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**Department of Sustainability, Environment, Water, Population and Communities**



**NATIONAL POLLUTANT INVENTORY**

**EMISSION ESTIMATION TECHNIQUE MANUAL**

**FOR**

**MINING**

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# EMISSION ESTIMATION TECHNIQUES FOR MINING

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# 1 Introduction

The purpose of all Emission Estimation Technique (EET) manuals is to assist Australian manufacturing, industrial and service facilities to report emissions of NPI substances to the National Pollutant Inventory (NPI). This manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in the mining of coal and metalliferous minerals.

The mining industries covered in this manual are: coal, iron ore, bauxite, copper ore, gold ore, nickel ore, silver-lead-zinc ore, uranium ore and other metallic ores.

EET MANUAL: Mining

ANZSIC CODES: 0600, 0801, 0802, 0803, 0804, 0805, 0807 and 0809

This manual was prepared by Sustainable Infrastructure Australia (SIA), on behalf of the Australian Government.

The manual has been developed through a process of national consultation involving state and territory environmental departments and key industry stakeholders. Particular thanks are due to the Minerals Council of Australia (MCA), Greenbase Pty Ltd and the Clean Air Society of Australia and New Zealand (CASANZ) as well as their members for their comments, advice and information.

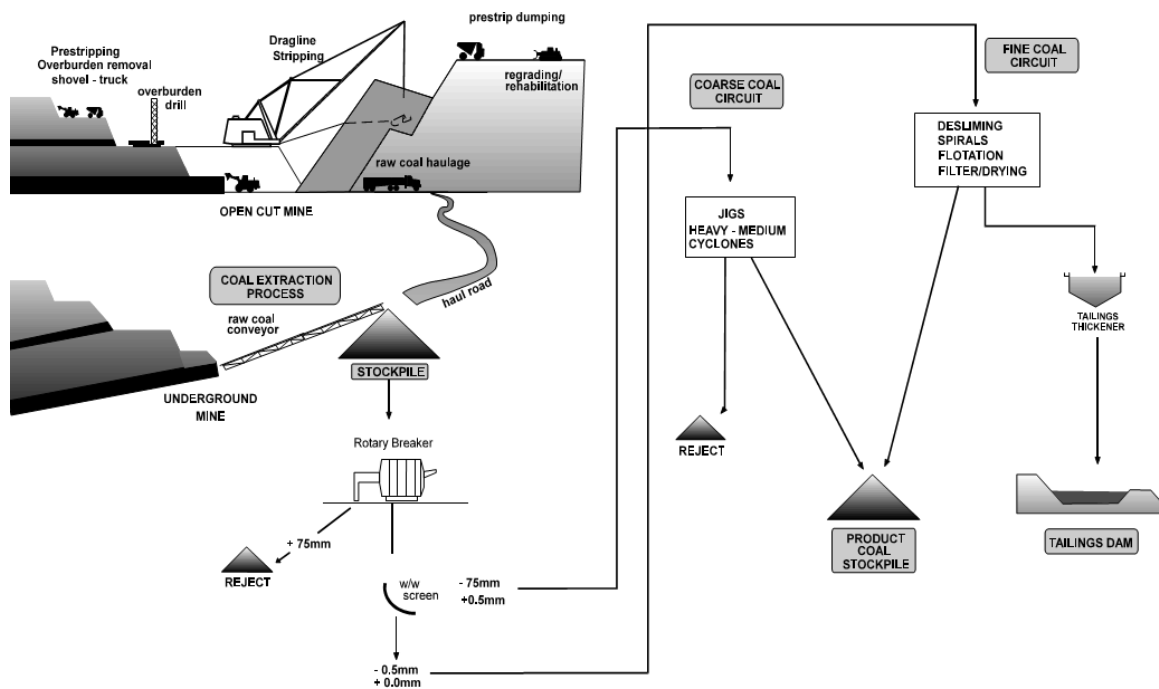
## 2 Process description

The mining activities covered by this EET manual include operations at both open-cut and underground mines. Generic process flow diagrams are provided in Figures 1 and 2. Because each mine is unique, you may need to develop a facility process diagram for your own operations, identifying the main activities or processes that involve NPI substances, and the emissions and transfers resulting from the operation of each activity or process.

The coal and mineral mining activities covered by this manual are those primarily for the production of raw materials for the manufacture of metals and alloys. The geological strata in which these minerals occur contain a wide range of inorganic compounds that need to be considered in assessing potential pollution sources from mining and washery operations. In Australia, open cut and underground mining techniques are used for coal and metallic ores.

### 2.1 Mining of coal

#### 2.1.1 Open-cut mining for coal



**Figure 1: Open-cut/underground coal mining facility process diagram**

Figure 1 is a generalised facility process diagram for open-cut coal mining. In general open-cut mining occurs in layers as material is excavated over a period of time.

The main activities carried out at open-cut coal mines that could lead to emissions to air, water, and land, or transfers of NPI substances, are as follows:

- removing vegetation and topsoil
- drilling and blasting overburden and coal
- removing and placing overburden
- extracting, transporting and dumping coal
- breaking and sizing of coal



- washery and workshop operations
- transporting and placing washery rejects
- wind eroding from exposed areas and stockpiles
- rehabilitation.

### **2.1.2 Underground mining**

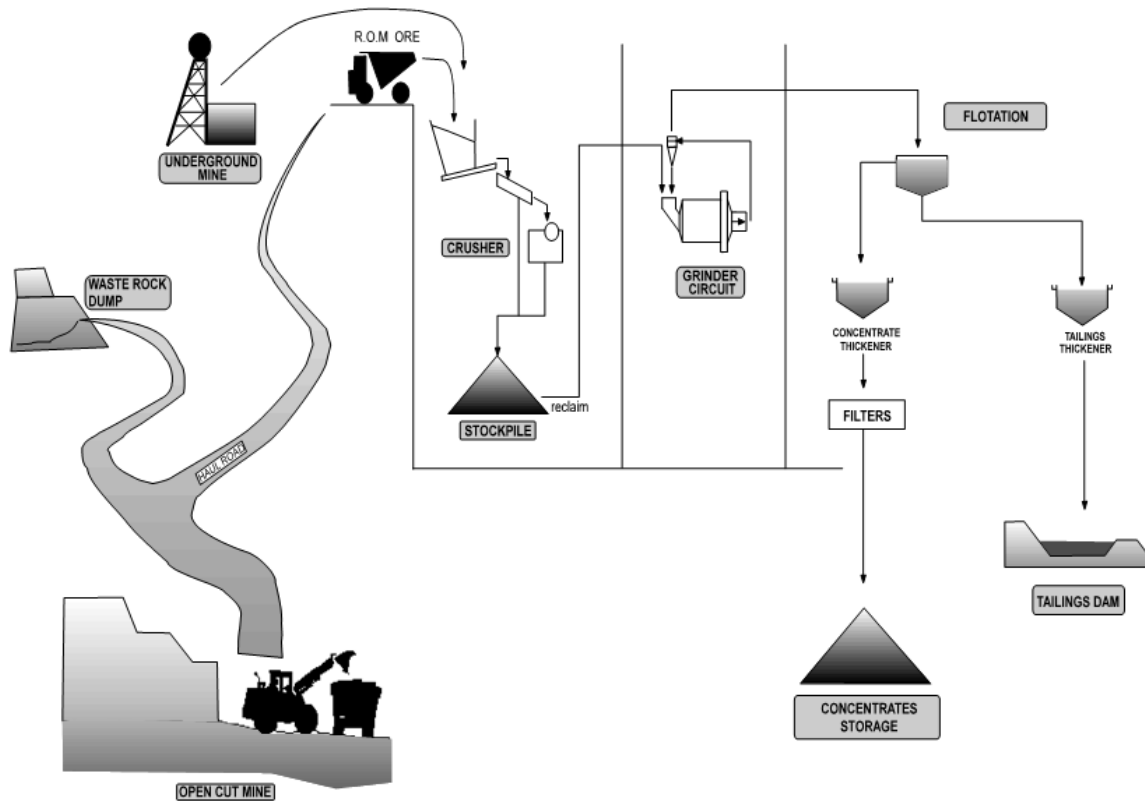
Figure 1 also includes a description of underground coal mining. In general underground mining occurs in horizontal tunnels with access to the surface via large vertical shafts.

The main activities carried out at underground coal mines that could lead to emissions to air, water, and land, or transfers of NPI substances, are as follows:

- earthmoving
- shaft/drift access and ventilation development
- underground drilling and blasting emissions where exhausted from the mine through ventilation shafts
- extracting, transporting, and dumping coal
- breaking and sizing of coal
- washery, workshop, and power plant operations
- transporting and placing washery rejects
- wind eroding from exposed areas and stockpiles
- rehabilitation.

## 2.2 Mining of metallic ores

### 2.2.1 Open-cut mining for metallic ores



**Figure 2: Open-cut/underground metallic ore mining facility process diagram.**

Figure 2 is a generalised facility process diagram for open-cut metallic ore mining. In general open-cut mining occurs in layers as material is excavated over a period of time. The main activities carried out at open-cut ore mines that could lead to emissions to air, water, and land or transfers of NPI listed substances in waste are as follows:

- removing vegetation and topsoil
- drilling and blasting overburden
- drilling and blasting of ore
- removing overburden and ore
- transporting and stockpiling overburden
- extracting, transporting, and dumping ore
- crushing ore
- floatation and thickening
- ore beneficiation;
- workshop operations
- rehabilitation.

### 2.2.2 Underground mining

Figure 2 also includes a description of underground metallic ore mining. In general underground mining occurs in horizontal tunnels with access to the surface via large vertical

shafts.

The main activities carried out at underground ore mines that could lead to emissions to air, water, and land are as follows:

- earthmoving associated with the development of the surface facilities
- shaft/decline access and ventilation development
- extracting, transporting, and dumping ore
- crushing ore (including primary, secondary and tertiary crushing)
- floatation and thickening
- ore beneficiation
- washery, workshop, power plant operations.

### 3 Threshold calculations

The NPI has six different threshold categories (1, 1a, 1b, 2a, 2b and 3), and each NPI substance has at least one reporting threshold. If an NPI substance exceeds a threshold all emissions of that substance from the facility must be reported. In the case of mining operations, the tripping of substance thresholds is likely to result from:

- materials contained in the raw ore and waste rock
- materials used in the extraction of products from the ore
- fuel storage / usage.

Other on-site operations may also result in threshold exceedences, including the transfer of NPI substances such as total nitrogen and total phosphorus in aqueous waste.

For detailed information on how to determine if your facility has tripped thresholds, please refer to *The NPI Guide* which provides detailed information on thresholds and methods for identifying emission sources.

#### 3.1 Developing a substance usage inventory

The first step in determining whether Category 1, 1a or 1b reporting thresholds have been tripped is preparing a materials and substance inventory for your facility.

##### 3.1.1 Common chemicals

When preparing a materials inventory, determine the mass of all materials that have been used, for example, the mass of chemicals used in the mining or beneficiation process, including:

- coolants - *Ethylene glycol*
- lead nitrates - *lead and compounds*
- sulfuric acid
- solvents (e.g. MIBC, trichloroethane) - *total VOC*
- xanthates - precursor of *carbon disulfide*
- ammonia (total)
- hydrochloric acid
- cyanide (inorganic) compounds
- copper sulfate - *copper and compounds*.

*For the purposes of NPI “usage” is defined as the handling, manufacture, import, processing, coincidental production, or other use of a substance.*

##### 3.1.2 Common fuels

Also, the mass of fuels that enters the facility needs to be collected. Information on the amount of fuel combusted will contribute to Category 2a/2b emissions and the amount of fuel stored will contribute to Category 1a for emissions of volatile organic compounds. Common fuels in use include:

- diesel

- petrol
- coal
- residual oil
- LPG/CNG/biodiesel.

*Typically diesel fuel is the predominant fuel used on mining sites, the VOC composition of diesel fuel is 7.6 per cent and the fuel density is 0.836 kg/L. The storage or usage of approximately 394,000 L of diesel will trip the Category 1a threshold for the usage of 25,000 kg of Total VOCs.*

Furthermore, the mass of materials used for ancillary activities such as maintenance works and equipment cleaning is required to be included to determine the mass of each NPI substance used. These substances could also be found as components of paints and solvents. In addition, emissions which result from coincidental production also needs to be considered.

The next step is to determine the amount of each NPI substance in each material used during the reporting year. This process is called material speciation. Material speciation profiles detail the concentration of each substance (or species) within each material. They can be obtained from Material Safety Data Sheets (MSDSs) or from the supplier of the material. If site specific material speciation profiles are not available, use the speciation profiles detailed in Table 1.

**Table 1: Location of useful material speciation profiles to determine substance usage**

Material	Location of material speciation profile
<ul style="list-style-type: none"> <li>• Petrol</li> <li>• Diesel</li> <li>• Fuel oil</li> <li>• Crude oil</li> </ul>	NPI EET manual for Fuel and Organic Liquid Storage
<ul style="list-style-type: none"> <li>• Paints</li> <li>• Solvents</li> </ul>	NPI EET manual for Surface Coating

**Example 1: Calculating the total mass of Category 1 substances used**

This example shows how the usage of manganese and compounds is calculated from a facility that handles coal and bauxite. The following data are available:

Mass of coal used	=	100,000	t/y
Mass of bauxite used	=	2,540,000	t/y
Concentration of manganese and compounds in coal used	=	41	mg/kg
Concentration of manganese and compounds in bauxite used	=	70	mg/kg

Mass of manganese and compounds

$$\begin{aligned} \text{used in reporting period} &= (100,000 \times 41/1,000 + 2,540,000 \times 70/1,000)/1,000 \\ &= 182 \text{ t} \end{aligned}$$

In this example, the total mass of manganese and compounds used by the facility is 182 tonnes. Therefore, the Category 1 threshold for manganese has been tripped and all emissions and mandatory transfers of manganese and compounds must be reported to the NPI.

### Example 2: Calculating usage across reporting periods

Depending on ore grade requirements for processing, blending of ores of different grades often occurs. This can result in ore being mined and being placed in an intermediate stockpile for time periods which may cross over from one NPI reporting period to another.

If a mine has extracted material during the first year and placed it into storage, and then processed it in the next year, then the usage during the second year would be counted on the first movement of the material as it was moved from storage to be processed. In this situation, usage is based on the first movement in the process; any subsequent movements would not need to be included as part of the usage, but multiple process specific movements or process steps need to be taken into account when determining emissions.

If a material has already been counted for usage during the reporting period, further reprocessing will not contribute to additional usage to eliminate double counting.

## 3.2 Fuel combustion and explosives

Fuel is commonly used on mining facilities for vehicles, equipment and in some cases as part of explosives. For detailed information on how to determine if your facility has tripped thresholds for the usage of fuel, please refer to *The NPI Guide*.

*Fuel used during blasting activities needs to be considered when assessing if 1 tonne or more of fuel or waste has been burnt in an hour during the reporting period.*

If your facility trips either the Category 2a or 2b thresholds you must estimate and report any emissions of the substances listed in the relevant category.

*If Category 2a or 2b have been tripped, PM<sub>2.5</sub> is only reportable for combustions sources, other potential sources including stockpiles and road surfaces are excluded.*

## 4 Estimation of Emissions and Transfers

Estimates of emissions of NPI substances to air, water and land should be reported for each substance that triggers a threshold. The NPI substance list and detailed information on thresholds are contained in *The NPI Guide*. In general, there are five emission estimation techniques (EETs) that may be used to estimate emissions from your facility:

- sampling or direct measurement
- mass balance
- fuel analysis or other engineering calculations
- emission factors
- approved alternatives.

Select the EET, (or mix of EETs), that is most appropriate for your purposes. For example, you might choose to use the mass balance technique to best estimate fugitive losses from pumps and vents, direct measurement for stack emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of ‘acceptable reliability’. Similarly, if your relevant environmental department has approved the use of EETs that are not outlined in NPI reporting guidance materials, your data will also be displayed as being of ‘acceptable reliability’.

This manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this or other NPI reporting guidance materials does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

*You are able to use emission estimation techniques that are not outlined in NPI guidance materials. You must, however, seek the consent of your relevant environmental agency. For example, if your company has developed site-specific emission estimation techniques, you may use these if approved by your relevant environmental agency*

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (e.g. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions. The emission resulting from a spill is the net emission, i.e. the quantity of the NPI substance spilled, less the quantity recovered or consumed during clean up operations.

### ***Metals Speciation:***

*Reporting facilities have the option to report either:*

*(a) the total emissions of each of the metals for which reporting is triggered, or*

*(b) the individual compounds (or species) that comprise the emission, providing the total emissions sum to the total metal emissions from the facility. You must, however, seek the consent of your relevant environmental agency for the use of EETs for metal speciation.*

## **4.1 EETs in this manual**

Emission estimation techniques in this manual are divided into four main sections, as follows:

- Emissions to Air (Section 5)
- Emissions to Water (Section 6)
- Emissions to Land (Section 7)
- Transfers (Section 8)

The emissions to air section is divided into two separate sections for coal and for metallic ore mines. The other sections are applicable to either mine type.

Each of these sections follows the same general structure:

- general background information;
- what is to be reported
- emission estimation techniques.

Where relevant, these include default emission factors as well as guidance on the application of these or other EETs to characterising emissions. Appendix A provides a detailed description of the sources of the particulate emission factors presented in Section 4.

Appendix B provides a series of worked examples to illustrate the application of the EETs for emissions to water and land.

## **4.2 Emission Factor Rating**

Many published emission factors have an associated emission factor rating (EFR) code. These EFR codes are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA).

Consequently, the ratings may not be directly relevant to Australian industry. Where available, EFR codes have been provided in this manual. However, these EFR codes will not form part of the public NPI database.

For more information about emission factor ratings, please refer to *The NPI Guide*.



## 5 Emissions to air

The main emissions to air from mining operations consist of wind-borne dust, and the products of combustion from blasting, vehicle usage, materials handling and, mine power generation (if any). Depending on the levels at which they are present, trace metals in mined material as well as the primary metal being mined could also lead to the Category 1 or 1b reporting threshold being triggered.

In most cases fugitive air emissions can be estimated using emission factors combined with site-specific information such as the silt and moisture content of material being handled.

Most of the work in developing emission factors for fugitive emissions has been undertaken in the United States (see USEPA (1985) and USEPA (1998)). Some work has also been undertaken in Australia (see State Pollution Control Commission (SPCC) (1983) and National Energy Research and Demonstration Council (NERDDC) (1988)). Although the Australian work is not nearly as comprehensive as the US work, it is useful because it confirms that the US emission factors are relevant for Australian conditions provided that appropriate variables are used. The Australian work also highlights those emission factors that are not appropriate for particular operations.

The emission factors presented in this manual should be used with caution. You should always consider the range of conditions under which the factors were developed to assess whether the factors are suitable for the particular activity being considered. To assist in assessing the suitability of a specific emission factor for your particular operations, a detailed discussion of the sources of the various emission factors presented can be found in Appendix A of this manual.

USEPA emission factors are published in a large number of references, and are often referred to in different ways. The most comprehensive compilation of emission factors is that in the USEPA document referred to as AP-42. Chapters from AP-42 are updated periodically and are available from the USEPA's website<sup>1</sup>.

*Often the date of the reference will be given as the date of the re-formatting of the AP-42 chapter. Different chapters have been reformatted in different years.*

*In this manual, for example, reference is made to USEPA (1998). This is taken from a version of AP-42 Chapter 11 that was re-formatted in 1995. Some authors will reference this as USEPA (1995). This chapter of AP-42 includes work done in the late 1970s and the 1980s.*

### 5.1 Overview of air emission sources

The air emissions considered in this manual are:

- fugitive emissions of particulate matter (Section 5.3.1.1) and metals (Section 5.3.1.2)
- exhaust emissions from mining equipment (Section 5.5)
- emissions from spontaneous combustion (Section 5.6)
- volatile organic compound (Total VOC) emissions (Section 5.7)
- emissions of carbon disulfide from flotation processes (Section 5.8); and
- emissions from power generation and combustion processes (Section 5.9).

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<sup>1</sup> <http://www.epa.gov/ttnchie1/AP-42.html>

Guidance on emission control technologies and post process emission reductions is discussed in Section 5.4.

## 5.2 General equations for estimation emissions to air

Emission factors can be used to estimate emissions of TSP and PM<sub>10</sub> to the air from various sources. Emission factors relate the quantity of a substance emitted from a source to some measure of activity associated with the source. Common measures of activity include distance travelled, quantity of material handled, or the duration of the activity.

Emission factors are used to estimate a facility's emissions by the general equation:

$$E_{i \text{ (kg/yr)}} = \left[ A_{\text{(t/h)}} \times OP_{\text{(h/yr)}} \right] \times EF_{i \text{ l(kg/t)}} \times \left[ 1 - \frac{CE_i}{100} \right] \quad \text{Equation 1}$$

where:

$E_{i \text{ (kg/yr)}}$	= emission rate of pollutant i, kg/yr
$A_{\text{(t/h)}}$	= activity rate, t/h
$OP_{\text{(h/yr)}}$	= operating hours, h/yr
$EF_{i \text{ l(kg/t)}}$	= uncontrolled emission factor of pollutant i, kg/t
$CE_i$	= overall control efficiency for pollutant i, kg/t

If no emission controls are used, Equation 1 reduces to

$$E_{i \text{ (kg/yr)}} = \left[ A_{\text{(t/h)}} \times OP_{\text{(h/yr)}} \right] \times EF_{i \text{ l(kg/t)}} \quad \text{Equation 2}$$

For fugitive emissions of particulate matter and metals, uncontrolled emission factors are provided in Sections 5.3.1 and 5.3.2 of this manual. Emission reduction efficiencies for a range of dust control measures are provided in Section 5.4. Controls are multiplicative when more than one control is applied to a specific operation or activity.

For example, using controls from Table 4, water sprays used in conjunction with wind breaks give an emission that is  $(1 - 0.5) \times (1 - 0.7) = 0.15$  of the uncontrolled emission.

### 5.2.1 Mining coal

The major air emission from coal mining is fugitive dust. The PM<sub>10</sub> component of dust is reportable under the NPI. Reporting may be triggered by fuel combustion or on-site power generation (see *The NPI Guide* for further information).

In addition, certain metals may need to be reported if fuel combustion exceeds the threshold, or if NPI metals are present in the mined material in levels that lead to the Category 1 or 1b threshold being exceeded. In these cases total suspended particulate (TSP) emissions will need to be calculated (in addition to PM<sub>10</sub>) to determine the metal emissions.

Mining operations can be considered as a series of unit operations (e.g. dragline operations, shovel operations, truck haulage of materials). Table 2 provides emission factor equations and default emission factors for emissions of both TSP and PM<sub>10</sub> from mining. A detailed explanation of the way in which these equations and factors have been determined is provided in Appendix A. The emission equations should be used where site specific data such as silt and moisture content is available. Otherwise, the default emission factors can be used.

#### 5.2.1.1 Determination of PM<sub>10</sub> emissions

All emission factor equations and default emission factors listed in Table 2 are for

uncontrolled emissions. Section 5.4 provides information on the efficiency of control methods. This information can be incorporated into the determination of emissions as outlined in Equation 1.

The process for determining PM<sub>10</sub> emissions is:

1. Identify sources of emissions.
2. Obtain information on the scale of the activity (i.e. the activity data required to apply the equation).
3. Apply the relevant PM<sub>10</sub> emission factor equation or default emission factor from Table 2 to the activity data (using Equation 2). A suitable surrogate for calculating vehicle kilometres travelled (VKT) emissions may be to determine the fuel consumption in various items of equipment. Using typical fuel efficiencies, it should then be possible to determine the total VKT.
4. Where applicable, apply control efficiency factors from Section 5.4 (using Equation 1).

#### 5.2.1.2 Determination of Metallic Emissions

A similar process can be used to determining emissions of those NPI-listed metals for which reporting is required, except in this case you will need to use the TSP emission equations or factors, rather than those for PM<sub>10</sub>.

The process for determining metals emissions is:

1. Identify sources of emissions (as for PM<sub>10</sub>).
2. Obtain information on the scale of the activity (as for PM<sub>10</sub>).
3. Apply the relevant TSP equation or emission factor to the activity.
4. If particle size data are available, the proportion of TSP that constitutes the dust fraction (i.e. less than 50 microns) may be used to estimate metal emissions.
5. Estimate metal emissions. Metal emissions can be estimated as a fraction of the TSP emissions, based on available assay data. Where assay data or site specific information is not available for metals in TSP emissions, the default concentrations in Appendix B can be used.
6. Where applicable, apply control efficiency factors from Section 5.4.

*Although incomplete at the time of issue of this manual, Geoscience Australia was undertaking a National Geochemical survey of Australia which will provide region-specific trace metal concentration data. The results of the study are due to be published in mid 2011.<sup>2</sup>*

#### 5.2.1.3 Determination of acidic emissions

Information on the estimation of emissions from acid storage tanks can be found in the *Emission Estimation Technique manual for Alumina refining*, which can be found on the NPI website.

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<sup>2</sup> <http://www.ga.gov.au/energy/projects/national-geochemical-survey.html>

#### *5.2.1.4 Determination of VOC emissions from Fuel and Organic Liquid storage*

Information on the estimation of emissions from fuel or organic liquid storage tanks can be found in the *Emission Estimation Technique manual for Fuel and organic liquid storage*.

**Table 2: Emission Factor Equations and Default Emission Factors for Various Operations at Coal Mines 1, 2**

Operation/Activity	TSP Equation	PM <sub>10</sub> Equation	TSP Default Emission Factor	PM <sub>10</sub> Default Emission Factor	PMR <sub>10</sub> PM <sub>10</sub> /TSP Ratio based on Emission Factors	Units	EFR
Draglines (on overburden).	$EF_{TSP} = 0.0046 \times \left( \frac{d^{1.1}}{M^{0.3}} \right)$	$EF_{PM_{10}} = 0.0022 \times \left( \frac{d^{0.7}}{M^{0.3}} \right)$	0.06	0.026	0.43	kg/bcm	B
Excavators/Shovels/ Front-end loaders (on overburden).	See Appendix A Section 1.1.2	See Appendix A Section 1.1.2	0.025	0.012	0.47	kg/t	U
Excavators/Shovels/ Front-end loaders (on coal).	$EF_{TSP} = 0.580 / (M)^{1.2}$	$EF_{PM_{10}} = 0.0447 / M^{0.9}$	0.029	0.014	0.48	kg/t	C
Bulldozers on coal.	$EF_{TSP} = 35.6 \times \frac{(s)^{1.2}}{(M)^{1.4}}$	$EF_{PM_{10}} = 6.33 \times \left( \frac{(s)^{1.5}}{(M)^{1.4}} \right)$	102	32.5	0.32	kg/h/vehicle	B
Bulldozer on material other than coal.	$EF_{TSP} = 2.6 \times \frac{(s)^{1.2}}{(M)^{1.3}}$	$EF_{PM_{10}} = 0.34 \times \left( \frac{(s)^{1.5}}{(M)^{1.4}} \right)$	17	4.1	0.24	kg/h/vehicle	B
Trucks (dumping overburden).	See Appendix A Section 1.1.6	See Appendix A Section 1.1.6	0.012	0.0043	0.35	kg/t	U
Trucks (dumping coal).	See Appendix A Section 1.1.7	See Appendix A Section 1.1.7	0.010	0.0042	0.42	kg/t	
Drilling.	See Appendix A Section 1.1.8	See Appendix A Section 1.1.8	0.59	0.31	0.52	kg/hole	C
Blasting <sup>3</sup> .	$EF_{TSP} = 0.00022 \times A^{1.5}$	$EF_{PM_{10}} = 0.000114 \times A^{1.5}$			0.52	kg/blast	C
Operation/Activity	TSP Equation	PM <sub>10</sub> Equation	TSP	PM <sub>10</sub>	PMR <sub>10</sub>	Units	EFR

			Default Emission Factor	Default Emission Factor	PM <sub>10</sub> /TSP Ratio based on Emission Factors		
Wheel and bucket <sup>4</sup>	$EF_{TSP} = 0.74 \times 0.0016 \times \frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$	$EF_{PM_{10}} = 0.35 \times 0.0016 \times \frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$	0.00032	0.00015	0.47	kg/t	C
Wheel generated dust from unpaved roads at industrial sites	$EF_{TSP} = \frac{0.4536}{1.6093} \times 4.9 \times \left(\frac{s}{12}\right)^{0.7} \times \left(\frac{W \times 1.1023}{3}\right)^{0.45}$	$EF_{PM_{10}} = \frac{0.4536}{1.6093} \times 1.5 \times \left(\frac{s}{12}\right)^{0.9} \times \left(\frac{W \times 1.1023}{3}\right)^{0.45}$	4.23	1.25	0.30	kg/VKT	B
Wheel generated dust from unpaved roads (used by light duty vehicles)	$EF_{TSP} = 1.69 \times \frac{(s/12) \times (S/48)^{0.3}}{(M/0.5)^{0.3}} - 0.0013$	$EF_{PM_{10}} = 0.51 \times \frac{(s/12) \times (S/48)^{0.5}}{(M/0.5)^{0.2}} - 0.0013$	0.94	0.33	0.35	kg/VKT	B
Scrapers (travel mode)	$EF_{TSP} = 9.6 \times 10^{-6} \times s^{1.3} \times W^{2.4}$	$EF_{PM_{10}} = 1.32 \times 10^{-6} \times s^{1.3} \times W^{2.4}$	2.08	0.52	0.25	kg/VKT	A
Scrapers (removing topsoil)	See Appendix A Section 1.1.13	See Appendix A Section 1.1.13	0.029	0.0073	0.25	kg/t	E
Graders	$EF_{TSP} = 0.0034 \times S^{2.5}$	$EF_{PM_{10}} = 0.0034 \times S^{2.0}$	0.19	0.085	0.31	kg/VKT	B
Loading stockpiles	See Appendix A Section 1.1.15	See Appendix A Section 1.1.15	0.004	0.0017	0.42	kg/t	U
Unloading from stockpiles	See Appendix A Section 1.1.15	See Appendix A Section 1.1.15	0.03	0.013	0.42	kg/t	U
Loading to trains	See Appendix A Section 1.1.15	See Appendix A Section 1.1.15	0.0004	0.00017	0.42	kg/t	U
Miscellaneous transfer points (including conveying)	$EF_{TSP} = 0.74 \times 0.0016 \times \frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$	$EF_{PM_{10}} = 0.35 \times 0.0016 \times \frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$	0.00032	0.00015	0.47	kg/t/transfer point	U
Wind erosion	See Appendix A Section 1.1.17 to 1.1.18	See Appendix A Section 1.1.17 to 1.1.18	0.4	0.2	0.50	kg/ha/h	U

Operation/Activity	TSP Equation	PM <sub>10</sub> Equation	TSP Default Emission Factor	PM <sub>10</sub> Default Emission Factor	PMR <sub>10</sub> PM <sub>10</sub> /TSP Ratio based on Emission Factors	Units	EFR
Highwall Mining	See Appendix A Section 1.1.19	See Appendix A Section 1.1.19	0.00032	0.00015	0.47	kg/t/transfer point	U

- See Appendix A for details of the sources of these emission factors and emission estimation equations
- d = drop distance in metres;  
M = moisture content in % (by weight, in natural state, i.e. prior to addition of H<sub>2</sub>O for dust control);  
bcm = bank cubic metres;  
t = tonne;  
s = silt content in % (by weight);  
A = area blasted in m<sup>2</sup>;  
D = depth of blast holes in metres;  
U = mean wind speed in m/s  
W = vehicle gross mass in tonnes  
VKT = vehicle kilometres travelled;  
S = mean vehicle speed in km/h  
PMR<sub>10</sub> = PM<sub>10</sub> / TSP ratio
- Additional guidance on the characterisation of emissions of PM<sub>10</sub> and other substances is provided in the Emission Estimation Technique manual for Explosives Detonation.
- A significant proportion of open-cut coal mining for softer brown coals is carried out using bucket wheel excavators.
- Exponents for “Wheel generated dust from unpaved roads at industrial sites”: A = 0.9 (for PM<sub>10</sub>) & 0.7 (for TSP)
- Exponents for “Wheel generated dust from unpaved roads used by light duty vehicles”: B = 0.5 (for PM<sub>10</sub>) & 0.3 (for TSP), C = 0.2 (for PM<sub>10</sub>) & 0.3 (for TSP)
- emission factors quoted in Table 2 apply to all operations typically associated with the process. Therefore, emissions from a primary crushing activity include emissions from the screens, the crusher, the surge bin, the apron feeder, and conveyor belt transfer points that are integral to the crusher.





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*When applying emission factors from Table 2, information on moisture and silt contents for US mines can be found in Section 11.9 (table 11.9-3) of AP-42. However where possible, information based on local conditions should be used.*

### **5.2.2 Mining of metalliferous minerals**

As for the mining of coal, the major fugitive emission from metalliferous mining is dust, of which the PM<sub>10</sub> fraction is reportable under the NPI. Reporting is triggered by the fuel burnt at the facility (see *The NPI Guide* for further information). In addition, emissions of certain metals will need to be reported if fuel combusted exceeds the defined thresholds, or if NPI-listed metals are present in the mined ore or waste in levels which lead to the Category 1 threshold being exceeded. In this case, total suspended particulate (TSP) emissions will need to be calculated (in addition to emissions of PM<sub>10</sub>) to determine the metal emissions.

Many of the activities at metalliferous mines will be the same as for coal mining. In these situations, the mining emission factors and equations presented in Section 5.3.1 may be used as an alternative if no other means of estimation is available. Table 3 provides default emission factors for specific activities associated with metalliferous mining. The table presents factors for high-moisture<sup>3</sup> content ores and low moisture content ores. A discussion of the sources of these emission factors is provided in Appendix A, Section 1.2.

All emission factors are for uncontrolled emissions. Section 5.4 provides information on the efficiency of control technologies. Factors in Table 4 can be incorporated into the calculation of emissions using Equation 1.

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<sup>3</sup> Generally, a high-moisture ore is taken to be one that either naturally, or as a result of additional moisture at the primary crusher (usually), has a moisture content of more than 4% by weight. However, exceptions apply. For bauxite, the high moisture ore threshold is 5% (Reference Pitt p304 and sighting of company reports). For ores at Broken Hill, a site specific definition should be used. These definitions will need to be used with caution and local knowledge.

**Table 3: Default Emission Factors for Various Operations at Metalliferous Mines 1, 2**

Operation/Activity	TSP Default Emission Factor	PM <sub>10</sub> Default Emission Factor	PM <sub>10</sub> /TSP Ratio	TSP Default Emission Factor	PM <sub>10</sub> Default Emission Factor	PM <sub>10</sub> /TSP Ratio	Units	Emission Factor Rating
	<b>High Moisture Content Ores</b>			<b>Low Moisture Content Ores</b>				
Primary crushing	0.01	0.004	0.4	0.2	0.02	0.1	kg/t	C
Secondary crushing	0.03	0.012	0.4	0.6	NDA		kg/t	D
Tertiary crushing	0.03	0.01	0.33	1.4	0.08	0.06	kg/t	E
Wet grinding (milling)	0	0		0	0		kg/t	
Dry grinding with air conveying or classification	14.4	13	0.9	14.4	13	0.9	kg/t	C
Dry grinding without air conveying or classification	1.2	0.16	0.13	1.2	0.16	0.13	kg/t	D
Drying (all minerals except titanium / zirconium sands)	9.8	5.9	0.6	9.8	5.9	0.6	kg/t	C
Handling, transferring, and conveying including wheel and bucket reclaimers (except bauxite) 3	0.005	0.002	0.4	0.06	0.03	0.5	kg/t	C
Screening				0.08	0.06	0.75	kg/t	C
Bauxite/alumina				0.6	NDA		kg/t	C

1. See Appendix A for details of the sources of these emission factors
2. t = tonne; NDA - No data available
3. Factors are applied to each operational activity

### 5.3 Control Technologies

There are a number of ways in which dust emissions from mining operations can be controlled. Most dust control techniques involve the use of water sprays to keep surfaces damp, but there are also other methods. Table 4 summarises the methods used and the effect they have on reducing dust emissions (Holmes Air Sciences, 1998). These are drawn from control factors documented in USEPA (1998), discussions with Greenbase and Buonicore and Davis (1992: Table 3, p 794).

**Table 4: Estimated control factors for various mining operations**

Operation / Activity	Control method and emission reduction <sup>1</sup>
<b>Coal Mines</b>	
Scrapers on topsoil	50% control when soil is naturally or artificially moist
Dozers on coal or other material	No control
Drilling	99% for fabric filters
	70% for water sprays
Blasting coal or overburden	No control
Loading trucks	No control
Hauling	50% for level 1 watering (2 litres/m <sup>2</sup> /h)
	75% for level 2 watering (> 2 litres/m <sup>2</sup> /h)
	100% for sealed or salt-encrusted roads
Unloading trucks	70% for water sprays
Draglines	Control dust by minimising drop height
	50% for water sprays
Loading stockpiles	25% for variable height stacker
	75% for telescopic chute with water sprays
	99% for total enclosure
Unloading from stockpiles	50% for water sprays (unless underground recovery then, no controls needed)
	50% for water sprays
Wind erosion from stockpiles	30% for wind breaks
	99% for total enclosure
	30% for primary earthworks (reshaping/profiling, drainage structures installed)
	30% for rock armour and/or topsoil applied
Loading to trains	70% for enclosure
	99% for enclosure and use of fabric filters
	90% control allowed for water sprays with chemicals
Miscellaneous transfer and conveying	70% for enclosure
	99% for enclosure and use of fabric filters
Wind erosion	30% for primary rehabilitation
	40% for vegetation established but not demonstrated to be self-sustaining. Weed control and grazing control.

	60% for secondary rehabilitation
	90% for revegetation
	100% for fully rehabilitated (release) vegetation

**Metalliferous Mines**

All activities listed in Table 2	30% for windbreaks
	50% water sprays to keep ore wet
	65% for hooding with cyclones
	75% for hooding with scrubbers
	83% for hooding with fabric filters
	100% enclosed or underground

Pit retention	50% for TSP
	5% for PM <sub>10</sub>

Sources: Holmes Air Sciences (1998) and Greenbase (2009)

1 Controls are multiplicative when more than one control is applied to a specific operation or activity. On stockpiles, for example, water sprays used in conjunction with wind breaks give an emission that is

$$(1 - 0.5) \times (1 - 0.7) = 0.15 \text{ of the uncontrolled emission.}$$

The emission control factors as presented in Table 4 can be applied to the uncontrolled emissions as derived using the emission factors and equations presented in Table 2 and Table 3 using Equation 1, as described in Section 5.3 of this manual.

**5.4 Vehicle exhaust emissions**

For vehicles, emission estimation techniques can be found in the Emission Estimation Technique manual for Combustion Engines. Table 5 lists typical vehicles used on mine sites, and how they are classified in the *Emission Estimation Technique manual for Combustion Engines*.

**Table 5: Typical mining vehicle definitions**

Mine Equipment	Engine/Vehicle Type (from Combustion Engines EET manual)	Comments
Haul Truck	Off-highway truck	
Water Cart (Small)	Heavy Good Vehicle	
Water Cart (Large)	Off-highway truck	
Loader	Wheeled loader	
Bogger	Wheeled loader	
Dozer	Track Type Tractor	
Wheeled Dozer	Wheeled dozer	
Tractor	Wheeled tractor	
Bobcat	Wheeled loader	
Backhoe	Wheeled tractor	
Excavator	Track type loader	
-Grader	Motor Grader	
Scraper	Scraper	
Drill	Heavy Good Vehicle	

Jumbo	Heavy Good Vehicle	
Commercial (<5t)	Medium goods vehicle	
Bus	Bus	Commercial buses, 20 or more passengers
Forklift	Forklift	
Road Train	Very Heavy Good Vehicle	
Light	Light Goods Vehicle	Light Vehicles <4 tonnes, including 4WD, small buses, utility, light trucks
Car	Car	Sedan, station wagon, small 4WD, or LGV
Field Generator	Ground power unit	Default power rating = <450kW
Compressor	Ground power unit	Default power rating = <450kW
Lighting Plant	Ground power unit	Default power rating = <450kW
Pump	Ground power unit	Default power rating = <450kW
Crane	Wheeled tractor	
Rollers	Rollers and Compactors	
Concrete/shotcrete trucks	Heavy goods vehicle	
Fuel trucks	Heavy goods vehicle	
Heavy service trucks	Heavy goods vehicle	

## 5.5 Spontaneous combustion

If it occurs, spontaneous combustion in coal mines will contribute to emissions of PM<sub>10</sub>, PM<sub>2.5</sub> and other products of combustion from the mine site. However as this is a highly site specific issue., there are no published emission factors that can be used, If spontaneous combustion is an issue at a particular facility, it is the operator's responsibility to develop a suitable emission estimation technique to enable these emissions to be reported under the NPI.

## 5.6 Total Volatile Organic Compounds (Total VOCs)

In addition to the VOCs emitted from vehicle exhausts, there will also be emissions of VOCs from workshops, cleaning and other site maintenance activities. In some instances, volatile substances can be released during mining processes.

Emissions of volatile solvents can be estimated on the basis of annual usage, assuming that all solvents are volatilised (i.e. released direct to air). Any vapour recovery or other control systems, should be accounted for in characterising these emissions.

Emissions from the storage of fuel can be determined using the *Emission Estimation Technique manual for fuel and organic liquid storage*.

## 5.7 Carbon disulfide

Xanthates are widely used in Australia in flotation processes to concentrate sulfide ores. They have the propensity to decompose in the presence of moisture and/or heat to produce carbon disulfide, an NPI substance. When xanthates are used as a flotation agent they are usually pre-mixed with water at concentrations of about 10 per cent. Typical xanthates include sodium ethyl xanthate (SEX) and sodium isobutyl xanthate (SIBX). Other xanthates and their molecular weights are given in Table 6 below.

**Table 6: Typical xanthates used in Austrlian mines**

Xanthate	Formula	MW	Approximate Usage to Trip	
			Alkaline Conditions (tonnes)	Acidic Conditions (tonnes)
Potassium Amyl Xanthate	KC <sub>6</sub> H <sub>11</sub> OS <sub>2</sub>	202	26,500	13,500
Potassium Butyl Xanthate	KC <sub>5</sub> H <sub>9</sub> OS <sub>2</sub>	188	25,500	12,500
Potassium Ethyl Xanthate	KC <sub>3</sub> H <sub>5</sub> OS <sub>3</sub>	160	21,000	10,500
Potassium Isobutyl Xanthate	KC <sub>5</sub> H <sub>9</sub> OS <sub>2</sub>	188	24,500	12,500
Potassium Isopropyl Xanthate	KC <sub>4</sub> H <sub>7</sub> OS <sub>2</sub>	174	23,000	11,500
Sodium Amyl Xanthate	NaC <sub>6</sub> H <sub>11</sub> OS <sub>2</sub>	186	24,500	12,000
Sodium Butyl Xanthate	NaC <sub>5</sub> H <sub>9</sub> OS <sub>2</sub>	172	22,500	11,500
Sodium Ethyl Xanthate	NaC <sub>3</sub> H <sub>5</sub> OS <sub>2</sub>	144	19,000	9,500
Sodium Isobutyl Xanthate	NaC <sub>5</sub> H <sub>9</sub> OS <sub>2</sub>	172	22,500	11,500
Sodium Isopropyl Xanthate	NaC <sub>4</sub> H <sub>7</sub> OS <sub>2</sub>	158	21,000	10,500

Most of the xanthates are retained in the froth that contains the ore concentrate collected during the flotation process. Some (approximately 1 per cent) will be discharged to the tailings dam.

The ultimate fate and decomposition of xanthate is not completely understood. However for the purposes of NPI reporting it can be assumed that 0.2 per cent will decompose hydrolytically to release carbon disulfide. Heat and low pH will accelerate this process. In the mining industry, xanthate solutions are usually used in a pH range of between 7 and 11. For xanthates in the ore concentrate, decomposition will occur during drying or smelting.

The decomposition stoichiometry will vary with the form of xanthate used at particular facilities. Facilities should verify the stoichiometry based on their use of xanthate types. The stoichiometry of xanthate composition, and hence carbon disulfide formation, will also vary according to the pH.

**Table 7: Typical xanthate decomposition rates**

Conditions	Decomposition Coefficient "D" (Stoichiometry of hydrolytic decomposition of xanthate to CS <sub>2</sub> )
Alkaline	1.0:0.5
Acidic	1:1

The emissions of CS<sub>2</sub> resulting from use of xanthates can be calculated using the following equation:

$$E_{CS_2} = D \times 0.2\% \times M_{xanthate} \times \frac{MW_{CS_2}}{MW_{xanthate}} \quad \text{Equation 3}$$

Where

- $E_{CS_2}$  = Emission of CS<sub>2</sub> (kg/yr)
- D = Decomposition Coefficient
- $M_{xanthate}$  = Mass of xanthate consumed (kg/yr)
- $MW_{CS_2}$  = Molecular weight of CS<sub>2</sub> (=76)
- $MW_{xanthate}$  = Molecular weight of xanthate (See Table 6)

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### Example 3: CS<sub>2</sub> emissions

A facility uses 150kg of sodium ethyl xanthate, and maintains the tailings dam under alkaline conditions.

$$E_{\text{CS}_2} = D \times 0.2\% \times M_{\text{xanthate}} \times \frac{MW_{\text{CS}_2}}{MW_{\text{xanthate}}}$$

$$E_{\text{CS}_2} = 0.5 \times 0.002 \times 150 \times \frac{76}{144}$$

$$E_{\text{CS}_2} = 0.08\text{kg}$$

## 5.8 Power Generation

For facilities with on-site power generation, EETs can be found in the *Emission Estimation Technique manual for Fossil Fuel Electric Power Generation*. For sites that use boilers (e.g. for steam raising), emission estimation techniques can be found in the *Emission Estimation Technique manual for Combustion in Boilers*. For sites that use diesel engines, emission estimation techniques can be found in the *Emission Estimation Technique manual for Combustion Engines*.

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## 6 Emissions to Water

### 6.1 Background

Emissions to water are site-specific and that there are no default emission factors currently available to determine these emissions. The purpose of this section is to provide general guidance on approaches that may be adopted to determine these emissions, using data that is typically available (or can readily be gathered) for mining operations. Appendix B provides a number of worked examples to illustrate the application of the emission estimation techniques.

### 6.2 What needs to be reported?

Emissions of NPI substances to water can be categorised as discharges to:

- surface waters (lakes, rivers, dams, estuaries),
- coastal or marine waters, and
- stormwater runoff

Emissions of toxic substances to waterways may pose environmental hazards. Most facilities emitting NPI substances to surface waters are required by their state or territory environment agency to closely monitor and measure these emissions. Existing sampling data can be used to calculate annual emissions.

If no wastewater monitoring data exists, emissions to water can be determined using a mass balance. Discharge of NPI substances to a sewer or tailings dam is not regarded as an emission to water but is reportable as a transfer. Further guidance on reporting transfers is provided in Section 8 of this manual, *The NPI Guide*, and the *Transfer Information Booklet*.

### 6.3 Emissions Estimation

This manual provides a general guide on how site-specific data may be manipulated to estimate the reportable emissions. You should note that you may use alternative EETs to those specified in this manual, depending on the data available. As noted in Section 4, approval for the use of EETs not presented in this manual will need to be obtained from your relevant state or territory environmental agency.

*It is suggested that the best approach to determining emissions to water is to relate potential emissions to the facility's water management practices. The extent of catchment segregation and facility water balances (which define all aspects of facility water management) can be used to define both emissions and transfers.*

*With regard to emissions and transfers, it is recognised that actual emissions are highly dependent on weather conditions over the reporting period. For example, a system may be designed and operated to contain run-off from rainfall with a 1 in 5 - 20 year return period. In that situation, estimation of emissions will be required where overflows have occurred. Where reporting is triggered but there are no emissions, the number reported is zero.*

#### 6.3.1 Notes on Reportable Substances:



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### 6.3.1.1 *Dissolved Substances and Suspended Sediment*

Most metals are recovered from sulfides and silicates that have solubility coefficients of  $<10^{-20}$  to  $10^{-50}$  g/L under neutral pH and redox conditions and are, therefore, effectively insoluble. This means that these substances are generally handled as either a transfer or as an emission to land.

Emissions of dissolved metals should be considered if the following substances occur and/or are produced at the mine site: arsenic trioxide, borax, copper sulfate, and cobalt sulfate. In acidic conditions, nickel oxide emissions should also be considered. In general, most soluble compounds would be present in unsaturated conditions and longer retention times in containment facilities would increase dissolved metal concentration towards saturation.

### 6.3.1.2 *Volatile Organic and Chlorinated Hydrocarbons*

Chlorinated hydrocarbon compounds (e.g. trichloroethane and solvents such as methyl ethyl ketone (MEK)) that are used for plant and equipment maintenance are volatile and would be expected to be either absent from the mine water system or occur at very low concentrations.

For the purposes of NPI reporting, and in the absence of specific information (i.e. monitoring data) regarding these substances, it can be assumed that all emissions of volatile organic and chlorinated hydrocarbons are to the atmosphere (refer Section 5.7) and that water emissions are zero.

## 6.4 Overview of Water Emission Sources

Reportable metal compounds will be present in most site waters, albeit in trace quantities. These emissions must be estimated and reported if thresholds are triggered as noted in Section 6.1. Transfers are also required to be reported; please refer to Section 8 for guidance on reporting.

Sections 6.4.1 to 6.4.4 provide a description of the main sources of liquid effluents/emissions from mine sites and relevant emission estimation techniques. The sources considered are:

- Process waters from mining
- Process waters from beneficiation
- Surface water runoff
- Leachate from stockpiles.

### 6.4.1 Process Waters from Mining

Most of the non-process related uses for process waters in mining will be classed as transfers. For example, process water in underground mines is routinely used for dust suppression, cooling of equipment such as drills, continuous miners, and tunnel boring machines. Excess waste waters from these activities are pumped to the surface for treatment.

Emissions will be associated with overflows and/or discharges of excess mine process waters to surface waters, coastal/marine waters, or groundwater. All emissions of NPI substances (except those which are directed to, and contained by, purpose built facilities) are to be reported if relevant thresholds have been tripped.

### 6.4.2 Process Waters from Beneficiation

Beneficiation of ore commonly involves crushing and flotation, using recycled water complemented by make-up water, to accommodate losses and to maintain quality at an acceptable level for the process. The losses include evaporation and water entrained with

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product or waste materials. Water is also used to transport slurries (30-40 per cent solids) within the plant and wastes or tailings to appropriate impoundments.

In most cases, beneficiation process water is recycled. If that is the case, any NPI substances contained within the process water are neither emitted or transferred, as they are considered to be retained within the process.

The NPI reportable substances used or coincidentally produced in the beneficiation process can include substances such as ammonia, carbon disulfide from xanthate decomposition, copper sulfate, inorganic cyanide compounds (sodium cyanide) and methyl isobutyl carbonyl (MIBC) or methyl isobutyl ketone (MIBK). With regard to these substances, the following points should be noted:

- Copper sulfate is formed in copper heap leach operations or may be used as a flotation chemical.
- Where process waters are recycled no emissions of MIBC would be expected.
- Ammonia and hydrochloric acid have specific uses in nickel/cobalt and gold recovery respectively.
- Xanthates may be synthesised from carbon disulfide (CS<sub>2</sub>) and these substances decompose to form carbon disulfide. CS<sub>2</sub> is relatively insoluble in water (0.1g/L at 20°C) and volatile. For the purposes of NPI reporting, it can be assumed that all emissions of carbon disulfide are to air. Emission estimation techniques for characterising these emissions are provided in Section 5.8 of this manual. The one exception to this is where xanthates are used in a solvent extraction process. In such situations, they may be retained within the solvent, and can consequently be associated with a water emission if the solvent is discharged from the facility to a water course.

*Methyl isobutyl carbonyl is not a listed NPI substance, however it is considered a volatile organic compound and needs to be accounted for when determining emissions of Total Volatile Organic Compounds.*

### **6.4.3 Surface water run-off**

Surface water run-off includes runoff from haul roads, waste dumps, and administration areas and overflow from tailings dams.

In the case of process waters discussed previously, discharges to surface waters, coastal/marine waters, or groundwater will be reportable. Depending on the characteristics of the land surrounding the facility, run-off from other mineralised areas can also contain reportable metal compounds and will need to be estimated.

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#### **6.4.4 Leachate from stockpiles, overburden, waste rocks and tailings to surface waters**

Leachate will emanate from elevated features such as stockpiles, waste rock and overburden materials as a result of the seepage of excess process water and the infiltration of rainfall run-off. Leachate may also occur in pits as a result of leaching of waste rock material.

Ores commonly include sulfidic compounds (e.g. iron pyrite) which, after beneficiation, will be considered as a waste product. These materials will oxidise to form sulfate. In the absence of buffering capacity, oxidation of sulfates may result in acid drainage. The presence of acid drainage may also increase dissolved metal concentrations in leachate. Actual acid drainage generation depends on several site specific factors including management practices, nature of pyrite, crystal type and size, presence of neutralising materials in the associated rock, and availability of air and water to the material.

Emissions will be associated with overflows and/or discharges of excess mine process waters to surface waters, coastal/marine waters, or groundwater. All emissions of NPI substances are to be reported to the NPI.

Those flows of substances which are directed to, and contained by, purpose built facilities are to be reported as transfers.

### **6.5 Application of EETs for water emissions**

The following steps should be followed to determine the emissions that need to be estimated:

1. Identify and list all reportable substances associated with the mining operation that have triggered a threshold.
2. Identify and list all sources of waters used in the mine and the reportable substances present, or likely to be present, in these waters. In addition, the management of these waters should be considered to establish whether the particular water use is associated with a transfer or an emission. You should refer to the general discussion on transfers and emissions in Section 6.1 above to assist you with this.
3. Identify and list all emissions to water from the facility over the reporting period. In above-average rainfall years, the number of emission sources and soil erosion can be expected to increase.
4. Identify and list the data available on the facility to estimate the reportable emissions. This data could include total flows, flow rates after various rainfall/run-off events, suspended solids concentrations, concentrations of trace metals in various materials on the facility, and erosion rates. Supplementary information such as rainfall and rainfall patterns over the reporting period may also be available to assist with emissions estimation. It is recognised that the data available varies widely from facility to facility and a comprehensive range of data may not be available at all facilities. Wherever possible, emissions should be estimated based on site specific data.

#### **6.5.1 Direct monitoring - water quality and volume**

Where available, site specific information on water quality and flow rates should be used to determining emissions for the purposes of NPI reporting. General guidance on the use of monitoring and flow data for emissions estimation is provided in Appendix B. Data that might be routinely available to help estimate emissions include, but is not limited to:

- Water quality of certain effluent streams is likely to be routinely monitored with the specific variables analysed being dependent on site specific circumstances including the requirements of relevant licences and permits.

- Water flows and flow rates from specific catchments as a result of direct monitoring, or from estimations based on calibrated models, or engineering calculations, e.g. Australian rainfall and runoff.
- Quantities of reportable substances produced, consumed, and/or used at the facility over the reporting period.
- Typical quantities or concentrations of relevant consumables and process variables in the beneficiation plant (e.g. quantities of MIBC consumed, average grams of MIBC used per tonne of ore treated).
- Mineral composition and properties of relevant ores, concentrates, waste rock, spoils, tailings, soils, adjacent weathered rock, including those reportable substances present in trace quantities. Trace metal composition of some waste materials may be available from specific studies undertaken at the facility (e.g. geological modelling, analyses of surface materials to assess their suitability as growing media for rehabilitation). The ash composition of coals should be known, as this is routinely required by customers;
- Survey information that can be used to identify relevant matters such as mining blocks, dimensions of waste rock dumps, catchments, sub-catchments, and areas from which emissions could occur.
- Typical erosion rates from the mine area may be obtained by monitoring or interpretation of suitable models calibrated for the facility.

In many cases, not all of the data required will be available and emission estimates will need to be based on available data together with other information (e.g. default emission factors if available). For example:

- Flows may be known and survey data can be used to apportion part of the measured flow to run-off from mine operational areas.
- Trace metal concentrations of emissions may not be known and would need to be estimated from other site data as indicated in Section 6.5.2.

### **6.5.2 Estimation methods for non-monitored substances**

Where a reportable substance is not monitored, default concentrations will need to be inferred or developed to provide an estimate of emissions. When site specific trace element concentration data are not available, the typical concentrations presented in Appendix B can be utilised.

Where water soluble reportable substances occur on a mine site, data on the metal solubility and site specific flows should be used.

### **6.5.3 Mass balance calculations**

Mass balance involves the quantification of total materials into and out of a process with the difference being accounted for in terms of releases to air, water, and land, or as transfers. On a dry mass basis, for example, the mass of product will be the total quantity mined less the quantities of waste produced (e.g. waste rock and tailings). Similarly, a catchment area will be equal to the sum of the areas of its particular sub-catchments. Water losses at a plant will be the total water brought on site, less the water entrained in the waste and product streams, discharged to sewer and evaporated.

It is essential to recognise that the emission values produced when using mass balance are only as good as the values used in performing the calculations, and small errors in data can lead to potentially large errors in the final estimates. In the context of mining operations, the

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failure to use representative data can lead to significant inaccuracy in the predicted emissions.

#### 6.5.4 Estimation methods for leachate borne emissions

These emissions will generally be insignificant except in specific cases (e.g. when acid generation has resulted in elevated copper and cobalt sulfate concentrations and when water soluble reportable substances are present in locations where they may be discharged from the facility).

The estimation of emissions will need to take site specific circumstances and conditions into account. In particular, the following should be considered: the site water balance, rainfall infiltration and leachate volumes and flow rates, metal/substance concentrations in leachate waters, and the relevant properties of the leachate source materials (e.g. host rock, tailings materials).

#### 6.5.5 Estimation methods for acid drainage

Exposed sediments containing iron pyrite (acid sulfate soils) can be oxidised by air, which may result in an emission to water of sulfuric acid (i.e. acid drainage).

It may be assumed that unless it has been neutralised, the sulfuric acid may be present and that the emissions of sulfuric acid to water should be estimated using the following equation:

$$E_{\text{H}_2\text{SO}_4(\text{t/yr})} = A_{(\text{ha})} \times \frac{F_{(\text{kg/ha/yr})}}{1,000_{(\text{kg/t})}} \quad \text{Equation 4}$$

Where:

$$\begin{aligned} E_{\text{H}_2\text{SO}_4(\text{t/yr})} &= \text{Quantity of H}_2\text{SO}_4 \text{ emitted (t/yr)} \\ A_{(\text{ha})} &= \text{Area of exposed acid sulfate (pyritic) material (ha)} \\ F_{(\text{kg/ha/yr})} &= \text{Acid run-off emission factor (kg/ha/y) (default = 240)} \end{aligned}$$

Where site specific information is available, the emission factor F should be estimated by the equation below:

$$F_{(\text{kg/ha/yr})} = G_{\text{R}(\text{t/m}^3)} \times F_{\text{A}(\text{kg/t})} \times R_{\text{E}(\text{m}^3/\text{ha})} \quad \text{Equation 5}$$

Where:

$$\begin{aligned} F_{(\text{kg/ha/yr})} &= \text{Acid run-off emission factor (kg/ha/y) (default = 240)} \\ G_{\text{R}(\text{t/m}^3)} &= \text{Density of rock generating acid run-off (t/m}^3\text{), (default = 1.5)} \\ F_{\text{A}(\text{kg/t})} &= \text{Acid production potential per 1\% sulfur in rock (kg/t), (default = 16)} \\ R_{\text{E}(\text{m}^3/\text{ha})} &= \text{Erosion/exposure of material (m}^3\text{/ha), (default = 10)} \end{aligned}$$

(A discussion of the source of this emission factor is provided in Appendix B, Section 1.2).

## 6.6 Emissions to waters from specific operations

### 6.6.1 Open-cut mining operations

The first step is to identify emissions and transfers using the definitions presented in Section 6.1. Where applicable:

- Estimate direct emissions off-site (e.g. pumping of excess water from a pit to a water course).

- 
- Estimate the volume of run-off of contaminated waters (e.g. from activities such as road watering and general dust suppression) that is not directed to a suitable containment facility as defined in Section 6.1.
  - Estimate volumes of run-off from waste rock dumps and other site areas to estimate the mass of suspended solids transported off-site.
  - Estimate leachate emissions off-site. Where appropriate, include leachate that carries suspended solids loading.

Data for the above sources may not be directly available and you may need to use a combination of the techniques presented in this manual to estimate emissions. Appendix B of this manual illustrates the types of data that can be used to assist in determining emissions.

Direct emissions should be estimated from available data that may include pumping rates. The facility should nominate appropriate and realistic pumping rates that take head losses, leaks, and availability into account. When pumping rates have not been determined, it should be assumed that the rate is 80 per cent of the rated capacity for the particular pump and that the availability is equal to the operating hours for that pump.

### **6.6.2 Workshop and maintenance operations**

The first step is to identify reportable substances and the quantities of substances used from inventories and hazardous substances registers.

The quantities used will provide an estimate of the total emissions and transfers of NPI substances. It is expected that in most cases, reporting will be associated with air emissions, and characterised using the EETs in Section 5.7. If, however, emissions of these substances occur to water (e.g. from wash-down of floors), these may also need to be considered and estimated.

### **6.6.3 Underground mining operations**

Water from underground operations will be pumped to specific points from where it may be discharged, retained, recycled in the beneficiation plant, or used for road watering. As for open-cut mining operations (see Section 6.6.1 above), the first step is to identify emissions and transfers using the definitions presented in Section 6.1.

Emissions should be characterised based on available data on flow rates and NPI substance concentrations. The facility should nominate appropriate and realistic pumping rates that take head losses, leaks, and availability into account. When pumping rates have not been determined, it should be assumed that the rate is 80 per cent of the rated capacity for each pump in question and that the availability is equal to the operating hours for the pump.

### **6.6.4 Beneficiation operations**

Process water management, including the location and operation of facilities such as run of mine material storage, product storage, and tailings storage facilities will be dependent on site specific factors. A major factor will be the location of the ore body with respect to infrastructure areas and catchment/sub catchment areas within the lease.

The occurrence of reportable metal compounds in the materials handled in the plant will usually be known from mine and process monitoring. Similarly, the flotation reagents used and their rates of consumption should be known from process management and monitoring. Emissions from the beneficiation plant may be determined from monitoring data and the emission estimation process should have regard to the following:

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- the definition of transfers and emissions presented in Section 6.1
  - flows, volumes, and water balances for all aspects of the beneficiation operation, with particular emphasis on water losses to the environment (e.g. leachate and overflows from tailings storage facilities and discharges from the plant site)
  - the composition of target and trace metals in all materials handled, particularly in run-off waters;
  - available water quality monitoring data
  - materials lost from the plant. These would mainly be tailings and wastes and may also include spillages of materials (e.g. losses of concentrate, tailings, and overflows of process waters as a result of operational problems)
  - losses of reportable substances should be estimated directly or from mass balances involving the quantities of solids and liquids treated and their composition
  - mass balances of materials treated and flotation reagents used based on plant throughput, details of the particular plant and water circuit, and the composition of the materials handled
  - certain reportable substances will be consumed (e.g. cyanide) and substances such as carbon disulfide will be formed (see Section 6.4.2 for a discussion of this).

#### **6.6.5 Sewage treatment plants**

Many mine sites have on-site sewage treatment plants. The emissions from such plants can be characterised using the *Emission Estimation Technique manual for Sewage and Wastewater Treatment*.

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## 7 Emissions to land

Emissions to land are a highly site specific issue and there may not be default emission factors currently available to determine these emissions. The purpose of this section is to provide general guidance on approaches that can be adopted to determine these emissions, using information that is typically available (or can readily be gathered) for mining operations. Appendix B provides a number of worked examples to illustrate the application of the emission estimation techniques provided.

Emissions of substances to land include NPI substances contained in solid wastes, slurries, sediments, spills and leaks, and storage and distribution of liquids. Emission sources can be categorised as:

- surface impoundments of liquids and slurries
- unintentional leaks and spills
- emissions to groundwater
- agricultural applications of substances to land and irrigation.

Some facilities may use treated wastewater for irrigation. This wastewater need only be considered for NPI reporting if it contains an NPI listed substance. For NPI purposes this is generally categorised as an emission to land.

*When the emission is seen as beneficial, for example in the case of Total Nitrogen and Total Phosphorus in water recycled for use in irrigation. In this case the discharge may be reported as a voluntary transfer.*

### 7.1 Land emission sources

#### 7.1.1 Waste rock and spoil dumps

Substances discharged to tailings dams are regarded as transfers under the NPI and are not considered as emissions. However, discharges, spills and leaks from tailings dams are required to be reported as emissions to land.

The characterisation of such releases is highly site specific and simple emission factors are not available. In such situations, it is your responsibility to determine these emissions.

#### 7.1.2 Surface impoundments of liquids and slurries

Mine and process waters and contaminated surface water run-off may be contained in pits and/or purpose built structures such as tailings and environmental containment dams. NPI substances sent to tailings dams constitutes a transfer (see the definition presented in Section 8.1.1), providing that the reportable substances are contained within the particular site facilities.

Seepages to aquifers are treated as an emission to land, whilst overflows are water emissions if directly discharged to surface waters or water courses. Refer to Sections 6.4 for emission estimation techniques for emissions to water.

#### 7.1.3 Agricultural application of substances to land / irrigation

The application of NPI substances to land (e.g. for irrigation) are usually classed as an emission, any NPI substances contained in the irrigated liquid is reportable if reporting



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thresholds have been reached for the substances. If the application of total nitrogen and total phosphorus is considered beneficial, it may be reported as a voluntary transfer.

#### **7.1.4 Unintentional leaks, seepages and spills**

Under the NPI, spills, leaks, and seepage are required to be reported as emissions to land or water. If the discharge is to a body of water as per Section 6.2, then it should be reported as an emission to water. If the substance is volatile, it may be an emission to air rather than an emission to land or water.

To determine the emissions of NPI substances in spills and leaks, you should determine the difference between the quantity of material released or spilled and the quantity of material collected during the first 24 hours. The difference is the emission to land or water.

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## 8 Transfers of NPI substances in waste

It is mandatory to report NPI substances that are transferred in waste to a final destination. Transfers are required to be reported if a Category 1, Category 1b or Category 3 reporting threshold is exceeded. For example, if the threshold has been exceeded for the Category 1 substance - lead and compounds - as a result of use of this substance on site, transfers to final destination as well as emissions are reportable. Both emissions and transfers are reportable in kilograms.

There is no requirement to report transfers of:

- substances that are exclusively Category 2a or Category 2b;
- substances which are both Category 2a or Category 2b and Category 1 (e.g. copper and compounds) or Category 1b, in the event that the substance has tripped the Category 2a and 2b threshold only; or
- Total VOC (Category 1a, Category 2a and Category 2b).

### 8.1.1 What is a transfer?

A transfer is defined in the National Environment Protection (National Pollutant Inventory) Measure 1998 (NPI NEPM) as:

*“... the transport or movement, on-site or off-site, of substances to a mandatory reporting transfer destination or a voluntary reporting transfer destination.”*

A mandatory reporting transfer destination is defined in the NPI NEPM as:

*“(a) destination for containment including landfill, tailings storage facility, underground injection or other long term purpose-built waste storage structure;*

*(b) an off-site destination for destruction;*

*(c) an off-site sewerage system;*

*(d) an off-site treatment facility which leads solely to one or more of the above;”*

A containment destination may be on-site, such as a tailings storage facility on a mine site, or off-site, such as a landfill operated by a third party.

The transfer of NPI substances to a destination for reuse, recycling, reprocessing, purification, partial purification, immobilisation, remediation or energy recovery are defined in the NPI NEPM as “voluntary reporting transfer destinations” and transfers to such destinations can be reported voluntarily.

Further information regarding transfers, including how to estimate and report, can be found in *the NPI Guide* and *the Transfers Information Booklet*.

### 8.1.2 What is not a transfer?

A transfer does not include the transport or movement of substances contained in overburden, waste rock, uncontaminated soil, uncontaminated sediment, rock removed in construction or road building, or soil used for the capping of landfills.

A voluntary reporting transfer destination means a destination for reuse, recycling, reprocessing, purification, partial purification, immobilisation, remediation or energy recovery. While voluntary transfers are considered in the NPI NEPM, this manual focuses only on methodology concerned with mandatory transfers.

### 8.1.3 Example reporting

Table 8 lists a number of scenarios relevant to mining activities where reporting of transfers may be applicable. Other examples can be found in the *NPI Guide* and the *Transfers Information Booklet*.

**Table 8: Transfers reporting scenarios**

Scenario containing NPI substances	Reporting liability
Waste rock and overburden transported from mine face to dumps and stockpiles	No reporting required Movement of NPI substances in waste rock or overburden is not regarded as a transfer
Reshaping of the landform containing previous overburden or waste rock for rehabilitation or landscape management purposes	No reporting required Movement of NPI substances in waste rock, overburden or clean soil is not regarded as a transfer
Tailings containing NPI substances used to backfill an underground mine	Reporting is mandatory The tailings may contain metals and/or cyanide compounds or other NPI substances. Reporting is required.
Tailings directed to an on-site tailings storage facility	Reporting is mandatory The tailings may contain contaminant metals and cyanide compounds and/or other NPI substances.
Waste oil from the workshop collected by an outside contractor and transported to an offsite waste oil recycling facility	Reporting is voluntary If any of the oil is treated and recycled by the contractor then mandatory reporting is not necessary, however, voluntary reporting is encouraged.
Waste oil stored on-site due to oil recyclers being over-capacity	No reporting required until waste oil is moved off-site. Type of reporting (mandatory or voluntary) will depend on fate of the oil.
Process water sent to an on-site recycling process and prepared for reuse	No reporting required Onsite recycling of this nature does not trigger transfer reporting of NPI substances contained in the process water. Such recycling can be regarded as an internal process step.

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Materials sent to an non-process incinerator for disposal

Reporting is mandatory

NPI substances in the materials are to be included in transfers, since the transfer is to a final destination. Note that emissions from the incineration process are also reportable.

Spent 200L drums and used bulker bags deposited in an on-site landfill

Reporting is mandatory

NPI substances contained in the waste drums (e.g. chemicals remaining in the drums) are reportable as transfers, since the transfer is to a final destination. Any escape of NPI substances from the landfill site is reportable as an emission.

## 8.2 What should be reported?

Typical transfers encountered in mining operations are circumstances where NPI substances are:

- transferred to tailings storage facilities
- in tailings used to backfill an underground mine or above ground disused pit
- transferred to landfills (either on or off-site)
- sent to a non-process incinerator for disposal
- sent to sewer, where such a connection exists

The substances triggered by mining operations for the reporting of transfers are typically:

- metals and their compounds
- cyanide (inorganic) compounds
- hydrochloric, nitric, phosphoric and sulfuric acids
- ammonia
- some individual organic compounds (noting that Total VOC is not reportable as a transfer).

## 8.3 Transfers to tailings storage facilities

NPI substances deposited into tailings storage facilities are the primary form of mandatory reporting transfer for many mining operations. Availability of good monitoring data for all NPI substances in the input slurry is rare and almost never encompasses the breadth of substances that have triggered the reporting thresholds.

However, data about slurry flow volumes entering a tailings storage facility are more routinely measured, as are solid content estimates (the latter expressed as a percentage or density figure).

Because of data limitations, a number of assumptions apply in determining a practical approach to transfer estimation; in particular estimating NPI substance concentrations in the input slurry.

### 8.3.1 Metals assumed to be present in the solid phase only

A study of gold mining company's transfer data submitted for the first year of transfer reporting, suggests that the vast majority of metals discharged to tailings are located in the

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solid phase (Greenbase, TSF Transfer Comparison, August 2009). The geochemistry of each tailings storage facility, and hence the distribution of metal species between the solid and aqueous layers, will be different. However, in the absence of better site specific data, it can be assumed for the purposes of estimating transfers to tailings for the NPI that all of the metal species discharged into a tailings storage facility will be present in the solid phase.

This assumption has the effect, for metals and compounds transfer estimation, of eliminating the need to monitor the aqueous phase, including recycled process water removed from the tailings storage facility.

### **8.3.2 Non-target metals in tailings assumed to correlate to original ore concentration**

Due to data limitations, particularly for those NPI listed metals that are not of mining interest, i.e. ‘non-target’ metals, estimation of their transfer may require additional testing of the inlet slurry to the tailings storage facility. While this is encouraged as the most accurate method to apply, it is also recognised that a default concentration would be helpful.

For the purposes of estimating transfers to tailings for the NPI it can be assumed that the dry basis ore typical concentrations for these metals are equal to the dry basis solids concentrations entering the tailings storage facility. Since a mine is likely to have good data on the composition of their ore body, this may alleviate the need to analyse for metals concentrations in the input slurry. However, further testing may be warranted if the concentration of metals in the waste stream are significantly increased during target metal extraction. Annual input volume and solids content of the slurry will still be required.

This assumption cannot hold for ‘target’ metals, which are those deliberately mined. This is because the purpose of the processing is to extract as much as possible of these to maximise yield figures. For the purposes of estimating transfers to tailings for the NPI, measurements of these metals entering the tailings storage facility will be required.

### **8.3.3 Tailings return waters**

The aqueous component of tailings is typically recirculated after separation from the solids within the tailings storage facility. Consistent with other examples of process water recycling, the recirculated water is seen as neither an emission nor a transfer, because it is within the closed loop of an internal process step.

### **8.3.4 Cyanides estimation**

Estimation of cyanides within tailings is not readily simplified due to the complex nature of cyanide species and their varied interactions within the tailings geochemistry. Broadly speaking, cyanides may be bound as stable metal complexes within the solid phase, weaker metal complexes more readily soluble in the aqueous phase and simpler cyanide anions amenable to emission to air as hydrogen cyanide, particularly at lower than neutral pH and exposure to sunlight. A more detailed discussion of the fates of cyanide in gold mining can be found in the *Gold Processing Manual*, section 5.2.

An overview of the various fates of cyanide in a typical tailings storage facility is represented in Figure 5 below. A similar diagram depicts emissions from tailings storage facilities (to air, water and land) in the *Gold Processing manual*, section 5.2.3.

The total mass of cyanide lost within the tailings circuit (i.e. complexes with tailings solids, decomposed or emitted to the air or ground) may be estimated using the equation:

$$M_{\text{CN(kg)}} = M_{\text{i(kg)}} - M_{\text{r(kg)}} \quad \text{Equation 6}$$

Where:

- $M_{CN(kg)}$  = Mass of cyanide lost to TSFs (kg)  
 $M_i(kg)$  = Mass of cyanide carried to TSF (kg)  
 $M_r(kg)$  = Mass of cyanide in TSF return water (kg)

The total mass of cyanide reportable as a mandatory transfer to tailings and can then be determined by:

$$T_{CN(kg)} = M_{CN(kg)} - E_{CN(kg)} - S_{CN(kg)} - OF_{CN(kg)} \quad \text{Equation 7}$$

Where:

- $T_{CN(kg)}$  = Mass of cyanide **transferred** to TSFs (kg)  
 $M_{CN(kg)}$  = Mass of cyanide **lost** to TSFs (kg)  
 $E_{CN(kg)}$  = Mass of cyanide emitted to air (kg)  
 $S_{CN(kg)}$  = Mass of cyanide lost to seepage (kg)  
 $OF_{CN(kg)}$  = Mass of cyanide lost in overflow events (kg)

Transferred cyanide includes both cyanides bound in the solid phase and cyanides remaining in the aqueous phase. Cyanide volatilisation to air would be expected to be the most significant loss from the tailings storage facility, assuming low seepage rates and limited overflows caused by irregular events such as significant rainfall.

A complete discussion of the methodology for cyanide losses to air and its dependence on pH can be found in the *Gold Processing EET manual*, section 6.2.2.

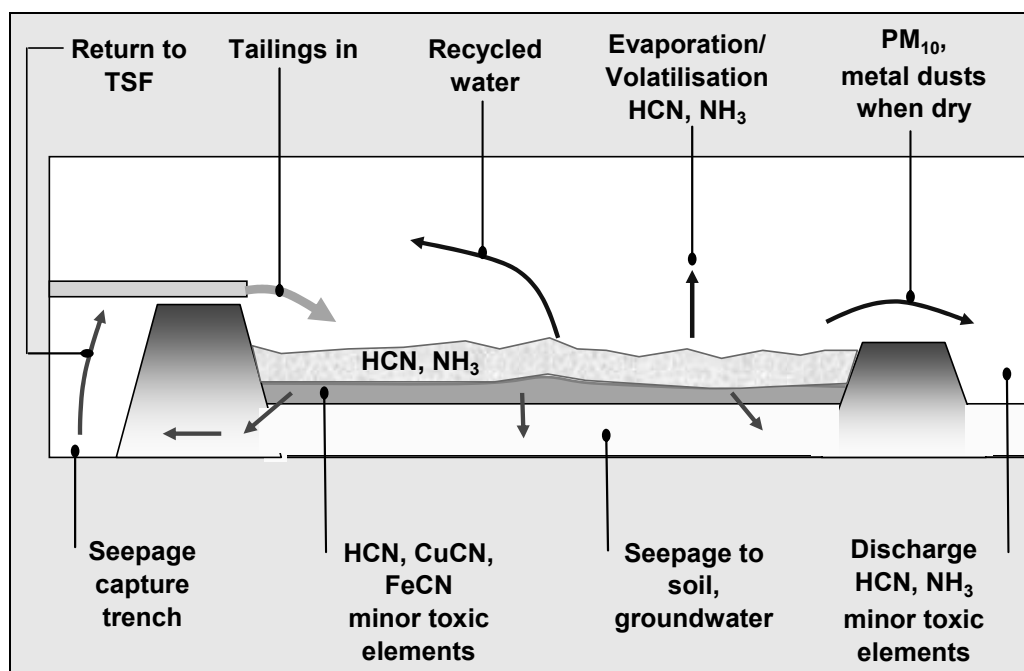


Figure 5: Overview of Tailings Storage Facility emission pathways<sup>4</sup>

## 8.4 Overview of estimation process

The following steps should be followed to determine the transfers that need to be estimated:

1. Identify and list all reportable NPI substances associated with the mining operation that

<sup>4</sup> Connell Wagner EET manual Gold Processing & Refining Review, June 2008

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have triggered a threshold.

2. Identify and list all sources of possible transfer points at the facility and the reportable substances present, or likely to be present.
3. Identify and list the data available on the facility to estimate the reportable transfers. Data would include ore concentrations, tailings input flow rates and total flows, solids concentration in tailings input, tailings return water flow rates and total flows, tailings return water NPI substance concentrations, tailings water pH, groundwater monitoring and seepage trench monitoring data. Supplementary information such as rainfall and rainfall patterns over the reporting period may also be available to assist with estimation. It is recognised that the available data may vary widely from facility to facility and a comprehensive range of data may not be available at all facilities. Wherever possible, transfers should be estimated based on site specific data.

## **8.5 Transfer Estimation Techniques (TETs)**

As described in Section 4, there are generally four types of transfer estimation techniques (TETs) that may be used to estimate transfers from your facility:

- sampling or direct measurement
- mass balance
- engineering calculations
- transfer factors.

Often a combination of these is required depending on what site specific data are available.

Site specific measured data will always provide more accurate information than default data, and should be used wherever possible.

### **8.5.1 Direct Monitoring – waste stream concentration and volume**

The approach to direct monitoring of transfers is analogous to direct monitoring of water emissions of NPI listed substances. A measure of the typical concentration of NPI substances in the waste stream is required, which can then be multiplied by the typical volume of the waste stream that has been transferred in the reporting period.

If the waste stream is solid or slurry, such as in the case of inputs into a tailings storage facility or a landfill, representative concentration measurements of the solid/ slurry need to be obtained. Alternatively, estimates of these concentrations may be acceptable, such as the use of non-target metals ore composition data in the case of a tailings transfer. In either case the solids concentration is usually expressed as a “dry basis” to standardise for variable water (or moisture) content between different samples.

This concentration must then be multiplied by the volume of that solid or slurry material that has been transferred, adjusted for water content to convert to dry basis.

If the waste stream is a liquid, such as in the case of transfers to sewer, the same approach applies, but simplifies because of the lack of “dry basis” conversion required, i.e., both the concentration and volume figures are measured on a liquid basis. These are simply multiplied together, adjusting for any unit conversions.

### **8.5.2 Mass balance calculations**

Mass balance can be an appropriate approach to estimating transfers, particularly in the case of tailings storage facilities. This requires information about all NPI substance inputs and

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outputs from a process to determine the unknown component, in this case the amount of the substance transferred.

See Section 8.3, for an example of a mass balance approach to determine the amount of total cyanide remaining in the tailings storage facility.

*Accuracy of a mass balance equations is dependent on the accuracy of the individual input or output data, due to the compounding effect of uncertainties in individual measurements.*

### **8.5.3 Engineering calculations**

Engineering calculations are a catch-all technique used to describe calculations that estimate emissions based on known chemical or physical processes such as chemical reactions. This approach tends to be more applicable to emissions estimation.

### **8.5.4 Emissions from transfer destinations**

There is potential for emissions to air, water or land from transfer destinations such as landfills and tailings storage facilities. When considering possible emissions to land in particular, the following guidance should be noted:

- Where the permeability of underlying strata is  $< 10^{-6}$  m/s, the potential for the release of NPI substances to land (soil and/or groundwater) should be insignificant. Emissions of suspended sediment will be effectively absent as fine material will block pores in the strata thereby reducing its permeability and effectively sealing the strata.
- The presence of fractures in the substrata will increase the potential for substances to migrate to aquifers.
- Most metal species at mines are sulfides that have typical solubilities of  $< 10\text{-}20$  g/L at neutral pH. Unless there are huge volumes of water in very permeable strata, metal losses to groundwater will be negligible.
- Waste containers such as 200 litre drums will always contain residual quantities of their contents. Where containers of reportable substances (e.g. solvents and reagents) are placed in landfills, unless specific data are available, it should be assumed that two kilograms of the substance per container are placed in the landfill. Migration of those substances from the landfill site will depend on the site's permeability.



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## REFERENCES

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NERDDC (1988), Air Pollution from Surface Coal Mining: Volume 2 Emission Factors and Model Refinement, National Energy Research and Demonstration Council, Project 921.

Pitt, O., Fugitive PM<sub>10</sub> Emission Factors, 15th International Clean Air and Environment Conference, Sydney, 27-30 November 2000, p303-306.

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

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USEPA (1998), 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.

Greenbase (2009).

The following Emission Estimation Technique manuals referred to in this manual can be obtained from the NPI website:

- *EET manual for Fossil Fuel Electric Power Generation*
- *EET manual for Combustion in Boilers*
- *EET manual for Combustion in Engines*
- *EET manual for Sewage and Wastewater Treatment*
- *EET manual for Explosives Detonation*
- *EET manual for Fuel and Organic Liquid Storage*
- *EET manual for Zinc Concentrating, Smelting and Refining*
- *EET manual for Lead Concentrating, Smelting and Refining*
- *EET manual for Nickel Concentrating, Smelting and Refining*
- *EET manual for Copper Concentrating, Smelting and Refining*
- *EET manual for Gold Ore Processing.*

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## Errata

### **Mining manual Erratum (Version 3.1 - January 2012) – Previous version 3.0 issued June 2011.**

Page	Outline of alteration
15, 16, 48 and 55	Correction to equations related to wheel generated dust from unpaved roads at industrial sites and excavators, shovels and front-end loaders on coal.

### **Mining manual Erratum (Version 3.0 - June 2011) – Previous version 2.3 issued December 2001.**

Page	Outline of alteration
throughout	Rewrite of manual by SIA Environmental Change to ANZSIC 2006
2	Update of activities associated with open cut and underground mining
6	Discussion of threshold calculations and development of a substance usage inventory
7	Added Table 1: Location of useful material speciation profiles to determine substance usage Added Example 1: Calculating the total mass of Category 1 substance used
8	Added Example 2: Calculating usage across reporting periods
15	Updates to Default emission factors for various operations at coal mines (including change in table number from 1 to 2)
20	Updates to Default emission factors for various operations at metaliferous mines (including change in table number from 2 to 3)
22	Added Table 5: Typical mining vehicle definitions Removed Table 4 from previous manual, this information is now found in the <i>Emission Estimation Technique Manual for Combustion in Engines</i> .
24	Updated discussion of carbon disulphide emissions from xanthates
26	Updated discussion of emissions to water
34	Updated discussion of emissions to land
36	Addition of discussion of transfers of NPI substances
44	Errata moved to end of manual
46	Updated discussion of suitable emission factors

### **Mining manual Erratum (Version 2.3 - 05 December 2001) – Previous version 2.2 issued 23 October 2000.**

Page	Outline of alteration
13	The moisture cut off for high and low moisture Bauxite has been lowered to 5wt%.

### **Mining manual Erratum (Version 2.2 - 23 October 2001) – Previous version 2.1 issued 11 October 2000.**

Page	Outline of alteration
40	The first reference to moisture content in the last paragraph was changed to silt content.

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**Mining manual Erratum (Version 2.1 - 11 October 2000) – Previous version 2.0 issued 22 August 2000.**

Page	Outline of alteration
12 Table 1	For wheel generated dust on paved roads the k value for the TSP equation is changed from 0.74 to 2.82 and for the PM <sub>10</sub> equation from 0.35 to 0.733.
40 A1.1.11	ki for TSP changes from 0.74 to 2.82 and for PM <sub>10</sub> from 0.35 to 0.733

**Mining manual Erratum (Version 2.0 - 22 August 2000) – Previous version issued March 1999.**

Page	Outline of alteration
1	Highlights that manual includes Uranium mining
7	Change of web address for AP-42 emission factors from the USEPA
9	Inclusion of overall control efficiency factor in Equation 1 (CEi)
12	Major changes to table 1 – Include Wheel generated dust form unpaved roads - Change of emission factors for scrapers – Addition of coefficients for new equation for dust from unpaved roads
14	Alteration in Bauxite emission factor – table 2
18	Discussion referring to xanthates in general rather than only to sodium ethyl xanthate
19	Reference to combustion engines manual to estimatengine emissions
21	Deletion on triggering reporting (previously 5.1.2)
34	Addition of definition of Bank Cubic Metres (bcm)
35	Addition of units to PM <sub>10</sub> equation, kg/bcm Deletion of line providing k for PM <sub>10</sub> calculations
38	Replace dust with TSP
39	TSP emission factor changes from 2.07 to 1.64
40	Specify calculation in A1.1.11 is for unpaved road and provide equation details.
50	Deletion of case C from table

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# APPENDIX A

## - EMISSION ESTIMATION TECHNIQUES - AIR

### 1 DISCUSSION ON INDIVIDUAL EMISSION FACTOR EQUATIONS

This appendix provides information on the sources of the emission factor equations and emission factors presented in Table 5-1 and Table 5-2 of this manual. Most of the equations and factors have been drawn from AP-42 (USEPA (1985) and USEPA (1998)) and the National Energy Research, Development and Demonstration Council (NERDDC, 1988) and State Pollution Control Commission of NSW (SPCC, 1983) studies in the Hunter Valley. When information from both sources (i.e. the US and Australia) is available, the two have been compared and, where possible, reconciled. Emission factors for both PM<sub>10</sub> (required to be reported under the NPI) and TSP (necessary as a basis for determining emissions of metal species) are provided and discussed.

#### 1.1 COAL MINES

The emission factor equations and emission factors discussed in this section relate to coal mining activities. However, as noted in Section 5 of this manual, many of these equations are also relevant to activities on metalliferous mines.

##### 1.1.1 Draglines (on overburden)

This operation refers to the removal of overburden by a dragline. It is recommended that the equations be used where there is site specific data for drop distance and/or moisture content. If not, the default values should be used.

##### TSP & PM<sub>10</sub>

The TSP equation used is as follows:

$$EF_{TSP} \text{ (kg/bcm)} = 0.0046 \times \left( \frac{d^{1.1} \text{ (m)}}{M^{0.3} \text{ (\%)}} \right) \quad \text{Equation 8}$$

$$EF_{PM_{10}} \text{ (kg/bcm)} = 0.0022 \times \left( \frac{d^{0.7} \text{ (m)}}{M^{0.3} \text{ (\%)}} \right) \quad \text{Equation 9}$$

Where:

$EF_{TSP} \text{ (kg/bcm)}$  = emission factor for total suspended particles

$EF_{PM_{10}} \text{ (kg/bcm)}$  = emission factor for PM<sub>10</sub>

$d^{1.1} \text{ (m)}$  = drop distance in meters

$M \text{ (\%)}$  = moisture content of overburden in % (by weight)

bcm = bank cubic meter (i.e. the volume of material in-situ prior to blasting)

#### Example 4: Particulate matter for draglines

A mine is using a dragline on overburden with a moisture content of 2% by weight, the drop distance of the material is 12m.

$$d = 12 \text{ m}$$

$$M = 2\%$$

For TSP

$$EF_{\text{TSP (kg/bcm)}} = 0.0046 \times \left( \frac{12^{1.1}(\text{m})}{2^{0.3}(\%)} \right)$$

$$EF_{\text{TSP (kg/bcm)}} = 0.057 \text{ kg/bcm.}$$

For PM<sub>10</sub>

$$EF_{\text{PM}_{10} \text{ (kg/bcm)}} = 0.0022 \times \left( \frac{12^{0.7}(\text{m})}{2^{0.3}(\%)} \right)$$

$$EF_{\text{PM}_{10} \text{ (kg/bcm)}} = 0.0102 \text{ kg/bcm}$$

In the absence of site specific information on drop distance and moisture content, an emission factor of 0.06 kg/bcm for TSP and 0.01 kg/bcm for PM<sub>10</sub> is recommended

#### Alternative method of calculating PM<sub>10</sub> emissions:

The NERDDC value for TSP is 0.072 kg/bcm. To convert this to PM<sub>10</sub> it is appropriate to use particle size data measured by the SPCC (1983). This data indicates that for draglines in the Hunter Valley, approximately 43% of TSP particles will be in the PM<sub>10</sub> range. Thus the NERDDC estimate of PM<sub>10</sub> emissions from dragline operations in the Hunter Valley is 0.031 kg/bcm.

#### Notes on source and suitability of equation:

The AP-42 equation, gives results that are consistent with the Hunter Valley work (NERDDC, 1988), providing that sensible drop distances and moisture contents are used. The NERDDC study measured an average emission factor of 0.072 kg/bcm for two Hunter Valley mines.

A 1% moisture content (also plausible for the Hunter Valley) gives an emission factor of 0.071 kg/bcm. Both of these are comparable with 0.072 kg/bcm measured in the NERDDC study.

#### Default values:

In the absence of site specific data and based on the emission factor for TSP of 0.06 kg/bcm, the recommended default PM<sub>10</sub> emission factor is  $0.06 \times 0.43 = 0.026$  kg/bcm.

#### 1.1.2 Excavators/shovels/front-end loaders (on overburden)

The equation in the previous manual gave values that were unrealistically low, so it is recommended that the default values derived from NERDCC and SPCC work are used.

#### Default values:

The NERDDC (NERDDC, 1988) work provides an estimate of TSP emissions from truck loading operations of 0.025 kg/t.

SPCC (1983) measurements in the Hunter Valley indicate that approximately 47% of TSP particles will be in the PM<sub>10</sub> range. The recommended PM<sub>10</sub> emissions factor is therefore  $0.025 \times 0.47 = 0.012$  kg/t.

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### Notes on source and suitability of equation:

The USEPA (USEPA, 1998: Section 13.2.4-3) provides an equation for batch loading, which give estimates that are unrealistically low for Australian conditions. The USEPA (USEPA: 1988: Section 11.9-10, Table 11.9-4) provides a further emission factor for “Truck loading by power shovel (batch drop)”. The TSP factor is 0.018 kg/t. The note provided with this figure however, encourages the user to make use of the equation rather than the 0.018 kg/t factor.

#### TSP & PM<sub>10</sub>

$$EF_{TSP} \text{ (kg/t)} = k_{TSP} \times 0.0016 \times \frac{\left(\frac{U_{(m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M_{(\%)}}{2}\right)^{1.4}} \quad \text{Equation 10}$$

$$EF_{PM_{10}} \text{ (kg/t)} = k_{PM_{10}} \times 0.0016 \times \frac{\left(\frac{U_{(m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M_{(\%)}}{2}\right)^{1.4}} \quad \text{Equation 11}$$

Where:

$EF_{TSP} \text{ (kg/t)}$  = emission factor for total suspended particles (kg/t)

$EF_{PM_{10}} \text{ (kg/t)}$  = emission factor for PM<sub>10</sub> (kg/t)

$k_{TSP}$  = 0.74 for particles less than 30 micrometres aerodynamic diameter

$k_{PM_{10}}$  = 0.35 for particles less than 10 micrometres aerodynamic diameter

$U_{(m/s)}$  = mean wind speed (m/s)

$M_{(\%)}$  = moisture content (% by weight)

#### 1.1.3 Excavators/shovels/front-end loaders (on coal)

The equation in the previous manual gave values that were unrealistically low, so it is recommended that the alternative USEPA equation specifically for the loading of coal (USEPA, 1998: Table 11.9-1) be used.

In the absence of site specific data on moisture content, the default values derived from NERDCC and SPCC work should be used.

#### TSP & PM<sub>10</sub>

$$EF_{TSP} \text{ (kg/t)} = \frac{0.580}{M^{1.2}} \quad \text{Equation 12}$$

$$EF_{PM_{10}} \text{ (kg/t)} = \frac{0.0447}{M^{0.9}} \quad \text{Equation 13}$$

Where:

$EF_{TSP} \text{ (kg/t)}$  = emission factor for total suspended particles (kg/t)

$EF_{PM_{10}} \text{ (kg/t)}$  = emission factor for PM<sub>10</sub> (kg/t)

$M$  = moisture content in % (by weight)

### Example 5: Excavator/shovels/front-end loader on coal

A coal mine is using an excavator on coal with a moisture content of 8%, the emission factor for TSP and PM<sub>10</sub> is calculated as follows:

$$EF_{TSP} \text{ (kg/t)} = \frac{0.580}{M^{1.2}}$$

$$EF_{TSP} \text{ (kg/t)} = \frac{0.580}{8^{1.2}}$$

$$EF_{TSP} \text{ (kg/t)} = 0.048 \text{ kg/t}$$

$$EF_{PM_{10}} \text{ (kg/t)} = \frac{0.0447}{M^{0.9}}$$

$$EF_{PM_{10}} \text{ (kg/t)} = \frac{0.0447}{8^{0.9}}$$

$$EF_{PM_{10}} \text{ (kg/t)} = 0.0069 \text{ kg/t}$$

#### Default values:

The NERDDC (1988) Hunter Valley work provides an emission factor for TSP of 0.029 kg/t.

If this TSP emission factor is adjusted using the particle size measurements obtained in the SPCC (1986) study, then 48% of the TSP fraction (0 to 30 µm) can be taken to be PM<sub>10</sub> particles. Thus, the default PM<sub>10</sub> emission factor becomes 0.014 kg/t.

#### Notes on source and suitability of equation:

As for overburden, the USEPA equation for batch loading seems to give estimates that are unrealistically low when applied to loading coal to trucks. Using Equation 10. If M is taken to be 8% (typical for ROM coal in the Hunter Valley) and U=3.6 m/s, the TSP emission factor is 0.00032 kg/t. Clearly, the US data provides a very different result to that quoted in the NERDDC study.

$$EF_{TSP} \text{ (kg/t)} = k_{TSP} \times 0.0016 \times \frac{\left(\frac{3.6 \text{ (m/s)}}{2.2}\right)^{1.3}}{\left(\frac{8(\%)}{2}\right)^{1.4}}$$

$$EF_{TSP} \text{ (kg/t)} = 0.74 \times 0.0016 \times \frac{\left(\frac{U \text{ (m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M(\%)}{2}\right)^{1.4}}$$

$$EF_{TSP} \text{ (kg/t)} = 0.00032 \text{ kg/t}$$

The number derived from using the suggested equations above are very close to the Hunter Valley factors from the NERDDC (1988) study, adjusted to obtain the PM<sub>10</sub> fraction (using the SPCC (1983) study), 0.014kg/t. Therefore, it is suggested that the USEPA (1998: Table 11.9-1) equation should be used with the actual moisture levels that apply for ROM coal.

### 1.1.4 Bulldozers on Coal

#### TSP & PM<sub>10</sub>

The TSP and PM<sub>10</sub> emission factor equation for bulldozers on coal are as follows (USEPA, 1988):

$$EF_{TSP} \text{ (kg/hr)} = 35.6 \times \frac{s^{1.2(\%)}}{M^{1.4(\%)}} \quad \text{Equation 14}$$

$$EF_{PM_{10}} \text{ (kg/hr)} = 6.33 \times \frac{s^{1.5(\%)}}{M^{1.4(\%)}} \quad \text{Equation 15}$$

Where:

$EF_{TSP} \text{ (kg/hr)}$  = emission factor for total suspended particles (kg/hr)

$EF_{PM_{10}} \text{ (kg/hr)}$  = emission factor for total suspended particles (kg/hr)

$s(\%)$  = silt content in %, by weight

$M(\%)$  = moisture content of overburden in % (by weight)

#### Example 6: Bulldozer on coal

A coal mine is using a bulldozer on material with a silt content of 7% and moisture content of 2.5%. Using equations 14 and 15, the emission factors are:

$$EF_{TSP} \text{ (kg/hr)} = 35.6 \times \frac{7^{1.2(\%)}}{2.5^{1.4(\%)}}$$

$$EF_{TSP} \text{ (kg/hr)} = 102 \text{ kg/hr}$$

$$EF_{PM_{10}} \text{ (kg/hr)} = 6.33 \times \frac{7^{1.5(\%)}}{2.5^{1.4(\%)}}$$

$$EF_{PM_{10}} \text{ (kg/hr)} = 32.5 \text{ kg/hr}$$

### 1.1.5 Bulldozer on Material other than Coal

#### TSP & PM<sub>10</sub>

The emission factor equation for TSP and PM<sub>10</sub> are as follows:

$$EF_{TSP} \text{ (kg/hr)} = 2.6 \times \frac{s^{1.2(\%)}}{M^{1.3(\%)}} \quad \text{Equation 16}$$

$$EF_{PM_{10}} \text{ (kg/hr)} = 0.34 \times \frac{s^{1.5(\%)}}{M^{1.4(\%)}} \quad \text{Equation 17}$$

Where:

$EF_{TSP} \text{ (kg/hr)}$  = emission factor for total suspended particles (kg/hr)

$EF_{PM_{10}} \text{ (kg/hr)}$  = emission factor for total suspended particles (kg/hr)

$s(\%)$  = silt content in %, by weight

$M(\%)$  = moisture content of overburden in % (by weight)



### Example 7: Bulldozer on material other than coal

A mine is using a bulldozer on ore material with a silt content of 10% and a moisture content of 2%. Using equations 16 and 17 the emission factors are:

$$EF_{\text{TSP}} (\text{kg/hr}) = 2.6 \times \frac{10^{1.2(\%)}}{2^{1.3(\%)}}$$

$$EF_{\text{TSP}} (\text{kg/hr}) = 17 \text{ kg/h}$$

$$EF_{\text{PM}_{10}} (\text{kg/hr}) = 0.34 \times \frac{10^{1.5(\%)}}{2^{1.4(\%)}}$$

$$EF_{\text{PM}_{10}} (\text{kg/hr}) = 4.1 \text{ kg/hr}$$

#### 1.1.6 Truck (Dumping Overburden)

The equation given in the previous manual's appendix gave values that were unrealistically low, so it is recommended that the default values derived from NERDCC and SPCC work are used.

*If a site specific size fraction is available, then this should be used in preference to the SPCC default.*

#### Default values:

The NERDDC (1988) TSP emission factor for dumping overburden is 0.012 kg/t.

SPCC (1983) measurements in the Hunter Valley indicate that approximately 35.5% of TSP particles from trucks unloading overburden will be in the PM<sub>10</sub> range. The recommended PM<sub>10</sub> emission factor is therefore 0.012 x 0.355 = 0.0043 kg/t.

Notes on source and suitability of equation:

The USEPA (1998) uses the same equation for unloading overburden as it does for loading overburden. Again this gives an emission factor that appears to be too low for Australian mining operations.

#### 1.1.7 Truck (Dumping Coal)

The equation in the previous manual's appendix gave values that were unrealistically low, so it is recommended that the default values derived from NERDCC and SPCC work are used.

*If a site specific size fraction is available, then this should be used in preference to the SPCC default.*

#### Default values:

The NERDDC TSP emission factor for dumping coal is 0.01 kg/t.

SPCC (1983) measurements in the Hunter Valley indicate that approximately 42% of TSP particles from truck unloading operations will be in the PM<sub>10</sub> range. The recommended PM<sub>10</sub> emissions factor is therefore 0.01 x 0.42 = 0.0042 kg/t.

#### Notes on source and suitability of equation:

The USEPA (1998) uses the same equation as for the loading of coal (see Section 1.1.3

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above). Again, this gives an emission factor that appears to be too low for Australian mining conditions.

### 1.1.8 Drilling

It is recommended that the USEPA default emission factors are used to estimate drilling emissions.

Note if a site specific size fraction is available, then this should be used in preference to the SPCC default.

#### Default values:

TSP: 0.59 kg/hole

PM<sub>10</sub>: 0.31 kg/hole

#### Notes on source and suitability of equation:

Emissions from drilling are a relatively minor component of the overall emission from an open-cut mine. The only available emission equation for drilling is a simple uncontrolled TSP emission factor of 0.59 kg/hole (USEPA, 1998: Table 11.9-4). Clearly, other variables such as the depth of the hole, diameter of the hole, and moisture content of the material being drilled would also be relevant and it might be supposed that an emission factor equation should take account of these variables. However, in the absence of other data (and given the relatively minor contribution of this source to overall emissions from mining operations), it is reasonable to accept the 0.59 kg/hole factor for TSP.

USEPA (1998) does not provide an emission factor for the PM<sub>10</sub> component. However, some measurements were obtained during the Hunter Valley studies (SPCC, 1983). The mean fraction of PM<sub>10</sub>/TSP for the four available samples was 0.52 (with a standard deviation of 0.10). These relate to drilling of overburden, and probably, there will be a difference for coal. However, in the absence of other information, the best estimate of the emission factor for drilling for PM<sub>10</sub> is 0.31 kg/hole.

### 1.1.9 Blasting

#### TSP

The previous version of the mining manual used the following equation for calculating an emission factor for blasting (AP-42 Ch 11, Appendix E). In the *Improvement of NPI fugitive particulate matter emission estimation techniques* report by SKM (2005) it was recommended that Equation 18 be replaced with Equation 19 as it was believed that Equation 18 overestimated the TSP from blasting activities. A comparison of the two equations is shown in Figure 6, from this comparison which was based on a moisture content of 5% and various blasting depths there is reasonable agreement between the two when the blasting depth is 30m.

$$EF_{TSP \text{ (kg/blast)}} = \frac{344 \times A^{0.8} \text{ (m}^2\text{)}}{M^{1.9} \text{ (\%)} \times D^{1.8} \text{ (m)}} \quad \text{Equation 18}$$

Where

A<sub>(m<sup>2</sup>)</sub> = the area blasted (m<sup>2</sup>)

M<sub>(%)</sub> = the moisture content of the blasted material (% by weight)

D<sub>(m)</sub> = the depth of the blast hole (m)



$$EF_{TSP} \text{ (kg/t)} = k_{TSP} \times 0.0016 \times \frac{\left(\frac{U_{(m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M_{(\%)}}{2}\right)^{1.4}} \quad \text{Equation 20}$$

$$EF_{PM_{10}} \text{ (kg/t)} = k_{PM_{10}} \times 0.0016 \times \frac{\left(\frac{U_{(m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M_{(\%)}}{2}\right)^{1.4}} \quad \text{Equation 21}$$

Where:

- $EF_{TSP} \text{ (kg/t)}$  = emission factor for total suspended particles (kg/t)
- $k_{TSP}$  = 0.74 for particles less than 30 micrometres aerodynamic diameter
- $EF_{PM_{10}} \text{ (kg/t)}$  = emission factor for  $PM_{10}$  (kg/t)
- $k_{PM_{10}}$  = 0.35 for particles less than 10 micrometres aerodynamic diameter
- $U_{(m/s)}$  = mean wind speed (m/s)
- $M_{(\%)}$  = moisture content (% by weight)

### Example 9: Wheel and bucket emissions

Using default values of 3.6 m/s for wind speed and 8% moisture content, the TSP emission factor is:

$$EF_{TSP} \text{ (kg/t)} = k_{TSP} \times 0.0016 \times \frac{\left(\frac{U_{(m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M_{(\%)}}{2}\right)^{1.4}}$$

$$EF_{TSP} \text{ (kg/t)} = 0.74 \times 0.0016 \times \frac{\left(\frac{3.6}{2.2}\right)^{1.3}}{\left(\frac{8}{2}\right)^{1.4}}$$

$$EF_{TSP} \text{ (kg/t)} = 0.00032 \text{ kg/t}$$

$$EF_{PM_{10}} \text{ (kg/t)} = k_{PM_{10}} \times 0.0016 \times \frac{\left(\frac{U_{(m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M_{(\%)}}{2}\right)^{1.4}}$$

$$EF_{PM_{10}} \text{ (kg/t)} = 0.35 \times 0.0016 \times \frac{\left(\frac{3.6}{2.2}\right)^{1.3}}{\left(\frac{8}{2}\right)^{1.4}}$$

$$EF_{PM_{10}} \text{ (kg/t)} = 0.00015 \text{ kg/t}$$

#### Notes on source and suitability of equation:

A significant proportion of open-cut coal mining for softer brown coals is carried out using bucket wheel excavators. The moisture content of these coals is generally very high and dust emissions are generally minor. In the absence of a specific emission factor it is recommended

that the equation for miscellaneous transfer and conveying be used. This will be a very small component of the overall inventory.

### 1.1.11 Wheel generated dust from unpaved roads

#### Notes on source and suitability of equation:

The AP-42 manual for miscellaneous sources (Chapter 13.2.2. Nov 2006) has new equations for wheel-generated dust from unpaved roads. There is an equation for “unpaved roads at industrial sites” and another for “publicly accessible roads, dominated by light duty vehicles”. The first one is higher (more analogous to the equation in the previous manual). Note that the original equations are for imperial measurements. Some conversion factors have been included where necessary.

#### Example 10: Unpaved roads from wheels

Using default values for surface material silt content of 10% and a vehicle gross mass of 48 t, with the k value of 1.38 gives the following default TSP emission factor for wheel generated dust:

$$EF_{(kg/VKT)} = \frac{0.4536}{1.6093} \times k \times \left( \frac{s(\%)}{12} \right)^a \times \left( \frac{W(t)}{3} \right)^b$$

Where:

$k_{TSP}$  = 4.9 for total suspended particles

$k_{PM_{10}}$  = 1.5 for  $PM_{10}$

$s(\%)$  = silt content of material (%)

$W(t)$  = vehicle mass (t)

$a_{TSP}$  = 0.7 (empirical constant)

$a_{PM_{10}}$  = 0.9 (empirical constant)

$b$  = 0.45 (empirical constant)

This results in the following emission factors

$$EF_{(kg/VKT)} = \frac{0.4536}{1.6093} \times k \times \left( \frac{s(\%)}{12} \right)^a \times \left( \frac{W(t)}{3} \right)^b$$

$$EF_{TSP(kg/VKT)} = \frac{0.4536}{1.6093} \times 4.9 \times \left( \frac{10}{12} \right)^{0.7} \times \left( \frac{48}{3} \right)^{0.45}$$

$$EF_{TSP(kg/VKT)} = 4.23 \text{ kg/VKT}$$

$$EF_{PM_{10}(kg/VKT)} = \frac{0.4536}{1.6093} \times k_{PM_{10}} \times \left( \frac{s(\%)}{12} \right)^a \times \left( \frac{W(t)}{3} \right)^b$$

$$EF_{PM_{10}(kg/VKT)} = \frac{0.4536}{1.6093} \times 1.5 \times \left( \frac{10}{12} \right)^{0.9} \times \left( \frac{48}{3} \right)^{0.45}$$

$$EF_{PM_{10}(kg/VKT)} = 1.25 \text{ kg/VKT}$$

The emission factor for TSP for a light duty vehicle was calculated using the same value for silt content, a vehicle speed of 50km/hr and a moisture content of 2%. The k value for this

equation is 1.69 and the values for B and C are both 0.3.

$$EF_{(kg/VKT)} = k \times \frac{\left(\frac{S(\%)}{12}\right) \times \left(\frac{S(km/hr)}{48}\right)^B}{\left(\frac{M(\%)}{0.5}\right)^C} - 0.0013$$

Where:

$k_{TSP}$  = 1.69 for total suspended particles

$k_{PM_{10}}$  = 0.51 for  $PM_{10}$

$S(\%)$  = silt content of material (%)

$S_{(km/hr)}$  = vehicle speed (km/hr)

$W_{(t)}$  = vehicle mass (t)

$M_{(\%)}$  = moisture content (% by weight)

B = (empirical constant)

C = (empirical constant)

$$EF_{TSP(kg/VKT)} = k_{TSP} \times \frac{\left(\frac{S(\%)}{12}\right) \times \left(\frac{S(km/hr)}{48}\right)^{0.3}}{\left(\frac{M(\%)}{0.5}\right)^{0.3}} - 0.0013$$

$$EF_{TSP(kg/VKT)} = 1.69 \times \frac{\left(\frac{10}{12}\right) \times \left(\frac{50}{48}\right)^{0.3}}{\left(\frac{2}{0.5}\right)^{0.3}} - 0.0013$$

$$EF_{TSP(kg/VKT)} = 0.94 \text{ kg/VKT}$$

The emission factor for  $PM_{10}$  for a light duty vehicle was calculated using the same default values for silt content, vehicle speed and moisture content as above. The k value for  $PM_{10}$  is 0.51, and the values for B and C are 0.5 and 0.2, respectively.

$$EF_{PM_{10}(kg/VKT)} = k_{PM_{10}} \times \frac{\left(\frac{S(\%)}{12}\right) \times \left(\frac{S(km/hr)}{48}\right)^B}{\left(\frac{M(\%)}{0.5}\right)^C} - 0.0013$$

$$EF_{PM_{10}(kg/VKT)} = .51 \times \frac{\left(\frac{10}{12}\right) \times \left(\frac{50}{48}\right)^{0.5}}{\left(\frac{2}{0.5}\right)^{0.2}} - 0.0013$$

$$EF_{PM_{10}(kg/VKT)} = 0.33 \text{ kg/VKT}$$

### 1.1.12 Scraper (travel mode)

The equation in the previous version of this manual was incorrectly copied from the 1995 (5<sup>th</sup> edition) of AP-42. (It was  $9.6 \times 10^{-6}$  in AP-42, but is stated as  $7.6 \times 10^{-6}$  in the manual). Also, the original AP-42 equation is for scrapers in travel mode, but the previous manual incorrectly said the equation is for topsoil removal by scrapers.

### Example 11: Scraper when travelling

Using values fairly typical of conditions on Australian mines of 10% silt content, and gross vehicle mass of 48t, the emission factor for TSP can be calculated as follows:

$$EF_{(kg/VKT)} = \frac{k \times s_{(\%)}^{1.3} \times W_{(t)}^{2.4}}{1,000,000}$$

Where:

$s_{(\%)}$  = silt content of material (%)

$W_{(t)}$  = vehicle mass (t)

$k_{TSP}$  = 9.6 for total suspended particles

$k_{PM_{10}}$  = 1.32 for  $PM_{10}$

$$EF_{TSP (kg/VKT)} = \frac{k_{TSP} \times s_{(\%)}^{1.3} \times W_{(t)}^{2.4}}{1,000,000}$$

$$EF_{TSP (kg/VKT)} = \frac{9.6 \times 10^{1.3} \times 48^{2.4}}{1,000,000}$$

$$EF_{TSP (kg/VKT)} = 2.08 \text{ kg/VKT}$$

$$EF_{PM_{10} (kg/VKT)} = \frac{k_{PM_{10}} \times s_{(\%)}^{1.3} \times W_{(t)}^{2.4}}{1,000,000}$$

$$EF_{PM_{10} (kg/VKT)} = \frac{1.32 \times 10^{1.3} \times 48^{2.4}}{1,000,000}$$

$$EF_{PM_{10} (kg/VKT)} = 0.53 \text{ kg/VKT}$$

#### 1.1.13 Scraper (removing topsoil)

AP-42 (1998) gives a new factor (not an equation) for topsoil removal by scraper. Note this is in kg/t of topsoil.

##### Default values:

AP-42 gives an emission factor of 0.029kg/t for TSP emissions produced by scrapers while removing topsoil.

The  $PM_{10}$  emission factor is derived using the same  $PM_{10}$ /TSP fraction as for the scraper in travel mode (i.e. 25%).

$$EF_{TSP (kg/t)} = 0.029 \text{ kg/t}$$

$$EF_{PM_{10} (kg/t)} = 0.0073 \text{ kg/t}$$

#### 1.1.14 Graders

The equations for the emission factors for estimating TSP and  $PM_{10}$  from grading are from AP-42 (USEPA, 1998). The equations are very sensitive to the operating speed assumed.

## Example 12: Graders

Assuming a vehicle speed of 5km/h, the emission factor for estimating TSP is calculated as follows:

$$EF_{TSP} \text{ (kg/VKT)} = 0.0034 \times S^{2.5} \text{ (km/hr)}$$

$$EF_{PM_{10}} \text{ (kg/VKT)} = 0.0034 \times S^{2.0} \text{ (km/hr)}$$

Where:

$$S_{\text{(km/hr)}} = \text{vehicle speed (km/hr)}$$

$$EF_{TSP} \text{ (kg/VKT)} = 0.0034 \times S^{2.5} \text{ (km/hr)}$$

$$EF_{TSP} \text{ (kg/VKT)} = 0.0034 \times 5^{2.5} \text{ (km/hr)}$$

$$EF_{TSP} \text{ (kg/VKT)} = 0.19 \text{ kg/VKT}$$

$$EF_{TSP} \text{ (kg/VKT)} = 0.0034 \times S^{2.0} \text{ (km/hr)}$$

$$EF_{TSP} \text{ (kg/VKT)} = 0.0034 \times 5^{2.0} \text{ (km/hr)}$$

$$EF_{TSP} \text{ (kg/VKT)} = 0.085 \text{ kg/VKT}$$

### 1.1.15 Primary and Secondary Crushing and Loading/Unloading Coal to/from Stockpiles

These activities include primary crushing of coal, secondary crushing of coal, loading of coal to stockpiles, or vehicles. In practice, these are very small contributors to the overall particulate emissions from typical coal mines.

#### LOADING STOCKPILES

$$EF_{TSP} \text{ (kg/t)} = 0.004 \text{ kg/t}$$

$$EF_{PM_{10}} \text{ (kg/t)} = 0.0017 \text{ kg/t}$$

#### UNLOADING FROM STOCKPILES

$$EF_{TSP} \text{ (kg/t)} = 0.03 \text{ kg/t}$$

$$EF_{PM_{10}} \text{ (kg/t)} = 0.013 \text{ kg/t}$$

#### LOADING TO TRAINS

$$EF_{TSP} \text{ (kg/t)} = 0.0004 \text{ kg/t}$$

$$EF_{PM_{10}} \text{ (kg/t)} = 0.00017 \text{ kg/t}$$

### 1.1.16 Miscellaneous Transfer and Conveying

AP-42 (USEPA, 1998) provides an emission factor equation for a continuous loading operation, which should be used to estimate emissions from conveyor transfer points.

## Example 13: Transfer and Conveying

Using typical values for mean wind speed (3.6m/s) and moisture content (8%), and a k value of 0.74, the emission factor for TSP for each transfer point is calculated as follows:



$$EF_{\text{(kg/t/transfer point)}} = k \times 0.0016 \times \frac{\left(\frac{U_{\text{(m/s)}}}{2.2}\right)^{1.3}}{\left(\frac{M_{\text{(%)}}}{2}\right)^{1.4}}$$

Where:

$k_{\text{TSP}}$  = 0.74 for total suspended particles

$k_{\text{PM}_{10}}$  = 0.35 for  $\text{PM}_{10}$

$U_{\text{(m/s)}}$  = mean wind speed (m/s)

$M_{\text{(%)}}$  = moisture content (%)

$$EF_{\text{TSP (kg/t/transfer point)}} = k_{\text{TSP}} \times 0.0016 \times \frac{\left(\frac{U_{\text{(m/s)}}}{2.2}\right)^{1.3}}{\left(\frac{M_{\text{(%)}}}{2}\right)^{1.4}}$$

$$EF_{\text{TSP (kg/t/transfer point)}} = 0.74 \times 0.0016 \times \frac{\left(\frac{3.6}{2.2}\right)^{1.3}}{\left(\frac{8}{2}\right)^{1.4}}$$

$$EF_{\text{TSP (kg/t/transfer point)}} = 0.00032 \text{ kg/t/transfer point}$$

$$EF_{\text{PM}_{10} \text{ (kg/t/transfer point)}} = k_{\text{PM}_{10}} \times 0.0016 \times \frac{\left(\frac{U_{\text{(m/s)}}}{2.2}\right)^{1.3}}{\left(\frac{M_{\text{(%)}}}{2}\right)^{1.4}}$$

$$EF_{\text{PM}_{10} \text{ (kg/t/transfer point)}} = 0.35 \times 0.0016 \times \frac{\left(\frac{3.6}{2.2}\right)^{1.3}}{\left(\frac{8}{2}\right)^{1.4}}$$

$$EF_{\text{PM}_{10} \text{ (kg/t/transfer point)}} = 0.00015 \text{ kg/t/transfer point}$$

### 1.1.17 Wind erosion from active coal stockpiles

The SPCC (1983) average value for wind erosion is 0.4 kg/ha/h (3,504 kg/ha/year). It is suggested that this value be adopted as a default in the absence of other information.

AP-42 (USEPA, 1998) states that 50% of the TSP is emitted as  $\text{PM}_{10}$ . Therefore, the default emission factor for  $\text{PM}_{10}$  is 0.2 kg/ha/h. If site specific particle size data are available, this should be used.

The AP-42 emission factor equation for wind erosion is:

$$EF_{\text{TSP (kg/ha/yr)}} = 1.9 \times \left(\frac{s_{\text{(%)}}}{1.5}\right) \times 365 \times \left(\frac{365 - p}{235}\right) \times \left(\frac{f_{\text{(%)}}}{15}\right) \quad \text{Equation 22}$$

Where:

$s_{\text{(%)}}$  = silt content (% by weight)

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$p$  = number of days per year when rainfall is greater than (0.25 mm)  
 $f_{(\%)}$  = percentage of time that wind speed is greater than 5.4 m/s at the mean height of the stockpile

Taking  $s=15\%$ ,  $p=80$  d/y and  $f=30\%$ ,  $EF_{TSP(kg/ha/yr)}$  is estimated to be 16,821 kg/ha/yr, which is equal to 1.92 kg/ha/h. This is believed to be a high estimate for Australian conditions. It is recommended that the SPCC (1983) default values be used.

**Default values:**

$$EF_{TSP(kg/ha/hr)} = 0.4 \text{ kg/ha/hr}$$

$$EF_{PM_{10}(kg/ha/hr)} = 0.2 \text{ kg/ha/hr}$$

### 1.1.18 Wind erosion from other exposed areas (chitter/waste emplacement dams and wind erosion from exposed areas)

In the absence of other information, it is recommended that the SPCC (1983) factor of 0.4 kg/ha/h be adopted for TSP. In a similar manner to active stockpiles, it can be assumed that 50% of TSP is in the  $PM_{10}$  fraction.

**Notes on source and suitability of equation:**

While the emission estimation equation for stockpiles presented in 1.1.17 above, can be used for characterising emissions from other exposed areas, dams are frequently located in sheltered, or low lying areas where wind speeds may be lower than typically measured.

**Default values:**

$$EF_{TSP(kg/ha/hr)} = 0.4 \text{ kg/ha/hr}$$

$$EF_{PM_{10}(kg/ha/hr)} = 0.2 \text{ kg/ha/hr}$$

### 1.1.19 Highwall mining

Highwall mining is a relatively new technique in Australian coal mines. It involves boring horizontally into the open-cut highwall. The coal cutting point is essentially underground and dust would not be expected to be released into the atmosphere, except at the point where the coal is brought to the open air on the pit floor. It is assumed that the dust generated would be equivalent to that for continuous loading operations. Dust from all other activities associated with handling the coal (e.g. loading it to trucks, transporting by road) will need to be considered using the various emission factors presented in Table 2 of this manual.

The emission factor suggested is for miscellaneous transfer and conveying as shown in section 1.1.16.

**Default values:**

$$EF_{TSP(kg/t/transfer\ point)} = 0.00032 \text{ kg/t/transfer point}$$

$$EF_{PM_{10}(kg/t/transfer\ point)} = 0.00015 \text{ kg/t/transfer point}$$

## 1.2 METALLIFEROUS MINES

### 1.2.1 General Comments

As for coal mines, metalliferous mines can be either underground or open-cut. For underground mines, those activities that take place do not contribute to dust emissions to the environment except for emissions from ventilation shafts. The emission from ventilation shafts should be estimated based on the average concentration of dust in the vented air and the

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annual volume of air vented.

Unlike the coal mining industry, metalliferous mines in Australia have not conducted field measurement programs to determine emission factors. As a consequence, there are no local emissions factors available to test the validity of USEPA emission factors.

Emission factors that are common between metalliferous and coal mines are:

- topsoil removal by scraper;
- bulldozers;
- drilling;
- blasting;
- haul truck traffic on premises;
- light/medium traffic on sealed roads;
- graders;
- wind erosion from stockpiles;
- truck loading (metalliferous mines as for overburden, not coal); and
- truck loading.

However, it is acknowledged that emissions will vary from mine to mine.

The emission factors that are different for metalliferous mines when compared with coal mines are:

- primary ore crushing;
- secondary ore crushing;
- tertiary crushing;
- wet grinding;
- dry grinding with air conveying or classifying;
- dry grinding without air conveying or classifying;
- drying;
- emissions from integrated de-dusting systems; and
- miscellaneous handling, transfer and conveying.

### 1.2.2 Loading Trucks and Unloading Trucks (rear dumping)

The USEPA equation (**Equation 10**) for batch loading/unloading is:

$$EF_{TSP} \text{ (kg/t)} = k_{TSP} \times 0.0016 \times \frac{\left(\frac{U_{(m/s)}}{2.2}\right)^{1.3}}{\left(\frac{M_{(\%)}}{2}\right)^{1.4}} \quad \text{Equation 10}$$

Where:

- $EF_{TSP} \text{ (kg/t)}$  = emission factor for total suspended particles (kg/t)  
 $EF_{PM_{10}} \text{ (kg/t)}$  = emission factor for  $PM_{10}$  (kg/t)

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$k_{TSP}$	= 0.74 for particles less than 30 micrometres aerodynamic diameter
$k_{PM_{10}}$	= 0.35 for particles less than 10 micrometres aerodynamic diameter
$U_{(m/s)}$	= mean wind speed (m/s)
$M_{(%)}$	= moisture content (% by weight)

This equation has the same inherent difficulty as it does in its application to coal mining: namely that the estimated emissions are very small. For example, with an average wind speed of 3.6 m/s and moisture content of 2%, the emission factor is 0.0022 kg/t.

For Australian mines, the dumping of overburden on coal mines has been calculated to generate 0.012 kg/t and the loading of trucks using a truck and shovel has been calculated to generate 0.0249 kg/t (NERDDC, 1988). The equation therefore provides estimates that are significantly less (a factor of 5 to 10 less) than appears reasonable based on the NERDDC measurements. However, the only option available seems to be to use the equation.

It should be noted that using the NERDDC (1988) equations for coal mine overburden to estimate emissions from the handling of ore may exaggerate emissions from ore handling, given that overburden is frequently weathered, and is likely to contain a higher fraction of fine material than many ores.

### 1.2.3 Other Processing Steps

Other processing steps include:

- primary ore crushing;
- secondary ore crushing;
- tertiary crushing;
- wet grinding;
- dry grinding - with air conveying;
- dry grinding without air conveying;
- drying; and
- emissions from integrated de-dusting systems.

The emission factor quoted for these activities in Table 2 is drawn from USEPA (1998, Section 11.24).

When considering emissions from metalliferous mining operations, it is useful to note that any ore (except bauxite) with moisture greater than 4% by weight, either naturally or by virtue of added water, is considered as a “high moisture” ore. If an ore is “high moisture” at the primary crusher, then it will remain so unless it is dried in the process. The other issue to note is that the emission factors quoted in Table 2 apply to all operations typically associated with the process. Therefore, emissions from a primary crushing activity include emissions from the screens, the crusher, the surge bin, the apron feeder, and conveyor belt transfer points that are integral to the crusher.

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# **APPENDIX B**

## **- EMISSION ESTIMATION TECHNIQUES - WATER & LAND**

### **1 INTRODUCTION**

The purpose of this appendix is to provide additional guidance on the characterisation of emissions to water and land. This appendix should be read in conjunction with Sections 6 and 7 of this manual and provides:

- Information on default concentrations of NPI substances in various rock and ore types (Section 1.1), including some discussion on the suitability of this data for use in emission estimation.
- General guidance on how to apply the emission estimation techniques presented in the manual, the types of data that may be available to assist in emission estimation, as well as some clarification of the term ‘transfers’ as it applies to mining (Section B.1.2).
- A discussion of the use of monitoring data for the characterisation of emissions
- A discussion of the use of mass balance as an emission estimation technique (Section 1.4).
- A discussion of the types of site specific data that may be available to assist in emissions estimation (Section 1.5).
- A series of worked examples to illustrate the application of the EETs provided for water and land.

**Table 8: Table of important elements**

Element1	Symbol	Atomic Weight <sup>2,3</sup> (Rounded)	Element	Symbol1	Atomic Weight <sup>2,3</sup> (Rounded)
Aluminium	Al	27	Iron	Fe	56
Antimony	Sb	122	Lead	Pb	207
Arsenic	As	75	Magnesium	Mg	24
Barium	Ba	137	Manganese	Mn	55
Beryllium	Be	9	Mercury	Hg	201
Bismuth	Bi	209	Molybdenum	Mo	96
Boron	B	11	Nickel	Ni	59
Cadmium	Cd	112	Nitrogen	N	14
Calcium	Ca	40	Oxygen	O	16
Carbon	C	12	Phosphorus	P	31
Chlorine	Cl	35	Selenium	Se	79
Chromium	Cr	52	Silicon	Si	28
Cobalt	Co	59	Silver	Ag	108
Copper	Cu	64	Sulfur	S	32
Fluorine	F	19	Tin	Sn	119
Gold	Au	197	Zinc	Zn	65
Hydrogen	H	1	Zirconium	Zr	91

1. It should be noted that the following are not NPI substances: aluminium, barium, bismuth, calcium, gold, iron, molybdenum, oxygen, silicon, silver, and zirconium. Some of the other substances listed are reportable only in certain forms (e.g. carbon disulfide). The information has been provided for the purposes of assisting you to calculate the proportion of NPI substances in compounds/minerals .
2. Based on atomic weight of carbon 12
3. Atomic weights can be used to calculate the weight of a reportable metal in minerals. For example, the chemical formula of chalcopyrite is  $\text{CuFeS}_2$  and its atomic weight will be  $64 + 56 + (2 \times 32) = 184$ . A tonne of chalcopyrite will therefore contain about 0.34 (64/184) tonnes of copper.

**Table 9: Naturally occurring concentrations of elements reportable under the NPI in various materials (all in mg/kg or g/tonne)**

Element	Symbol	Basalt	Granite	Coal	Soil	Earth's Crust	Marine Clays	Marine Carbonates	Shale	Limestone	Sandstone	Sediment
Antimony	Sb	0.69	0.2	3.5	1	0.2	1	0.05	1.5	0.3	0.05	1.2
Arsenic	As	1.5	1.5	6.5	6	1.5	13	1	13	1	1	7.7
Beryllium	Be	0.3	5	1	0.3	2.6	2.6		3	<1	<1	2
Boron	B	8	12	70	20	10	230	55	130	20	30	100
Cadmium	Cd	0.13	0.09	0.2	0.35	0.11	0.21	0.23	0.22	0.028	0.05	0.17
Chromium	Cr	200	4	20	70	100	90	11	90	11	35	72
Cobalt	Co	35	1	5.4	8	20	74	7	19	0.1	0.3	14
Copper	Cu	90	13	15	30	50	25	30	39	5.5	30	33
Fluorine	F	510	1,400	-	200	950	730	550	800	220	180	640
Lead	Pb	3	24	30	35	14	80	17	23	5.7	10	19
Manganese	Mn	1,500	400	41	1,000	950	6,700	1,000	850	620	460	770
Mercury	Hg	0.12	0.08	0.23	0.06	0.05	0.08	0.46	0.18	0.16	0.29	0.19
Nickel	Ni	150	0.5	15	50	80	225	30	68	7	9	52
Selenium	Se	0.05	0.05	2.9	7	0.05	0.17	0.17	0.5	0.03	<0.01	0.42
Zinc	Zn	150	240	31	90	190	150	20	160	20	220	150

1. Extracted and adapted from Bowen, H.J.M. 1979. Environmental Chemistry of the Elements, Academic Press and generally checked against Berkman, D.A. 1989 Field Geologist's manual, The Australasian Institute of Mining and Metallurgy.
2. The figures listed above are average concentrations of the particular element within the rock or material specified.
3. The NPI requires the reporting of emissions of the elements listed in this Table and their compounds (apart from fluoride compounds, nickel carbonyl and nickel subsulfide). As noted in the body of the manual, it is recognised that trace metal analyses are not routinely undertaken for mining operations. Where data on particular elements is not available, the average concentrations listed above for the particular material type should be used as a suitable default. In situations where this information is used, there are likely to be significant uncertainties in the emissions estimate and a low reliability would be attached to them
4. Further to Note 3, trace metal concentrations will be significantly greater than average where the reportable metal occurs at the site. For example, at a silver, lead or zinc mine, the concentrations of lead, zinc and probably cadmium in waste rocks, tailings and soils will be significantly greater than the average concentrations listed in the above Table. It

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is expected that where it is necessary to use an assumed trace metal concentration to estimate emissions from a site, the facility will nominate a credible figure that can be justified to your local environmental agency.



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## 1.1 General assumptions for emission estimation techniques

The methods outlined in this manual for the estimation of emissions from mine sites take the following matters and/or assumptions into account:

Routine monitoring ensures that environmental performance standards are met as are licence and permit requirements. In general monitoring will be directed to actual and perceived environmental issues that are significant for the particular mine. While it is not envisaged that facilities will need to conduct monitoring beyond that which is currently required, available monitoring data should be used to assist in determining emissions for the purposes of NPI reporting (see Section B.1.3 for a further discussion of this).

Reportable emissions are confined to the substances that are actually emitted to the environment. Materials retained in tailings storage facilities, sediment from disturbed areas held in ponds or pits and waste rock/spoil dumps are examples of transfers (see Section 8 for a further discussion of “transfer” as these terms apply to mining operations).

Volatile substances, such as chlorinated solvents and volatile organic compounds, are assumed to generate emissions to air. Similarly, carbon disulfide formed as a result of the decomposition of xanthates is assumed to be reported as an air emission. Methyl Isobutyl Carbinol (MIBC) held in a water or tailings storage facilities will be metabolised relatively quickly and, where retention times exceed about four weeks, there should be no emissions of MIBC to water.

MIBC emissions must be reported where there are overflows from water/tailings storage and/or leaks and discharges from the beneficiation plant. In these cases, the emission estimations should be based on the standard concentration of MIBC used in the plant and the volume of water discharged to the environment. If the MIBC concentration is not known, a figure of 10g/m<sup>3</sup> of water discharged should be assumed.

Actual emissions depend on a range of variables including materials handling and management practices, physical and chemical properties of wastes and soils, local topography, climate (including climatic extremes), slope, vegetation cover, moisture infiltration and related matters. These factors will vary from facility to facility and it is generally not possible to provide generic equations that will be applicable across the mining industry. It is therefore recognised that the estimation of emissions requires the application of techniques and methods that are appropriate to the facility. This section of the manual provides some guidance on the approaches that may be used when data from definitive monitoring is not available.

It is not the intention of the NPI to require facilities to extend or expand monitoring beyond that currently being conducted. In these situations it is considered acceptable to use figures based on the average concentration of trace metals in the various materials identified in Table 9 (NB: This is subject to the limitations indicated in Footnote 5 to the Table).

The heterogeneous distribution of minerals, including trace elements, between and within mine sites, requires detailed and rigorous sampling to accurately determine the concentrations of these minerals and substances within various areas of the mine operation. Emission estimates that use monitoring data and consider the distribution of substances and their emissions, will generally give reliable figures. Where assumptions or general terms or figures are used in calculations, inherent errors will be introduced and the reliability of the estimates will decrease. Where there are several steps and a number of assumptions required to estimate emissions, the use of generic data can lead to significant reductions in the accuracy of the estimates.

Sulfide or silicate materials typically have solubility coefficients of < 10-20 g/L. In general, it is not necessary to determine emissions of low solubility species separately from suspended solids emissions. In these circumstances, emissions of dissolved substances with low solubility would fall within the range of general estimation errors. For example, total losses of dissolved metals where flows are > 10<sup>10</sup> L/y would be measured in grams. In contrast, emissions of suspended solids may be in kilogram to tonne quantities with the accuracy of these emissions estimate likely, at best, to be ± 10%. As the maximum possible dissolved metal emission, say 10 grams, falls well within the total emission, say 100 kg ± 10 kg, it is not valid to report the emission as 100.01 kg/y.

Where site specific estimates of erosion are not available, the general figures indicated in the Table below may be used.

**Table 10: Erosion rates**

Erosion Rate	Guideline
40 tonnes per hectare per annum (t/ha/yr)	Exposed soils, vegetation cover <25%, dispersive material with high silt / clay content including tailings and similar materials.
20 tonnes per hectare per annum (t/ha/y)	areas disturbed by mining operations, including waste dumps, cleared land and infrastructure. other cases
<1 tonnes per hectare per annum (t/ha/y)	well vegetated sites and areas dominated by competent rock

1. Source: Personal Communication, C. Carroll, Department of Natural Resources, Emerald, Queensland (unpublished Thesis).
2. Note: Where sediment control structures are installed, the sediment estimates may be derived from filterable residues from dam discharges instead of run-off values.

Erosion of 40 t/ha/y may occur in areas with dispersive or loose soils with poor vegetation cover and rainfall of about 900 mm per annum. This can be used as a representative figure for “high erosion rate” and should be used for these situations, including direct erosion of tailings type materials.

Erosion from well vegetated sites and areas dominated by competent rock may be less than 1 t/ha/y under similar rainfall conditions and this may be regarded as “low erosion rate”. Where erosion data are not available, a figure of 20 t/ha/y may be assumed for the purposes of NPI reporting. (This figure may be applied to areas disturbed by the mining operation including waste dumps, cleared land and infrastructure.)

It should be noted that the above figures generally relate to average rainfall conditions and should be adjusted to reflect actual rainfall over the reporting period. Where rainfall is below average and up to 1.3 times higher than the average rainfall, a pro rata adjustment to the erosion rate should be made. Where rainfall is over 1.3 times annual rainfall the pro rata adjustment should be increased by 40% to fully account for the additional erosion that would be expected because of the higher rainfall.

Determination of sulfuric acid generation from pyrite oxidation is a complex matter and should be determined on a site by site basis. Acid drainage generated will be neutralised by naturally occurring alkaline materials. Therefore, pH and sulfate concentrations cannot be used in isolation to estimate sulfuric acid generation and emissions. This is discussed further in Section 6.5.5.

Where the pH of the discharge is considered acidic, sulfuric acid emissions must be estimated, preferably using site specific data. When site specific data are not available, it should be assumed that sulfuric acid generation is 240 kg/ha of exposed acid-generating material. (This is calculated on the basis that the oxidation of material with a 1% pyrite

content and no neutralising capacity will result in the generation of about 16 kg sulfuric acid per tonne of acid generating rock. The erosion/exposure of 1 mm of this material equates to 10 m<sup>3</sup>/ha, which at a density of 1.5 t/m<sup>3</sup> would have a mass of 15 t/ha, hence, 240 (15 x 16) kg per hectare).

### 1.1.1 Typical Data Availability

A summary of the data typically available at mine sites for use in emission estimation is provided below:

### 1.1.2 Fugitive Emissions: Dust

**Table 11: Fugitive emissions (Dust)**

Parameter	Availability
Drop in metres for draglines	Limited (from on-site estimates)
Moisture content of soil (%)	Available most sites
Mean wind speed (m/s)	Available most sites
Area blasted (m <sup>2</sup> )	Available
Depth of blast holes (m)	Available most mines
Silt content of soil (%)	Limited
Vehicle gross mass	Available
Mean vehicle speed (km/h)	Limited (estimates based on site speed limits)
Average level of reportable substances in overburden	Limited
Average level of reportable substances in waste rock	Limited
Average level of reportable substances in ore	Available some sites

### 1.1.3 Fugitive Emissions: Metals

**Table 13: Fugitive Emissions: Metals**

Parameter	Availability
Assay data	Limited
volume of fuel used per type of vehicle (tracked type tractor, wheeled tractor, scraper, grader, off-highway truck)	Available some sites
Water balance information	Limited
Reportable substances leaving the site either dissolved in water or as suspended solids	Very limited
Content in process waters	Available some sites
Content in surface water runoff	Available some sites

Leachate from stockpiles, overburden, waste rocks, and tailings to surface waters Available some sites

#### 1.1.4 Emissions to Waters

**Table 14: Emissions to Waters**

Parameter	Availability
Concentration of reportable substances	Very limited
Flow rate	Very limited
Quantities of reportable substances used in Workshops and maintenance operations	Generally available
Flows, volumes and water balances (leachate from tailings storage facilities & waste rock dumps)	Very limited
Composition of target and trace metals in all materials handled and in run-off waters	Available some sites
Water quality monitoring data	Limited parameters
Quantities of materials lost in any way from plant (e.g. tailings, coarse rejects, spillages)	Available some sites

## 1.2 Use of Monitoring and Flow Data

Monitoring and flow data can be used to estimate dissolved and suspended sediment emissions from specific catchments. When complete data sets are available (e.g. real time monitoring of flows, metal concentrations in water determined from specific monitoring), mass emission estimates will be relatively reliable. Where there are several catchments contributing to a measured flow (e.g. downstream monitoring of a mining lease where water quality is influenced by run-off from non-mining catchments plus run-off from areas affected by the mining operation) errors may be introduced when allocating a proportion of the flow to the mining operations. Similarly, if complete data are not available, an “average” metal concentration calculated from an incomplete data set will probably incorporate errors. Consequently the reliability of the estimate will be significantly reduced and should be noted in reporting.

### 1.2.1 Data Required/Available and Qualifications/Errors

The data that may be available and relevant comments on that data are described in the following table. It is recognised that certain data may be available from monitoring at different locations at the facility and therefore may only provide a partial characterisation of emissions (or only enable emissions from a specific area of the facility to be determined).

**Table 12: Potential data sources**

Variable	Comment
Water Balance	The water management plan for the facility may describe water management practices under general and extreme rainfall conditions. Run-off over the reporting period may be estimated from site data including water consumption, production losses and rainfall.
Flow and Flow Rate	May be directly monitored and total flows can be reported for each rainfall event. May be estimated from the cross sectional area of the water course and flow rates. Inherent errors due to differences in flow rates within water courses, (e.g. centre flows faster than the sides and bottom). May be estimated from Australian Rainfall and Run-off with site calibration.
Rainfall	Actual rainfall will vary significantly over large sites, particularly when storm events provide a high proportion of total rainfall. Site rainfall data should be used where available. Alternatively data from the nearest meteorological station may be used. Care should be taken to ensure that the data from off-site meteorological stations is representative of rainfall at a particular site.
Rainfall Run-off	Actual emissions will relate to run-off from the site which will depend on variables such as slopes, soil or rock types and properties, vegetation cover, soil permeability and moisture content, total rainfall, rainfall intensity and water use. Significant variations will occur between sites and from year to year at the same site. When flow data are not available, guidance on run-off as a proportion of total rainfall can be obtained from personnel within regional offices of state/territory Government primary industry and/or water resources departments.
Water Quality Data	The data will depend on the samples taken, the variables analysed and the analytical methods used. Water quality samples are commonly collected using automatic samples, for subsequent analysis. Continual monitoring and recording may be conducted for certain parameters (e.g. pH, electrical conductivity, and specific metals). Samples containing suspended solids may be filtered to provide an analysis of the filtrate and give dissolved metal concentrations. Analysis of the total sample, involving an acid digestion will give the total metal concentration in the sample (i.e. dissolved plus suspended solid material). As most metal species are insoluble, a relatively high metal concentration would suggest an acid digest. If data on concentrations of total metals is not available, it may not be necessary to estimate these from other information sources
Suspended Solids	Information on suspended solids can be obtained from gravimetric techniques from sampling or direct monitoring data. Such analyses do not usually include trace element concentrations. If suspended solids data are available, mass balance calculations can be used to estimate emissions.
Survey	Mine surveys will give data on land use within the area of interest

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Information (e.g. all sections of the mine, stockpiles, infrastructure, tailings and environmental dams, cleared and undisturbed areas). While catchment areas of each feature can be measured accurately, run-off, infiltration and sediment transport characteristics will vary. Without calibration for the site, any emission estimates based on sub-catchment areas will introduce errors.

Trace element data on solids (e.g. waste rock, concentrate, tailings) Trace metal concentrations may be routinely available from process monitoring (e.g. of concentrates and tailings). Trace metals will be present in waste rocks and sub-economic ore. Data may be available from geological modelling of the deposit. If representative data are not available for all waste rock types, estimates from incomplete data will introduce errors.

Relevant Background Data Background data may be available from monitoring and environmental studies (e.g. water quality data, trace element concentration in soils, suspended solids loadings).

In summary, where reliable flow and water chemistry data are available, emissions of metals and trace elements can be determined with a reasonable degree of accuracy. Reportable emissions can be calculated from the product of the flows and the trace element concentrations for those flows. Care should be taken to ensure that the data are sufficient to fully account for variations over the reporting period.