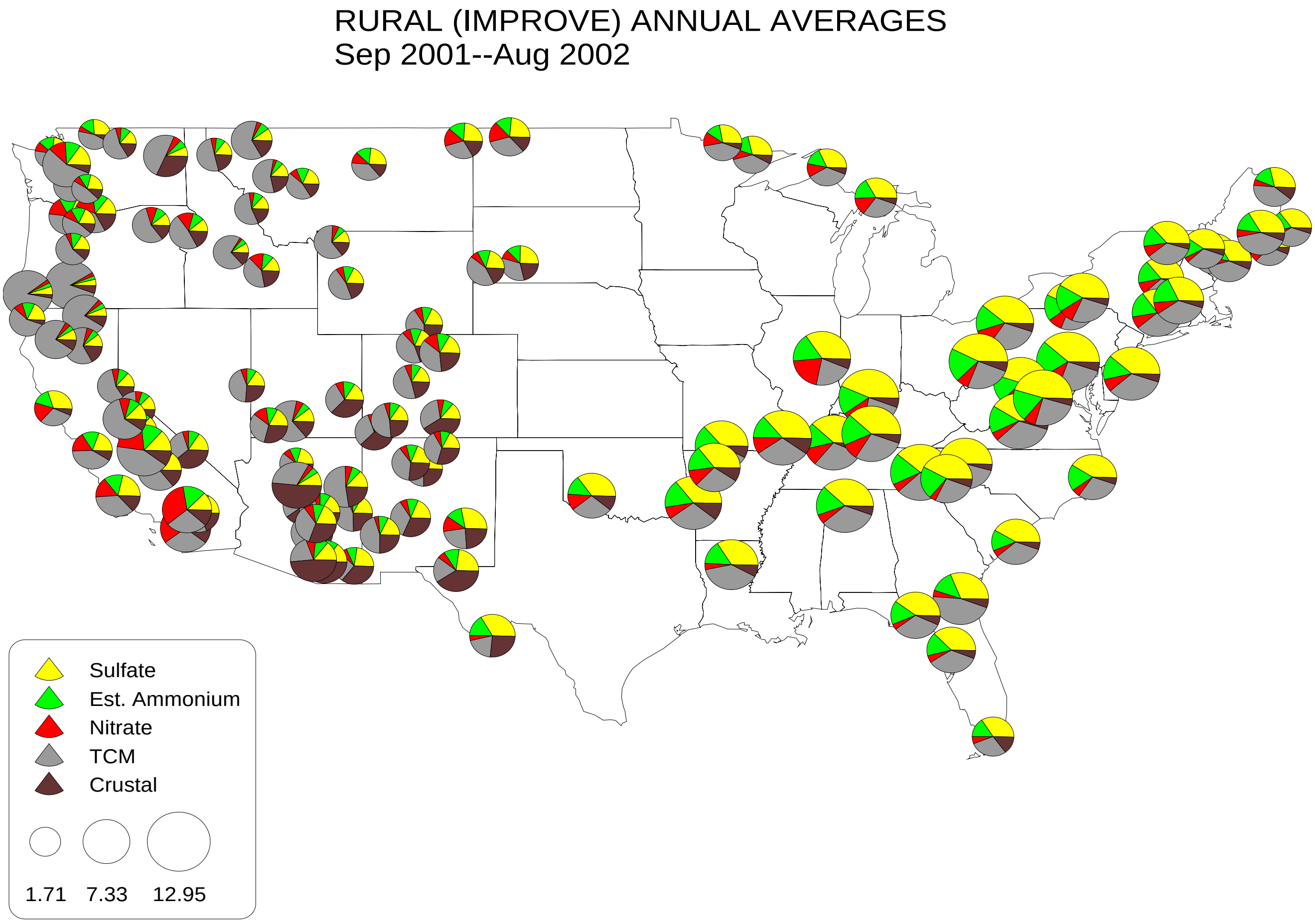
- Reasonable agreement between the AP-42 factors and vehicle generated particulate matter, particularly between AP-42 and SPCC (1986). Note the USEPA recently lowered the $PM_{2.5}$ and PM_{10} fractions in unpaved road particulate matter emissions;
- Higher percentage of smaller particulates from AP-42 factors for the load-in/load-out particles, especially for $PM_{2.5}$; and
- The AP-42 distribution has a much larger proportion of particles in the small size ranges for wind erosion than the other data. The actual source of the USEPA particle size distribution is not given, but it appears to be a very approximate distribution. It should be noted that the paper by Cowherd and Kuykendak (1997) recommended a much lower fraction for wind erosion than in the current AP-42 guide.

Besides the above data it is considered that, for wind erosion, there is a substantial amount of data on size distributions of wind blown particulate matter and reasonably sophisticated models for predicting particulate matter emissions and concentrations downwind in the wind erosion sciences. For example, the model of Alfaro and Gomes (2002) predicts the size distribution of particulate matter dependent on the soil particle size distribution and the friction velocity. Size distribution data is also generated in the model used by Lu et al (2004) though this is not routinely extracted or examined.

Another method that may be of use to assist in determining the particulate matter size distributions is the use of ambient samplers placed near particulate matter sources, where depletion is not significant and sampled particulate matter is predominantly from the source. Sites that may provide good measurements are those on mining area boundaries, such as those monitored by Alcoa, BHPBilliton at Port Hedland etc. Such data has not been assessed for this study, however it is recommended that a list of monitoring sites be compiled identifying sites, particularly with $PM_{2.5}$ and PM_{10} samplers, that meet the US Federal Reference Methods.

In summary, it is concluded that there are issues that are still being resolved with regard to particle size distribution of the various sources, with the current AP-42 distributions, for material handing (load-in/load-out) and wind erosion, possibly over-predicting the emissions of PM_{10} and particularly $PM_{2.5}$. The reason for this may be the sampling methodology used to derive these measurements and the sparsity of data.

With regard to $PM_{2.5}$, it is noted that there is a new NEPM for $PM_{2.5}$ with the goal to collect data to facilitate a review of the standard. As such, there is an expectation that the NPI should also provide $PM_{2.5}$ emission data. An argument against this, aside from the uncertainty in fugitive $PM_{2.5}$ emissions, is that much of the $PM_{2.5}$ is formed from gas to particle conversions, forming sulphate and nitrate aerosols. This is highlighted in **Figure 12** where it is considered that up to 90% of the $PM_{2.5}$ measured in rural US areas are from non-crustal sources. Therefore, if an accurate $PM_{2.5}$ inventory is required, the issue of gas to particle conversion must be addressed.



- **Figure 12 Estimated annual $PM_{2.5}$ composition for the U.S. from Countess et al (2000)**

Based on the above it is recommended that:

R 6.1 Fugitive particulate matter $PM_{2.5}$ emissions should not be included in NPI reporting at this stage. There is a need to resolve the various issues with estimating $PM_{2.5}$ from fugitive crustal sources, with the $PM_{2.5}$ emission factors likely to be revised substantially in the next few years. Secondly, fugitive $PM_{2.5}$ from crustal sources are a small component of overall $PM_{2.5}$ emissions, based on US work, with the majority of $PM_{2.5}$ originating from gas to particle conversion or from sources not covered in the current NPI reporting. Additionally, there are a number of issues in the TSP and PM_{10} emission estimation methods that should be resolved as a higher priority.

R 6.2 With the large amount of knowledge available on wind erosion (from wind erosion scientists) it is recommended that their work and models be utilised to develop more realistic particle size distributions at emission. It is considered that particle size distributions may have some wind speed dependence, and should not be a constant factor as in the current AP-42.

7. Metal Speciation

Metal speciation of fugitive particulate matter is determined typically (Watson et al, 1998) using either:

- Source dominated samples, where the samples are generally taken close to the source with the measured particulate matter sample dominated by the source in question; or
- Grab sampling and re-suspension in the laboratory. Here the samples are collected by sweeping, shovelling or vacuuming the area of interest with five to ten samples from the same source averaged to obtain a representative source profile. *"This method is semi-established, or at least as established as the chemical and physical analyses applied to it, because procedures are widely accepted and results are reproducible within a method, though not necessarily among methods. The main advantages of grab sampling and re-suspension are simplicity, reliability, and low cost"*. (Watson et al, 1998)

Speciation of particulate matter is required in cases where the composition of the processed material may be significantly different to that of the parent material. This can occur if the elemental composition of the material differs with particle size. For example, the majority of the large size fractions in iron ore are iron oxides, with impurities (comprising mainly silica and alumina) associated with the silt fraction. As particulate matter is generated from the silt fraction; particulate matter will have a higher proportion of the impurities and a lower fraction of iron than the bulk sample. For instance, in iron ore, the generated particulate matter may only have 50% Fe compared to the bulk ore with 65% Fe.

For particulate matter from wind erosion, the enrichment of nutrients and trace elements often exceeds a factor of three (Gupta et al, 1981). Raupach et al (1994) presented data for Australian soils with enrichment ratios of nitrogen and phosphorus (the ratio of the elemental composition less than 44 µm to the composition of the bulk samples) of around two for loamy soils and up to six and 19 for a coarse sandy soil.

Another example of enrichment occurs from particulate matter generated from drying areas of bauxite residue. In the drying process, sodium in the residue mud migrates to the surface and forms a white layer of sodium carbonate decahydrate. The sodium carbonate surfaces are very erodible and therefore, dependent on the fractional coverage and depth of these surfaces, will affect the composition of the particulate matter generated from the overall drying area.

7.1 Default NPI Speciation Provided

The NPI requires estimates of the TSP emissions in the fugitive dust. The NPI Mining Manual states that *"metal emissions can be estimated as a fraction of the TSP emissions, based on available assay data. Where no assay data or site-specific information is available for metals in TSP emissions, the default concentrations in Appendix D, Table B2 can be used*" (NPI, 2001). These default factors are provided for very broad classes such as basalt, granite, coal, Earth's crust, marine clays, marine carbonates, shale, limestone, sandstone and sediment. A summary of some of these classes and element concentrations are provided in **Table 7** and **Figure 13**.

The Aggregated Emissions from Paved and Unpaved Roads EET Manual (NPI, 1999b) lists a default speciation based on composite profiles for unpaved roads in the state of California (CARB, 1991). CARB has revised this speciation, with the new proposed speciation for Californian unpaved roads also listed in **Table 7**.

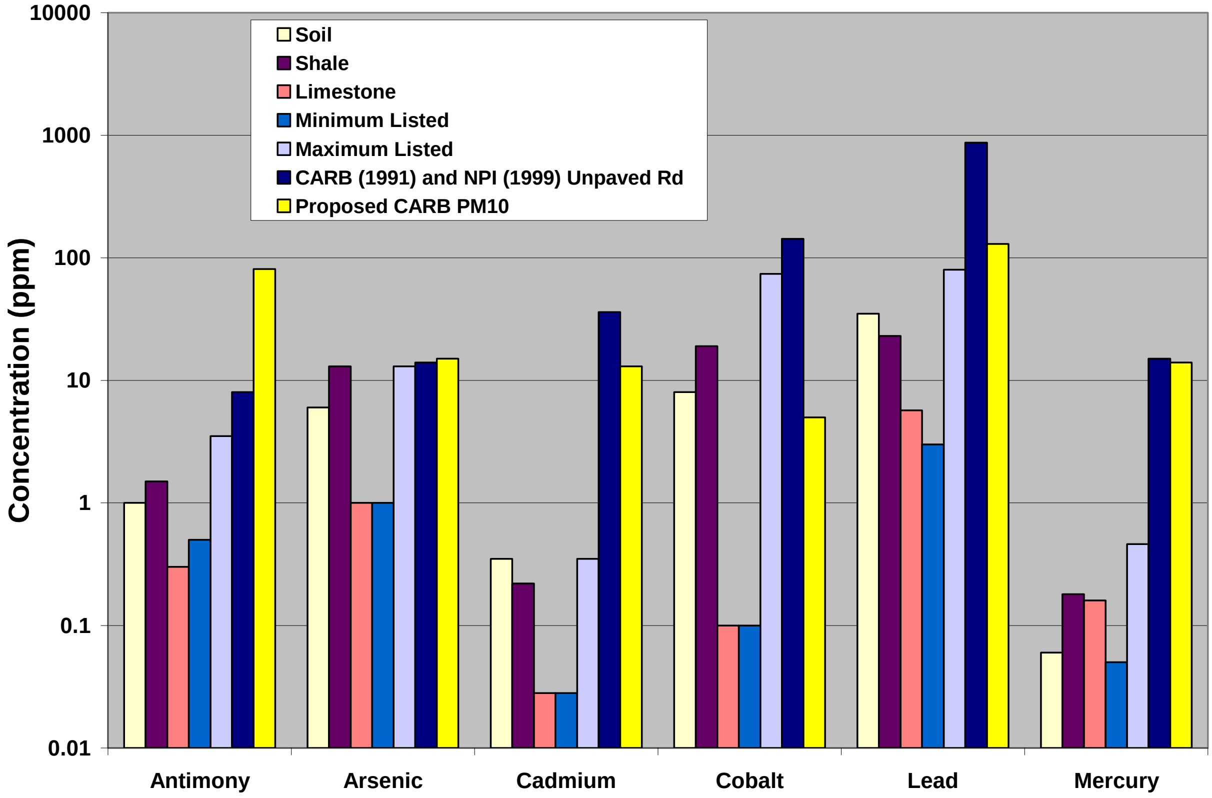
- **Table 7 Summary of metal speciation from the NPI Mining Manual and Aggregated Emissions from Paved and Unpaved Roads EET Manual**

Source	Antimony	Arsenic	Beryllium	Cadmium	Cobalt	Lead	Mercury	Selenium
NPI Mining Manual								
Coal	3.5	6.5	1	0.2	5.4	40	0.23	2.9
Soil	1	6	0.3	0.35	8	35	0.06	7
Earth's Crust	0.2	1	2.6	0.11	20	14	0.05	0.05
Shale	1.5	13	3	0.22	19	23	0.18	0.5
Limestone	0.3	1	<1	0.028	0.1	5.7	0.16	0.03
Minimum Listed	0.5	1	<1	0.028	0.1	3	0.05	<0.01
Maximum Listed	3.5	13	3	0.35	74	80	0.46	7
CARB (1991) and *Aggregated Emissions from Paved and Unpaved Roads EET Manual* (1999)	8	14	Not given	36	143	870	15	1
Proposed Californian unpaved roads (% PM_{10})	81	15	Not given	13	5	130	14	3

Note: All concentrations are of the TSP fraction except the new CARB speciation which is the concentration within PM_{10}

A comparison between the different speciation values in **Table 7** indicates:

- Large changes in the new CARB speciation, with antimony increasing by 10 times from the 1991 CARB speciation, upon which the Aggregated Emissions from Paved and Unpaved Roads EET Manual is based. On the other hand, cobalt and lead decrease by 29 and 6.7 times respectively, with the large decrease in lead considered to be due to the change in petrol formulation, and
- Large differences between the speciation provided in the NPI Mining Manual and Aggregated Emissions from Paved and Unpaved Roads EET Manual. For example cadmium and mercury in the NPI unpaved road emissions are higher by 103 and 33 times any of the speciation provided for any of the material classes provided in the NPI Mining Manual.



- **Figure 13 Comparison of selected metal concentrations in the NPI Mining Manual, Aggregated Emissions from Paved and Unpaved Roads EET Manual and new CARB speciation for Californian unpaved roads**

7.2 Recommendations

Upon review of metal speciation data, large variation in default metal speciation is revealed. There seems to be little or no publicly available Australian speciation data, and the NPI Mining Manual broad category speciation appears to be of little relevance. The review also suggests that "metal emissions" are potentially large. As such, the following are recommended to develop local speciation for use in the EET manuals:

R 7.1 Collate and review available metal speciation undertaken by different mining sectors to determine if sector based default factors can be developed. The speciations should preferably be for the silt fraction or even dust fraction and not the bulk ore;

R 7.2 If insufficient quality data is available from *R 7.1*, it is recommended that the NPI coordinate a study to obtain particulate matter speciation for fugitive particulate matter sources from mining activities within Australia. Such a study should involve:

- Coordinating particulate matter samples taken from representative mining sectors with the samples sent to a central laboratory for analysis. It is considered that coordinating one laboratory with the samples processed in a batch should achieve cost reductions and ensure consistency and quality of the data;
- Sampling sources from the surfaces of unpaved roads, wind erosion of stockpile areas and "tailings areas" using standard sampling techniques for roads and other areas. Unpaved and paved road areas should be composites of a facility's roads weighted by their contribution to particulate matter emissions or split into areas adjacent to stockpiles and elsewhere. This would provide representative road surfaces where there is deposition of ore and therefore potential enhancement of metals derived from the ore body. It is also suggested that analysis be conducted on the parent material to determine the potential enrichment for the metals;
- Conducting the analysis in a laboratory through sieving, re-suspension of the particulate matter and then sampling with the selected particle size sampler as described by Watson et al (1998). This procedure is recommended as this method is considered easier, subject to less interference from other particulate matter sources and more cost effective than sampling with a high volume air sampler immediately downwind of such sources.
- Sampling of mining sectors should include, but not be limited to iron ore, gold, quarrying, mineral sand and bauxite (including refineries). It is suggested that the size fraction for sampling should be PM_{10} to be consistent with CARB. Additionally, as this is between the $PM_{2.5}$ and TSP fractions, the speciation should not be too dissimilar to either of these size fractions; and
- Analysis of the full range of metals in the NPI list, and any others recorded by standard analytical methods as detailed in Chow and Watson (1998), with method detection limits below 0.01 ppm.

R 7.3 The NPI program consider undertaking testing for public unpaved roads at the same time as the testing in Recommendation 7.2. Such testing could involve sampling up to five representative unpaved road surfaces in each State. In Western Australia, this could include a typical Pilbara road, a coastal limestone-based road, a typical Wheatbelt road etc. This would significantly improve unpaved road metal speciation and would also provide data for comparison to mining road speciation. It is noted that in the Bunbury airshed study (SKM, 2003) unpaved/paved roads were estimated to contribute 85% of the PM_{10} emissions and over 73% of the emission for the 11 metals provided with default speciations.

8. Prioritising Particulate Matter Issues

This section provides a ranking of the fugitive particulate matter ($PM_{2.5}$, PM_{10}, TSP) and metal and metal compound EETs in terms of priority for additional work to improve their accuracy.

Though the prioritising was requested in terms of accuracy only, the prioritising in this study has also included the size of the source as a criterion. As such, the ranking has been conducted based on the size of the emissions, EF accuracy and control factor accuracy. This approach differs to that typically used in the US where prioritising is often undertaken in terms of the emission impacts on the community or to its contribution to causing non-compliance to their National Air Quality Standards. For this study, no consideration to the relative impact on the environment or public health and welfare is given, though the magnitude of the emissions will to some degree be related to offsite impacts.

The emissions have been ranked in **Table 8** to give the perceived accuracy of the current EETs and the magnitude of the sources. This follows the approach used in California as presented in Gaffney (2004) where the sources were prioritised by primary source magnitude, emission factor quality, activity and secondary scores of speciation data, spatial data and monthly variation quality (all with a weighting of 1/3 of the primary categories).

- **Table 8 Prioritising NPI EETs**

Source	Source Magnitude	EF Accuracy	Default EF Accuracy	Control Factor Accuracy	Activity Data	Metal Speciation	Total of Source Magnitude and EF Accuracy
Blasting	3	5	N/A	N/A	2	3	8
Crushing and Screening	3	4	4	3	2	3	7
Unpaved Roads	4	4	5	4	2	4	8
Wind Erosion	5	5	5	4	3	4	10
Material Handling	4	4	4	3	3	3	8
Average All Sources	3.8	4.4	4.5	3.4	2.4	3.4	8.2
Scale	**5 = most important**	**5 = v low accuracy**	**5 = v low accuracy**	**5 = v low accuracy 1= accurate**	**5 = v hard to quantify**	**5 low accuracy or data**	

Notes: the values are for the current NPI Mining Manual

The scores in **Table 8** were based on:

- Source Magnitude: This was estimated from a survey of several of the NPI reporters in Western Australia who specified the relative contributions to their NPI estimates as presented in **Figure 14**. This indicates that wind erosion and material handling operations were major sources, followed by unpaved roads and then blasting. Unpaved roads have been given a weighting of 4 given that USEPA (1998) found that haul road emissions were the largest source from western surface coal mines and, as such, were targeted by the USEPA in the nineties for revision of the emission factors (page 11-9-8, USEPA, 1998).

- Emission Factor Accuracy: The ranking of the emission factor accuracy is based on the findings in this report, which consider blasting and wind erosion to be very approximate, though all factors are considered to have a significant degree of uncertainty.
- Default Emission Factor Accuracy: Unpaved road and wind erosion are considered to have very low accuracy as they are based on very site-specific data, but have been recommended as defaults for all mines and climates within Australia.
- Control Factor Accuracy: The control factor accuracy (as noted in **Section 5.1.6**) is very dated, with very approximate control factors given for control by water cannon of wind erosion and for controls for road particulate matter suppression with no account for hyper-saline water control.
- Activity Data (how often a process occurs). For most activities, this data is considered reasonably well known or estimated. However, classifying areas that may be eroded by wind erosion is considered to be very subjective, with the interpretation of control factors also uncertain to a degree.
- Metal Speciation: Metal speciation is considered to be potentially inaccurate due to the large variations that can occur on a mine site. In addition, road particulate matter could be a mixture of ore and background soil type and the speciation of the particulate matter can be quite different to the bulk ore or overburden.

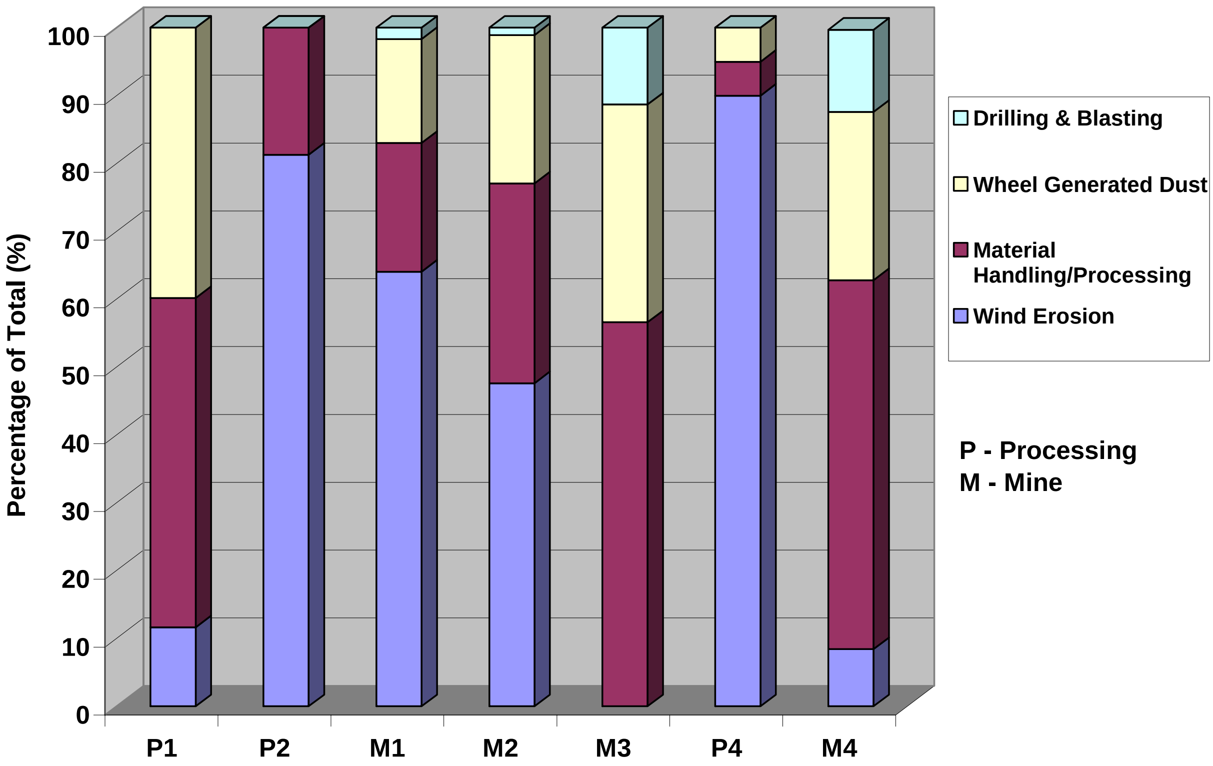
The results of the ranking (based on size of the emissions, emission factor accuracy and control factor accuracy), indicates that wind erosion factors, followed by unpaved roads, blasting and material handling are the areas which require greatest attention.

8.1 Comparison to Survey Respondents

The survey undertaken as part of this project (SKM, 2004b) was intended to provide an indication of the issues in terms of the methodologies used. It was not intended to rank the sources. In terms of the overall methods, the survey indicated that, in decreasing order of importance, the most significant issues for the respondents were:

- Accuracy of the reported emissions (average of 4.2 out of 5);
- Accuracy of default emissions and/or parameters (average of 4);
- Followed, with an average of 3.9, by:
  - Wind erosion particulate matter estimates;
  - The fact that the methods do not account for differences between source emissions and particulate matter that crosses the boundary; and
  - The accuracy of the control factors.

The survey, though not set in the same terms, indicates general agreement with the issues, with wind erosion highlighted in the survey as the only specific source.



- **Figure 14 Percentage of fugitive particulate matter emissions by various categories for Mines and Mining and Processing facilities such as refineries**

9. Conclusion and Recommendations

9.1 General Comments

It is considered that particulate matter emission sections included in the NPI Mining Manual and the current draft of the NPI Fugitive Emissions Manual are generally not well written or documented, with many of the emission factors in need of revision.

Therefore, it is recommended that:

1) As a priority, the draft NPI Fugitive Emissions Manual should be rewritten to incorporate the changes recommended in this report. This will involve incorporating the newer AP-42 equations and can be undertaken relatively quickly;
2) Individual default factors should be removed where possible with only the emission equation supplied, or the equation and a range of defaults. This is necessary because individual defaults on occasions may not be representative of the range of conditions that can occur within the mining industry. Examples of this are for unpaved roads and wind erosion emissions.
3) A number of actions and studies be undertaken to obtain/collate data to improve the factors for the Australian situation. It is recommended that, if funding permits, these studies be conducted with any resultant improvements to estimation techniques being added to future versions of relevant EET Manuals.

It is considered that the general poor state of the current NPI Mining Manual is due the lack of available funding and the lack of peer review before its release. It is suggested that to assist this process, industry should have a much greater role in the work and funding of the mining EETs. An example of successful industry involvement is the role of the Electricity Supply Association of Australia in updating the EET Manual Fossil Fuel Electric Power Generation (version 2.3) and the mineral sand industry's involvement with the Minerals Sands Mining and Processing EET Manual (version 1.0). To assist in any review, it is recommended that revisions to Manuals should involve at least an independent review, possibly including an international expert in the area.

With regards to the update it is noted that there appears to be some work in the U.S. to improve many of the factors. A recent survey by the U.S. on AP-42 concluded that:

"Existing emission factors should be updated and more factors are needed where gaps currently exist. In many cases, the new factors requested were related to more speciation (particle size for PM, specific chemicals for air toxics and VOCs). Attention also needs to be given to the development of regional factors and factors for unique events and circumstances." USEPA (2004a).

In the western States of the US, the WRAP is developing a wind erosion methodology for the regional scale and has commissioned a contract to develop a fugitive particulate matter handbook and website.

This will be a compilation of emission estimation methods and control techniques on paved roads, unpaved roads, materials handling, wind erosion from material storage piles, construction and demolition, open area wind erosion, agricultural tilling and agricultural wind erosion, and is due for release in early 2005. As such, it is expected that there will be some revisions or new methods available for some categories in the near future.

9.2 Specific Recommendations

The following sections provide a summary of specific recommendations.

Vehicle Emissions - Unpaved Roads

R5.1 Incorporate the recent December 2003 USEPA AP-42 unpaved road equations into the NPI Fugitive Emissions Manual. It is noted that the draft version of the NPI Fugitive Emissions Manual has a number of errors that require correction, such as deletion of the soil moisture table.

R 5.2 Single default emission factors should not be provided as there can be large variations between the vehicle fleets and road characteristics at different sites. If defaults are to be provided they should be given for the various combinations of typical vehicle fleets (for example vehicle usage on haul roads at a mine site and a typical light vehicle fleet) and for typical uncontrolled and controlled roads. To assist companies in estimating the appropriate emission factor for their site, it is recommended that the NPI Fugitive Emissions Manual include a compilation of typical silt contents, as well as moisture contents for various Australian industry groups, as per the USEPA guides.

R 5.3 Update the unpaved road control factor with separate methods for:

- Fresh water, using either:
  - The equation of Cowherd et al (1988). This will require mines to estimate the number of vehicle passes and watering rates on the various roads. Estimates of the hourly evaporation rate could be undertaken using annual evaporation estimates and converting these to a maximum hourly value using a multiplier as in Cowherd et al (1988); or
  - The current USEPA approach where moisture contents for the road in a controlled and uncontrolled state under typical traffic conditions are measured.
- Use of organic chemical suppressants, using for example the US AP-42 methodology; and
- Use of salts including the use of hyper-saline water. It is considered that test work, estimated at $20,000, is required to develop appropriate control factors.

R 5.4 Though not strictly applicable to the NPI Mining Manual, it is considered that the Aggregated Emissions from Paved and Unpaved Roads EET Manual should be updated to include the new

AP-42 equations, including a default moisture content of 1% (following the US NEI) and typical Australian data for road silt contents. This may involve a desktop study or in-field sampling.

Wind Erosion

R 5.5 The current default factor should be deleted. It is considered that emission estimates can be readily obtained with the current NPI equation and this should be used to take into account climate variations across Australia. This will result in some areas having emission factors that are twice as high as the current default with some areas having considerably lower emissions;

R 5.6 Though the current NPI equation is considered indicative only, there appears to be no ready replacement, with the existing AP-42 equation considered to be based on little data for non-coal mines and difficult to implement (e.g. estimation of threshold friction velocities). Therefore it is recommended that:

- The current NPI equation should be retained in the interim.
- The NPI coordinate with the US groups (USEPA and WRAPAIR) to determine and progress toward a new equation with more supporting studies for this.
- The NPI liaise with the wind erosion community within Australia to see if a more suitable equation or simple model for mines could be developed. Such work may include undertaking a single case study to verify the methodology or the development of portable wind tunnel methodology to determine relative erodibility potential of materials.

R 5.7 The NPI develops or commissions estimates for all fugitive particulate matter sources within Australia, such that the mining fugitive emissions can be placed in context, as is provided in the US NEI. At present in most regions of Australia, fugitive particulate matter from mining is presented as the only large source, with other larger sources of PM_{10} and “metals” such as from wind erosion of non mine areas, from agricultural activities and bush fires omitted. For wind erosion estimates it is recommended that the NPI liaise with those in the Australian Air Quality Forecasting System (AAQFS) who are currently evaluating a system that predicts PM_{10} wind erosion emissions and the resultant PM_{10} concentrations for Australia. Alternatively, a system using the CARB approach as used in the Pilbara and Bunbury airsheds (SKM, 2003 and SKM, 2003b) and recently undertaken for Victoria (Ng, 2004) could be used. The use of a national approach would also have the advantage of providing consistency across Australia. Other sources of particulate matter from agricultural practices and fires could also be coordinated at a national or at least state level. PM_{10} estimates from fires could be obtained in conjunction with the national greenhouse gas emission estimates as they both require fuel loading and the area burned**.** The development of estimates for all fugitive particulate matter sources within Australia has the potential to cost around $100,000.

R 5.8 Alternative methods, such as using validated particulate matter dispersion models, should be highlighted as an acceptable alternative to the AP-42 equation. Such a method can consist of well-sited ambient monitors that are free from confounding sources, along with the use of back-calculation techniques involving dispersion models. It is recommended that all such studies have an independent technical review to ensure that the estimates are acceptable. This method would initially require a statement in the manual indicating that is an acceptable option, though requiring agreement on a case by case basis with the relevant State NPI department.

R 5.9 Wind erosion control factors need to be improved to provide more detail on how to classify surface types. A possible method may be to supply photographic examples of bare areas as per the method used in RWEQ. This is recommended as greater than a factor of two variation can occur due to the subjective interpretation involved in classifying the amount of erodible area and the relevant control factors for a particular site.

R 5.10 A wider range of control factors is needed for water cannon control to give credit to facilities with well designed and maintained systems. To undertake this, a review of water cannon control is recommended as a first step. The authors are aware of one study currently underway to determine control factors for water cannon.

Material Handling

R 5.11 For loading/unloading trucks it is recommended that, as a first step, an in-depth review of the derivation of the USEPA AP-42 load-in/load-out emission equation is required to resolve the apparent large underestimation in emissions when using this equation, compared to that measured at Australian mines.

R 5.12 For transfers, reclaimers and stackers, it is recommended that, as per loading/unloading trucks a review of the derivation of the USEPA load-in/load-out equations be undertaken to resolve the apparent underestimation of emissions. As an interim measure it is recommended that the defaults be retained but usage of the equation be dissuaded.

R 5.13 When considering the moisture content of ores, as a second higher level of complexity to using the default 4% cut off between high and low moisture content ores, mines should be encouraged to use the rotating drum test to classify the dustiness of the ore as either high or low moisture. In general, the available data supports the default 4% cut off but the limited test work presented in this report indicates that thresholds may vary between at least 3 to 5.5%.

R 5.14 As a low priority task, it is recommended that dustiness tests be used to account for the dustiness of the ores as a function of moisture. It is considered that this captures the true dustiness of the ore rather than trying to fit a simple universal moisture and silt particulate matter relationship to the ore as is used for moisture in the current and both moisture and silt in the older AP-42 material handling equations.

R 5.15 For crushing emissions, the new AP-42 stone crushing and quarrying factors be included as the defaults for the stone crushing and quarrying industry.

R 5.16 For screening emissions, the emission factors should be updated with those in the new AP-42 crushed stone processing and pulverised minerals guide. For primary, secondary and tertiary screening at stone processing and quarrying operations the AP-42 "screening" factors are applicable, whilst for iron ore re-screening the "fines screening" factor is considered applicable.

Blasting

R 5.17 Though there is little support for the application of the current AP-42 blasting equation, and despite it being dropped from AP-42 Crushed Stone Processing and Pulverized Mineral Processing guide, it is recommended that:

- The new AP-42 equation be retained in the interim;
- NPI liaise with the USEPA to investigate further work planned to improve this factor; and
- NPI investigate the feasibility of conducting Australian testing using aircraft to profile the particulate matter plume to derive estimates. Such methods have been used for other aerosols such as smoke plumes from fires and industrial sources using the Flinders University aircraft and CSIRO.

Issue of Particulate Removal

R 5.18 It is recommended that the NPI review the issue of particulate removal, noting that depletion for pit retention is incorporated but other removal mechanisms, such as vegetation belts, are not. In the case of mines, it is considered that the pit retentions are very indicative and that guidance should be provided so mines can develop site-specific factors using a model such as ISC3.

Particulate Size Issues

R 6.1 Fugitive particulate matter $PM_{2.5}$ emissions should not be included in NPI reporting at this stage. There is a need to resolve the various issues with estimating $PM_{2.5}$ from fugitive crustal sources, with the $PM_{2.5}$ emission factors likely to be revised substantially in the next few years. Secondly, fugitive $PM_{2.5}$ from crustal sources are a small component of overall $PM_{2.5}$ emissions, based on US work, with the majority of $PM_{2.5}$ originating from gas to particle conversion or from sources not covered in the current NPI reporting. Additionally, there are a number of issues in the TSP and PM_{10} emission estimation methods that should be resolved as a higher priority.

R 6.2 With the large amount of knowledge available on wind erosion (from wind erosion scientists) it is recommended that their work and models be utilised to develop more realistic particle size distributions at emission. It is considered that particle size distributions may have some wind speed dependence, and should not be a constant factor as in the current AP-42.

Metal Speciation

R 7.1 Collate and review available metal speciation undertaken by different mining sectors to determine if sector based default factors can be developed. The speciations should preferably be for the silt fraction or even dust fraction and not the bulk ore;

R 7.2 If insufficient quality data is available from *R 7.1*, it is recommended that the NPI coordinate a study to obtain particulate matter speciation for fugitive particulate matter sources from mining activities within Australia. Such a study should involve:

- Coordinating particulate matter samples taken from representative mining sectors with the samples sent to a central laboratory for analysis. It is considered that coordinating one laboratory with the samples processed in a batch should achieve cost reductions and ensure consistency and quality of the data;
- Sampling sources from the surfaces of unpaved roads, wind erosion of stockpile areas and "tailings areas" using standard sampling techniques for roads and other areas. Unpaved and paved road areas should be composites of a facility's roads weighted by their contribution to particulate matter emissions or split into areas adjacent to stockpiles and elsewhere. This would provide representative road surfaces where there is deposition of ore and therefore potential enhancement of metals derived from the ore body. It is also suggested that analysis be conducted on the parent material to determine the potential enrichment for the metals;
- Conducting the analysis in a laboratory through sieving, re-suspension of the particulate matter and then sampling with the selected particle size sampler as described by Watson et al (1998). This procedure is recommended as this method is considered easier, subject to less interference from other particulate matter sources and more cost effective than sampling with a high volume air sampler immediately downwind of such sources.
- Sampling of mining sectors should include, but not be limited to iron ore, gold, quarrying, mineral sand and bauxite (including refineries). It is suggested that the size fraction for sampling should be PM_{10} to be consistent with CARB. Additionally, as this is between the $PM_{2.5}$ and TSP fractions, the speciation should not be too dissimilar to either of these size fractions; and
- Analysis of the full range of metals in the NPI list, and any others recorded by standard analytical methods as detailed in Chow and Watson (1998), with method detection limits below 0.01 ppm.

R 7.3 The NPI program consider undertaking testing for public unpaved roads at the same time as the testing in Recommendation 7.2. Such testing could involve sampling up to five representative unpaved road surfaces in each State. In Western Australia, this could include a typical Pilbara road, a coastal limestone-based road, a typical Wheatbelt road etc. This would significantly improve unpaved road metal speciation and would also provide data for comparison to mining road speciation. It is noted that in the Bunbury airshed study (SKM, 2003) unpaved/paved roads were estimated to contribute 85% of the PM_{10} emissions and over 73% of the emission for the 11 metals provided with default speciations.

10. Glossary

AAQFS	Australian Air Quality Forecasting System
Aerodynamic diameter	The diameter of a sphere of density 1g/cm^3 that has the same aerodynamic properties as the particle being considered
AP-42	USEPA's emission factor publications, available on the internet at http://www.epa.gov/ttn/chief/ap42/
ANZSIC	Australia New Zealand Standard Industry Classification
AUSPLUME	Gaussian Plume dispersion model developed in Australia by the Victorian EPA
CAAQES	Centre for Agricultural and Air Quality Engineering and Science (Texas A & M University)
CARB	California Air Resources Board
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Criteria pollutants	A group of six common air pollutants that are regulated under the US Clean Air Act. They include ozone, lead, nitrogen oxide, sulfur dioxide, carbon monoxide, and particulate matter.
de minimus amount	An amount that is so minor that it can disregarded. This in some regulations is defined as a fixed quantity.
DoE	Western Australian Department of Environment
EET	Emissions Estimation Technique (coordinated by Environment Australia)
EF	Emission Factor
EPA	Environmental Protection Authority
EPHC	Environmental Protection and Heritage Council
EPRCA	*Emergency Planning and the Community Right-to-Know Act*
Fetch Length	An area of the surface over which a wind with a constant direction and speed is blowing
Fugitive Particulate Matter	Solid airborne particulate matter emissions, which cannot be reasonably collected and are passed through a stack, chimney, vent or equivalent opening. These include sources such as wind erosion, wheel generated dust, road repairs, blasting, storage or

	transportation of particulate matter, sandblasting, tilling and feedlots.
HAP	Hazardous Air Pollutants. These are pollutants defined in the United States Clean Air Act that are not covered by ambient air quality standards but may present a threat of adverse impact to human health and the environment
ISC3	Industrial Source Complex Model. The United States Gaussian plume model
IWEMS	Integrated Wind Erosion Modelling System
MMD	Mass mean diameter
MOE	Ontario Ministry of Environment
MPO	Manufactured, processed or otherwise used
MRI	Midwest Research Institute
NAPAP	National Acid Precipitation Assessment Program, USA
NEI	National Emissions Inventory. Prepared by the USEPA
NEPM	National Environmental Protection Measure
NERDDC	National Energy Research Development and Demonstration Council
NO_x	Nitrogen oxides
NPI	National Pollutant Inventory. Australia's public database of pollutant emissions
NPRI	Canada's National Pollutant Release Inventory
NSW	New South Wales
NSWMC	New South Wales Mining Council
NTI	National Toxics Inventory
OHSA	Occupational Health and Safety Act
PBT	Persistent, bio-accumulative and toxic chemicals
PM	Particulate Matter
PM_x	Particulate Matter with a diameter of less than x μm

Quality Rating	The US EPA quality rating system for emission factors. This rating system varies from; A: excellent; B: above average; C: average; D: below average; and E: poor.
RWEQ	Revised Wind Erosion Equation. From Fryrear et al. (1998)
SKM	Sinclair Knight Merz
SPCC	State Pollution Control Commission
TPM	Total Particulate Matter
TRI	The USA's Toxics Release Inventory
TSP	Total Suspended Particulate. Includes particles less than 50 micrometers in diameter
USEPA	United States Environmental Protection Agency
US NEI	United States National Emissions Inventory
US TRI	United States' Toxic Release Inventory
VOC	Volatile organic compound
VKT	Vehicle Kilometres Travelled
VMT	Vehicle Miles Travelled
WA	Western Australia
WA DEP	Western Australian Department of Environmental Protection
WEPS	Wind Erosion Prediction System. Developed by Hagen et al (1995)
WEQ	Wind Erosion Equation. Developed by Woodruff and Siddoway (1965)
WRAP	Western Regional Air Partnership (Collaborative effort of tribal governments, state governments and various federal agencies to in the western half of the United States).

Table of Nomenclature

A	area of blast (m^2)
C	**As used in Equation 5.9:** emission factor for 1980s vehicle fleet exhaust, brake wear and tyre wear (kg/VKT)
C	**As used in Equation 5.11:** average control efficiency percent (%)
D	blast depth (m)
d	average hourly traffic rate (hr^{-1})
f	percentage of time the unobstructed wind at the mean pile height exceeds 5.4 m/s
i	application intensity (L/m^2)
k	**As used in equation 5.14:** constant
k	**As used in all other equations:** aerodynamic particle size multiplier
L	silt loading (g/m^2)
M	material moisture content (%)
M_{dry}	surface moisture under dry worst case conditions (%)
p	number of days with >= 0.25mm (0.01 in) precipitation
P	potential average daytime evaporation rate (mm/hr)
s	silt content of the road (%)
S	average vehicle speed (km/hr)
t	time between applications
u_*	friction velocity (m/s), and
u_{*t}	threshold friction velocity (m/s)
U	mean wind speed
w	number of wheels
W	mean vehicle weight (tonnes)
WS	wind speed (m/s)
WS_o	threshold for particulate matter lift off (m/s)
Y	dumping device capacity (m^3)

11. References

Air Noise Environment, 2003. *Improving Particulate Emissions Estimation.*. Prepared for Australian Association Research Programme, April 2003.

Alfaro, S, C, Gomes, L. 2001. *Modelling mineral aerosol production by wind erosion: Emission intensities and aerosol size distribution in source areas.* J. Geophysical Res, 106, D16, 18,075-18,084.

Axetell K. 1978. *Survey of Fugitive Dust from Coal mines.* EPA-908/1/-78-003, U.S. Environmental Protection Agency, Denver, CO, February 1978.

Axetell, C. and Cowherd, C 1981. *Improved emission factors for fugitive dust from western surface coal mining sources.* 2 Volumes, EPA contract N0. 68-03-2924, PEDCo Environmental, Inc., Kansas City, MO, July 1981.

Australian Standard 2000. Coal Preparation. Part C: Determination of dust/moisture relationship for coal. AS4156.6-2000.

Barnard, W.R. and Stewart, M.A. 1992. *Improved fugitive dust PM_{10} emissions estimates for trends. Proceedings, Emission Inventory Issues in the 1990s.* Air & Waste Management Association, Pittsburgh, PA, pp. 673-684.

Buonicore, A. J. and Davis, W. T. 1992. *Air Pollution Engineering Manual.* Air & Waste Management Association (US), Van Nostrand Reinhold, New York.

Californian Air Resources Board (CARB). 1997. *Section 7.11 Supplemental Documentation for Windblown dust - Agricultural Lands. April 1977.* California Environmental Protection Agency Air Resources Board.

Californian Air Resources Board (CARB) 1991. Identification *of Particulate Matter Species Profile.* CARB Speciation Manual, 2nd ed, Vol 1, Californian Air Resources Board, California, USA.

California Air Resources Board (CARB). 2004. Unpaved road dust speciation from spreadsheet pavenuroaddust.xls from http://www.arb.ca.gov/ei/speciate/pavedunroaddust.xls

Carras, J, N. Riley, K.W, Zegellin, S.J. and Barret, G.J. 1999. *Use of a portable micro-wind tunnel to measure the dust yield potential from mineral tailings and other surfaces.* 1999 Minerals Council of Australia Workshop.

Chow, J and Watson, J. 1998. *Guideline on Speciated Particulate Monitoring.* Desert Research Institute prepared for Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency. Research Triangle Park, NC 27711.

Coffey, P. and Evans, N. 2000. *Estimation of fugitive PM_{10} dust emissions from exposed tailings by monitoring & modelling*. In Conference Proceedings of the 15th International Clean Air & Environment Conference. Sydney Australia, 26-30 November 2000.

Coffey. 1999. Department of Environmental Protection. National Pollutant Inventory Kalgoorlie Mining Trial Aggregated Emissions Study. Report prepared for the Department of Environmental Protection, Perth.

Countess, R, J. 2001. *Development of a $PM_{2.5}$ Emissions Inventory for the South Coast Air Basin. J. Air & Waste Manage.* Assoc. 49, 125-132.

Countess, R.W. Barbard C, Claiborn, C. Gillette, D. Latimer, D. Pace, T. Watson, J. 2001. *Methodology for estimating windblown and mechanically resuspended road dust emissions applicable for regional scale air quality modelling*. Final Report prepared for Western Governor's Association, Electronically published at http://www.wrapair.org/reports/Fugitive Dust Final.doc. April 2001

Countess, R.W. Barbard C, Claiborn, C. Gillette, D. Pace, T. Vimont, J. and Watson, J. 2002. *A review and update of fugitive dust emission estimation methods*. Final Report prepared for Western Governor's Association, Electronically published at http://www.wrapair.org/reports/Dust%20Expert%20Panel%20Follow-Up-Report.pdf. November 2002

Cowherd, C., Jr. Axetell, K. Guenther, M. and Jutze, G.A. 1974. Development of emission factors for fugitive dust sources. Midwest Research Institute, Kansas City, Mo. Prepared for the Environmental Protection Agency, Research Triangle Park, N.C. under Contract No 68-02-0619. Publication No. EPA-450/3-74-037. June 1974.

Cowherd, C.Jr. 1983. *A new approach to estimating wind generated emissions from coal storage piles.* Presented at the APCA specialty conference on Fugitive dust Issues in the Coal Use Cycle, Pittsburg, PA, April 1983.

Cowherd, C. 1986. *Memorandum from Chatten Cowherd, MRI, to James Southerland, EPA, June 1986.* as presented in Appendix E of MRI (1998). Revision of Emission Factors for AP-42 Section 11.9. Western Surface Coal Mining. Revised Final Report for U.S. Environmental Protection Agency. EPA Contract 68-D2-0159. September 1998.

Cowherd, C, Muleski G,E and Kinsey, J.S. 1998. *Control of open fugitive dust sources*. EPA-450/3-88-008. U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

ENVIRON, 2004. *Final Report. Determining Fugitive Dust Emissions from Wind Erosion*, prepared for Western Governor's Association.

Environment Canada (EC), 2002. Guide for reporting to the National Pollutant Inventory. 2002. Available at http://www.ec.gc.ca/pdb/npri/npri_home_e.cfm

Etyemezian, V, Gillies, J, Kuhns, H, Nikoloic D, Watson, J, Veranth, J, Laban, R, Seshadri, G and Gillete, D. 2003. *Field Testing and evaluation of dust deposition and removal mechanisms: Final Report.* DRI Final Report prepared for the WESTAR council 1/1/03.

Fryrear, D.W., Bilbro, J.D., Saleh, A., Schomberg, H., Stout, J., and Zobeck, T.M. (1998). *RWEQ: Improved with erosion technology.* J. Soil Water Conserv. 55, 183-189.

Gillette, D.A. and Passi, R. 1988. *Modeling dust emission caused by wind erosion*. J. Geophys. Res. 93, 14233-14242.

Gupta, J.P, Aggarwal, R.K. and Rajkhy, N.P. 1981. *Soil erosion by wind from bare sandy plains in western Rajasthan, India*. J. Arid. Env. 4, 15-20.

Hagen, L. 1995. *USDA wind erosion predictions system: Technical description: Introduction.* Proceedings, WEPP/WEPS Symposium, Des Moines, IA.

Holmes, N. 2004. Personnel communication with Nigel Holmes of Holmes Air Sciences, Sydney.

Holmes Air Sciences. 1998. *Review of Load Based Licensing Requirements and Exploration of Alternative Approaches*. Report to the Minerals' Council of NSW, April 1998.

Lee, S. Cope, M. and Hess, D. 2003. Forecasting wind-blown dust events with the Australian Air Quality Forecasting System. In National Clean Air Conference, Newcastle, Australia, 23-27 November.

Lee, S. Cope, M. Hess, D. and Burgers, M. 2004. *Forecasting wind blown dust events with the Australian Air Quality Forecasting System (AAQFS*). Wind-blown Dust Workshop - The emission, transport and impacts of wind-blown dust from soil erosion: modelling and observation 8-10 November 2004 at CSIRO Division of Atmospheric Research, Aspendale, Victoria, Australia.

Leys, J.F. Larney, F.J. Müller, J.F. Raupach, M.R., McTainsh, G.H. and Lynch, A.W. 1998. Anthropogenic dust and endosulfan emissions on a cotton farm in northern New South Wales, Australia. The Science of the Total Environment, 220, 55-70.

Leys, J,F, Strong C, McTainsh, G, H. Heidenreich, S, Pitts, O, and French, P. 2002. *Relative Dust Emission Estimated from a mini-wind tunnel*. In Lee J,A, and Zobeck T,NM, 2002. Proceedings of ICAR5/GCTE-SEN Joint Conference, International Centre for Arid and Semiarid Lands Studies, Texas Tech University, Lubbock, Texas, USA, p117-121.

Lu, M. 1997. *Dustiness of coal shipped in China*. Bulk Solids Handling, vol 17, No. 4, 541-547.

Lu, H. and Shao, Y. 2001. *Toward quantitative prediction of dust storms: an integrated wind erosion modelling system and its applications.* Env. Modelling & Software, 16, 233-249.

Krayer, W.R, and Marshall, R.D. 1992. *Gust factors applied to Hurricane Winds.* Bulletin American Meteorological Society, 73, 613-617.

MacDougall, C. R. and Uhl. M.F. 2002. *Empirical method for determining Fugitive dust emissions from wind erosion of vacant land: "The MacDougall Method".* Clark County Department of air Quality Management.

MacDougall, B. 2004. *Personnel communication with Bryn MacDougall of Western Mining Corporation,* Belmont., Perth.

Mining Association of Canada (MAC), 2004. *Mining Association of Canada Guide for Completing the 2003 National Pollutant Release Inventory (NPRI).* Available at http://www.mining.ca/english/publications/index.html

Midwest Research Institute (MRI), 1998. Emission *factor documentation for AP-42. Section 13.2.2. Unpaved Roads. Final Report.* Report prepared for U.S. Environmental Protection Agency. September 1998.

National Energy Research Development and Demonstration Council (NERDDC), 1988, *Air Pollution from Surface Coal Mining: Volume 2 Emission Factors and Model Refinement*, Prepared by Dames & Moore 1988 for NERDDC, NERDDC Project Number 921.

National Pollutant Inventory (NPI). 1999a. *Emission Estimation Technique Manual for Mining, Version 1.0, (March 1999*). (part of the Mining Handbook)

National Pollutant Inventory (NPI). 1999b. *Emission Estimation Technique Manual for Aggregated Emissions from Paved and Unpaved Roads (September 1999*). Available by download from the NPI website at: http://www.npi.gov.au/handbooks/aedmanuals/pavedunpaved_ff.html

National Pollutant Inventory (NPI). 1999c. *Emission Estimation Technique Manual for Fugitive Emissions (December 1999).* Available by download from the NPI website at: http://www.npi.gov.au/handbooks/approved_handbooks/pubs/ffugitive.pdf

National Pollutant Inventory (NPI). 2000. *Emission Estimation Technique Manual for Mining, Version 2.0*, (part of the Mining Handbook)

National Pollutant Inventory (NPI). 2001. *Emission Estimation Technique Manual for Mining, Version 2.3, (5 December 2001) (part of the Mining Handbook).* Available by download from the NPI website at: http://www.npi.gov.au/handbooks/approved_handbooks/pubs/mining.pdf

National Pollutant Inventory (NPI). 2002. *Emission Estimation Technique Manual for Fugitive Emissions* (September 2002). Draft in preparation.

NSW Minerals Council. 2000. Particulate Matter and Mining. A NSW Minerals Council Technical Paper. Interim Report. 19 July 2000.

Ng, Y.L., 2004. *Estimating annual average windblown dust emissions from agricultural lands and unpaved roads* . Wind-blown Dust Workshop - the emission, transport and impacts of wind-blown dust from soil erosion: modelling and observation 8-10 November 2004 at Division of CSIRO Atmospheric Research, Aspendale, Victoria, Australia.

Pace, T. G. 2004. *Emission Inventory Training Course. Session VII. Reconciling Fugitive Dust. Emissions with Ambient Data*. USEPA. Denver, CO March, 2004. Available at http://www.westar.org/downloads.html

Pitts O. 2000. *Fugitive PM_{10} Emission Factors*. In Conference Proceedings of the 15th International Clean Air & Environmental Conference. Sydney Australia, 26-30 November 2000.

Queensland EPA (2005). http://www.epa.qld.gov.au/environmental_management/air/air_quality_monitoring/air_pollutants/airborne_particulates (accessed 11th January, 2005)

Raupach, M, McTainsh, G and Leys, J. 1994. *Estimates of dust mass in recent major Australian dust storms.* Aust. J. Soil and Water Conservation, vol 7, No 3, 20-24.

Scott, W.D. 1994. *Wind erosion of residue waste. Part 1. Using the wind profile to characterise wind erosion*. Catena, 21, 291-203.

Shao, Y., Raupach, M.R., and Leys J.F. 1996. *A model for predicting aeolian sand drift and dust entrainment on scales from paddock to region*. Aust. J. Soils Res., 34, 309-342.

Shao, Y and Leslie, L.M. 1997. *Wind erosion prediction over the Australian continent.* J. of Geophysical Res. 102, 30,091-30,105.

Shao, Y. Yang, Y, Wang, J. Song, Z, Leslie, L.M. Dong, C. Zhang, Z. Lin, Z. Kanai, Y. Yabuki, S and Chun, Y. 2003. Northeast Asian dust storms: real-time numerical prediction and validation. J. Geophysical Res. 108, D22, 4691

Shaw, B.W, Lacey, R,E. Capareda, S. Parnell, C.B. Wanjura, J. Wang, L. and Faulkner, W. 2004. *Performance of Particulate Matter Samplers When Exposed to Coarse Fraction Aerosol Particles.* Power point presentation available at BF2004ASAE.ppt (http://caaqes.tamu.edu/ Center for Agricultural Air Quality. Engineering and Science Biological and Agricultural Engineering Department Texas A&M University

Sinclair Knight Merz (SKM), 1997. *Dust Assessment - Pinjarra Bauxite Stockpile Area*. Report prepared for Alcoa of Australia

Sinclair Knight Merz (SKM), 2003a. *Aggregated Emissions Inventory for the Pilbara Airshed. 1999/2000. Emissions Inventory Report.* Revision 2 - June 2003. Available at http://www.npi.gov.au/publications/

Sinclair Knight Merz (SKM), 2003b. *Aggregated Emissions Inventory of NPI Substances for the Bunbury Regional Airshed*. July 2003. Emissions Inventory report prepared for the WA Department of Environment. Available at http://www.npi.gov.au/publications/

Sinclair Knight Merz (SKM), 2004a. *Kwinana Residue Area - Dust Buffer Study*. Report prepared for Alcoa World Alumina Australia.

Sinclair Knight Merz (SKM), 2004b. *Improvement of NPI Fugitive Particulate Matter Emission Estimation Techniques. Summary Response Document.* Report prepared for WA Department of Environment.

Slinn, W.G.N. 1982. *Predictions for particle to vegetative canopies.* Atmos. Environ, 16, 1785-1794.

Smithman, J.B. and Nicol, S.K. 1991. *Physico-chemical principles controlling the emission of dust from coal stockpiles*. Powder Technology, 64, 259-270

State Pollution Control Commission (SPCC) 1983. *Air Pollution from Coal Mining and Related Developments*, ISBN 0 7240 5936 9.

State Pollution Control Commission (SPCC). 1986. *Particle size distributions in dust from open cut coal mines in the Hunter Valley*. Report Number 10636-002-71, Prepared for the State Pollution Control Commission of NSW by Dames & Moore, Sydney.

US Department of Energy (US DOE). 1984. *Technical Guide for Estimating Fugitive Dust Impacts from Coal Handling Operations*, Report Prepared by Dames & Moore for US Department of Energy, Office of Fuels Programs, Division of Coal and Electricity, 1000 Independence Avenue, SW Washington, DC 20585, Report Number DOE/RG/10312-1(Vol.1).

U.S. Environmental Protection Agency (USEPA), 1974. *Development of emission factors for fugitive dust sources.* Report No. EPA-450/3-74/037 by U.S. Environmental Protection Agency, Research Triangle Park, NC.

U.S. Environmental Protection Agency (USEPA), 1982. *AP-42 Section 11.24 - Metallic Minerals Processing*. http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s24.pdf

U.S. Environmental Protection Agency (USEPA), 1983. *Compilation of Air Pollutant Emission Factors, AP-42, Third Edition. Supplement 14.* United States Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

U.S. Environmental Protection Agency (USEPA), 1984. *Improved Emission Factors for Fugitive dust from Western Surface Coal Mines*, EPA-600/7-84-048, U. S. Environmental Protection Agency, Volumes I and II, March 1984.

U.S. Environmental Protection Agency (USEPA), 1985. *Compilation of Air Pollutant Emission Factors, AP-42, Fourth Edition* United States Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

U.S. Environmental Protection Agency (USEPA), 1988a. *Supplement B to Compilation of Air Pollutant Emission Factors, AP-42, Fourth Edition*, United States Environmental Protection Agency, Office of Air and Radiation Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

U.S. Environmental Protection Agency (USEPA), 1988b. Control of Open Fugitive Dust Sources. Office of Air Quality Planning Standard Research Triangle Park. NC 27711, September 1988.

U.S. Environmental Protection Agency (USEPA), 1998. *Supplement E to Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition*, United States Environmental Protection Agency, Office of Air and Radiation Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

U.S. Environmental Protection Agency (USEPA), 1999. *Metal Mining Facilities. Section 313 of the Emergency Planning and Community Right-to-Know-Act. Toxic Chemical Release Inventory*, United States Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC, 20460. January 1999. EPA 756-B-99-001.

U.S. Environmental Protection Agency (USEPA), 2003. *Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, 2003*. United States Environmental Protection Agency, Office of Air and Radiation Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

U.S. Environmental Protection Agency (USEPA), 2004a. *Summary of Emissions Factors Improvement Project Fact Finding Survey, U.S. Environmental Protection Agency*. Office of Air Quality Planning Standard. Emissions Monitoring and Analysis Division. Emission factors and Policy Applications Group. Research Triangle Park. NC 27711, June 2004.

U.S. Environmental Protection Agency (USEPA), 2004b. AP-42 Section 13.2.2 - Unpaved Roads Spreadsheet available at http://www.epa.gov/ttn/chief/ap42/ch13/related/c13s02-2.html

U.S. Environmental Protection Agency (USEPA), 2004c. *AP-42 Section 11.19.2* Crushed Stone Processing and Pulverised Mineral Processing. http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s1902.pdf

Wang, L, Wanjura, J.D. Parnell, C.B, Lacey, R.E. and Shaw, B.W. 2003. *Performance Characteristics of low-volume PM_{10} Inlet and TEOM Continuous PM Sampler*. 2003 ASAE Annual International meeting. Available at http://caaqes.tamu.edu/. Center for Agricultural Air Quality. Engineering and Science Biological and Agricultural Engineering Department Texas A&M University

Watson, J. G. Robinson, N.F. Lewis, C.W. Coulter, C.T. Chow, J.C. Fujita, E.M. Conner, T.L. and Pace T.G. 1998. *CMB8 applications and validation protocol for $PM_{2.5}$ and VOCs. Report No. 1808.2D1*. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC, by Desert Research Institute, Reno, NV.

Watson, J. G. and Chow, J. 2000. *Reconciling urban fugitive dust emissions inventory and ambient source contribution estimates: Summary of current knowledge and needed research*. DRI Document No. 6110.4F

Western Australian Department of Environmental Protection (WADEP). 1999. *National Pollutant Inventory. Kalgoorlie NPI Trial*. October 1999. Available at http://www.npi.gov.au/publications/

Woodruff, N.P. and Siddoway, F.H. 1965. *A wind erosion equation*. Soil Science Society of America Journal 29, 602-608.

WRAPAIR, 2004. Summary of WRAP Dust Emissions Joint Forum Projects, March 26, 2004. Available at http://www.wrapair.org/forums/dejf/index.html projects_descriptions2.pdf