National Pollutant Inventory

Emission Estimation Technique Manual

for

MINING

Version 2.3

Disclaimer

The manual was prepared in conjunction with Australian States and Territories according to the National Environment Protection (National Pollutant Inventory) Measure.
While reasonable efforts have been made to ensure the contents of this manual are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents and shall not be liable for any loss or damage that maybe occasioned directly or indirectly through the use of, or reliance on, the contents of this manual.

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 5 wt%.

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.

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_{10} equation from 0.35 to 0.733.
40 A1.1.11	k_i for TSP changes from 0.74 to 2.82 and for PM_{10} 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 AP42 emission factors from the US EPA
9	Inclusion of overall control efficiency factor in Equation 1 (CE_i)
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 estimate engine 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_{10} equation, kg/bcm
	Deletion of line providing k for PM_{10} 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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LIST OF FIGURES & TABLES

1.0   Introduction

The purpose of all Emission Estimation Technique (EET) Manuals in this series is to assist Australian manufacturing, industrial and service facilities to report emissions of listed 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 apply to the following mine operations: Coal, Iron Ore, Bauxite, Copper Ore, Gold, Nickel Ore, Silver-Lead-Zinc Ore, Metallic Mineral Ore, Uranium.

EET MANUAL:	Mining
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This Manual was drafted by Woodward-Clyde, with assistance from Holmes Air Sciences, in conjunction with the NSW Environment Protection Authority, on behalf of the Commonwealth Government.

The Manual has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders. Particular thanks are due to the Minerals Council of Australia and its members for their comments, advice and information.

2.0   Process Description

The mining activities covered by this EET Manual include operations at both open-cut and underground mines. Generic flow diagrams are provided in Figures 1 and 2 for coalmines and metalliferous mines respectively. Because each mine is unique, you are encouraged to develop a process flow diagram for your own operations, identifying the main activities or processes that produce, or could produce, NPI-listed substances, and the wastes and emissions resulting from the operation of each activity or process.

2.1   Mining of Coal

Open-Cut Coal Mining

The flowsheet at Figure 1 provides a generalised description of open-cut coal mining.

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

- Removing vegetation and topsoil;
- Drilling and blasting overburden;
- Removing and placing overburden;
- Extracting, transporting and dumping coal;
- Crushing coal;
- Washery and workshop operations;
- Transporting and placing washery rejects; and
- Rehabilitation.

Underground Coal Mining

The flowsheet at Figure 1 also provides a generalised description of underground coal mining.

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

- Earthmoving associated with the development of the surface facilities;
- Shaft/drift access and ventilation development;
- Extracting, transporting, and dumping coal;
- Crushing coal;
- Washery, workshop, and power plant operations; and
- Rehabilitation.

Wind erosion from the open pit, stockpiles, and exposed areas will also contribute to dust emissions.
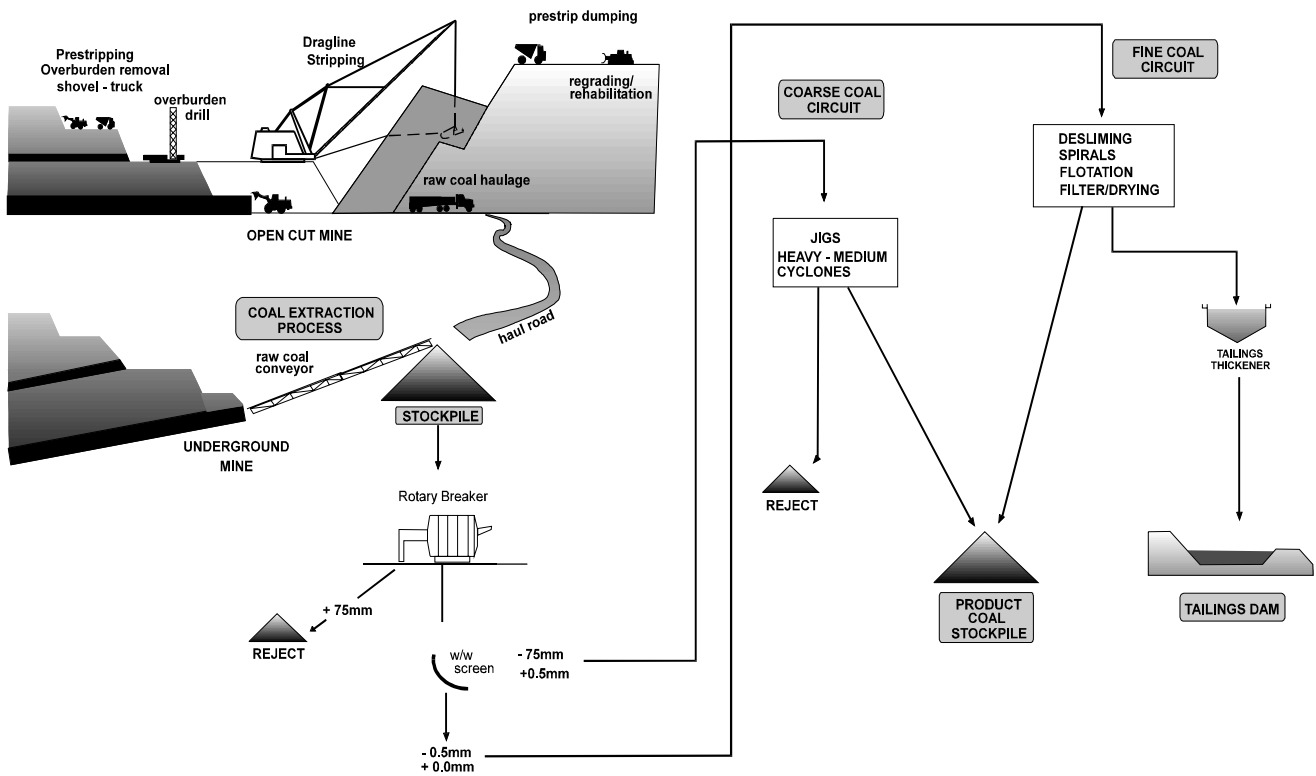
Figure 1: Open Cut/Underground Coal Mining and Washing Flow Chart.

2.2   Mining of Metalliferous Minerals

The mineral mining activities covered by this Manual are those primarily for the production 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.

Open-Cut Ore Mining

The flowsheet at Figure 2 provides a generalised description of open-cut mining.

The main activities carried out at open cut ore mines that could lead to emissions to air, water, and land 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;
- Ore beneficiation;
- Workshop operations; and
- Rehabilitation.

Underground Ore Mining

The flowsheet at Figure 2 also provides a generalised description of underground ore mining.

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;
- Ore beneficiation; and
- Washery, workshop, power plant operations.

Wind erosion from the open pit, stockpiles, and exposed areas will also contribute to dust emissions.
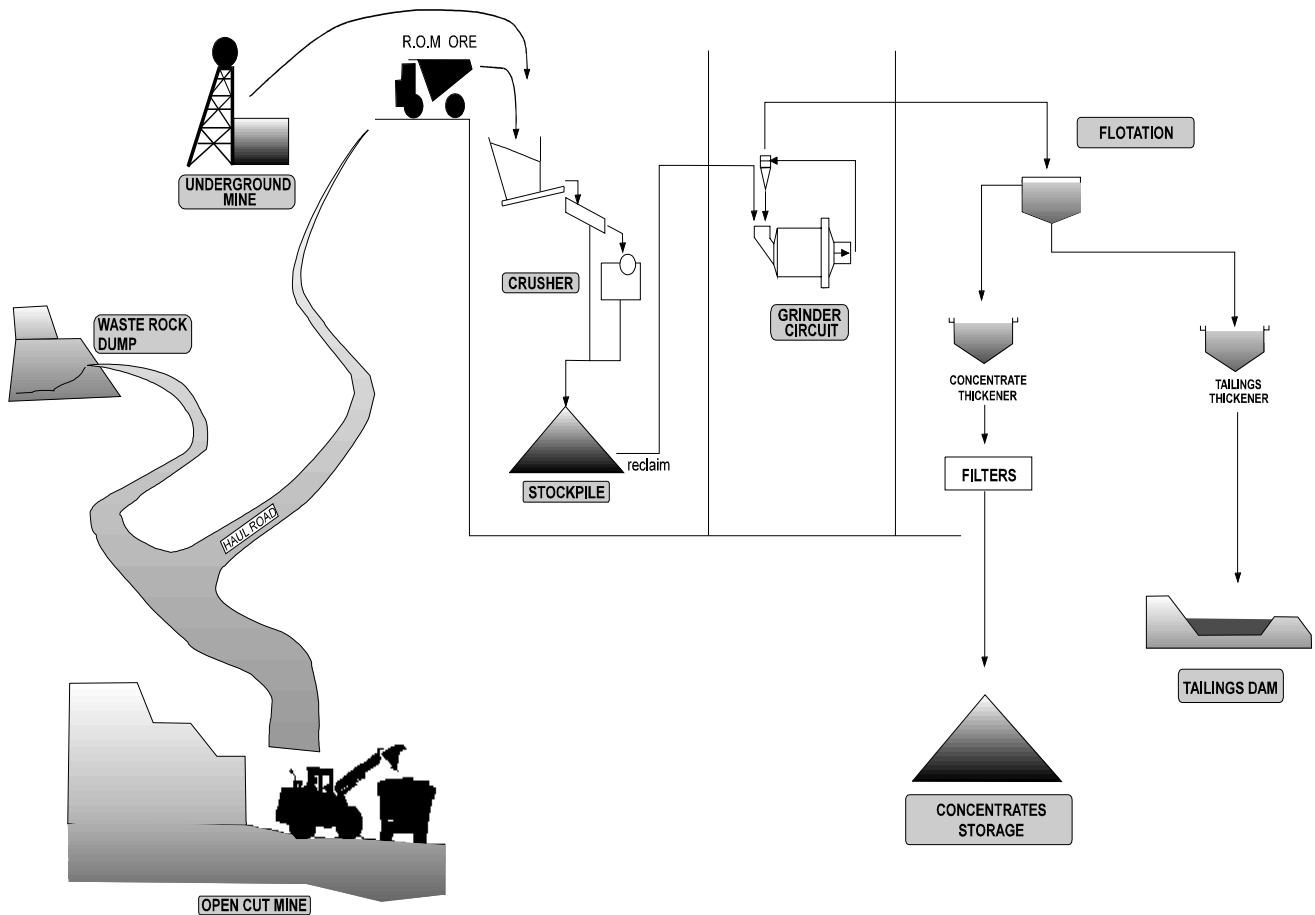
**Figure 2: General Mine and Concentrator Flow Chart**.

3.0   Emission Estimation

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold.   The reporting list and detailed information on thresholds are contained in *The NPI Guide* at the front of this Handbook.

In general, there are four types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility.

The four types described in *The NPI Guide* are:

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

Select the EET, (or mix of EETs), that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe 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 authority has approved the use of EETs that are not outlined in this handbook, 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 handbook 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 this document.   You must, however, seek the consent of your relevant environmental authority.   For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.

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 (eg: 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 for reporting purposes. The emission resulting from a spill is the net emission, ie., the quantity of the NPI reportable 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 authority for the use of EETs for metal speciation.

The usage of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for volatile organic compounds, VOCs) reporting threshold is exceeded. If the threshold is exceeded, emissions of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

3.1   EETs in this Manual

This Manual is divided into three main sections, namely:

Emissions to Air (Section 4)
Emissions to Water (Section 5)
Emissions to Land (Section 6)

Each of these sections follows the same general structure:

General background information;
What is to be reported; and
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.

4.0   Emissions to Air

4.1   Background

The main emissions to the air environment consist of wind-borne dust, and the products of combustion from mine transportation, mine power generation (if any), and blasting. Depending on the levels at which they are present, trace metals in mined coal could also lead to the Category 1 reporting threshold being triggered. Similarly, the metal content of ore bodies will need to be considered. Detailed guidance on reporting thresholds is presented in *The NPI Guide*.

In most cases fugitive emissions can be estimated using emission factors which, when combined with site-specific information (eg. the silt and moisture content of material being handled) can be used to determine emissions from the particular operation being analysed.

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 SPCC (1986) and 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 you 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).

Finally, it is worth pointing out that the 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 are those in the US EPA document referred to as AP-42. Chapters from AP-42 are updated periodically and are available from the USEPA's web site[1]. (Note: It is intended that this Manual will be updated periodically to reflect new research in both Australia and overseas. However, it is recognised that this revision process may, on occasion, lag behind developments in the US).

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

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[1] Http://www.epa.gov/ttnchie1/ap42.html

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.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

        A   -   Excellent
        B   -   Above Average
        C   -   Average
        D   -   Below Average
        E   -   Poor
        U   -   Unrated

4.3   Overview of Air Emission Sources

The air emissions considered in this Manual are:

Fugitive emissions of particulate matter and metals (Section 4.4). Section 4.5 provides guidance on the reduction in emissions expected when different emission control techniques are adopted;
Exhaust emissions from mining equipment (Section 4.6);
Emissions from spontaneous combustion (Section 4.7);
Various volatile organic compound (VOC) emissions (Section 4.8);
Emissions of carbon disulfide from flotation processes (Section 4.9); and
Emissions from power generation and combustion processes (Section 4.10).

4.4   Dust Emissions from Mining

Emission factors can be used to estimate emissions to the environment 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:

$$E_{kpy,i} = [A * OpHrs] * EF_i * [1 - (CE_i/100)] \qquad (1)$$

where:

$E_{kpy,i}$	=	emission rate of pollutant i, kg/yr
A	=	activity rate, t/h
OpHrs	=	operating hours, h/yr
EF_i	=	uncontrolled emission factor of pollutant i, kg/t
CE_i	=	overall control efficiency for pollutant i, %

If no emission controls are used, Equation 1 reduces to

$$E_{kpy, i} = A * OpHrs * EF_i \qquad (2)$$

where:

$E_{kpy, i}$	=	emission rate of pollutant i, kg/yr;
A	=	activity rate, t/h;
OpHrs	=	operating hours, h/yr; and
EF_i	=	uncontrolled emission factor for pollutant i, kg/yr.

For fugitive emissions of particulate matter and metals, uncontrolled emission factors are provided in Sections 4.4.1 and 4.4.2 of this Manual. Emission reduction efficiencies for a range of dust control measures are provided in Section 4.5.

4.4.1   Mining Coal

The major air emission from coal mining is fugitive dust. The PM_{10} component of dust is reportable under the NPI. Reporting is triggered by fuel usage or on-site power usage (see *The NPI Guide* for further information).

In addition, certain metals may need to be reported if fuel usage exceeds the triggering threshold, or if NPI-listed metals are present in the mined coal in levels that lead to the Category 1 threshold being exceeded. In these cases total suspended particulate (TSP) emissions will need to be calculated (in addition to PM_{10}) to determine the metal emissions.

Mining operations can be considered as a series of unit operations (eg dragline operations, shovel operations, truck haulage of materials). Table 1 provides emission factor equations and default emission factors for emissions of both TSP and PM_{10} from coal 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.

Calculation of PM$_{10}$ Emissions

All emission factor equations and default emission factors listed in Table 1 are for uncontrolled emissions. Section 4.5 provides information on the efficiency of control methods. This information can be incorporated into the calculation of emissions as outlined in Equation 1. Calculating emissions of PM$_{10}$ becomes a five-step process:

1. Identify sources of emissions.
2. Obtain information on the scale of the activity (ie the basic data required to apply the equation).
3. Apply the relevant PM$_{10}$ emission factor equation or default emission factor from Table 1 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 total VKT.
4. Where applicable, apply control efficiency reduction factors in Section 4.5 (using Equation 1).

With regards to emission controls for PM$_{10}$, in the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission estimation equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency.

Calculation of Metals Emissions

A similar process can be used to calculate 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$_{10}$. The process for calculating metals emissions is:

1. Identify sources of emissions (as for PM$_{10}$).
2. Obtain information on the scale of the activity (as for PM$_{10}$).
3. Apply the relevant TSP equation or emission factor to the activity.
4. 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, Table B2 can be used.
5. Where applicable, apply control efficiency reduction factors in Section 4.5.

TABLE 1   Emission Factor Equations and Default Emission Factors for Various Operations at Coal Mines [1,3]

Operation/Activity	TSP Equation	PM$_{10}$ Equation	TSP Default Emission Factor	PM$_{10}$ Default Emission Factor	PM$_{10}$/TSP Ratio based on Emission Factors	Units	Emission Factor Rating
Draglines	EF = 0.0046 * d$^{1.1}$ * M$^{-0.3}$	EF = 0.0022 * d$^{0.7}$ * M$^{-0.3}$	0.06	0.026	0.43	kg/bcm	B
Excavators/Shovels/Front-end loaders (on overburden)	EF = k * 0.0016 * (U/2.2)$^{1.3}$ * (M/2)$^{-1.4}$, k=0.74	As for TSP, using k=0.35	0.025	0.012	0.47	kg/t	C
Excavators/Shovels/Front-end loaders (on coal)	EF = k * 0.0596 * M$^{-0.9}$ using k = 1.56	As for TSP, using k=0.75	0.029	0.014	0.48	kg/t	C
Bulldozers on coal	EF = 35.6 * s$^{1.2}$ * M$^{-1.4}$	EF = 6.33 * s$^{1.5}$ * M$^{-1.4}$	102	32.5	0.29	kg/h	B
Bulldozer on material other than coal	EF = 2.6 * s$^{1.2}$ * M$^{-1.3}$	EF = 0.34 * s$^{1.5}$ * M$^{-1.4}$	17	4	0.24	kg/h	B
Trucks (dumping overburden)	--	--	0.012	0.0043	0.35	kg/t	
Trucks (dumping coal)	--	--	0.010	0.0042	0.42	kg/t	
Drilling	--	--	0.59	0.31	0.52	kg/hole	B
Blasting[4]	EF = 344 * A$^{0.8}$ * M$^{-1.9}$ * D$^{-1.8}$	As for TSP, Multiplying by 0.52	--	--	0.52	kg/blast	C
Wheel and bucket	--[2]	--[2]	--[2]	--[2]			

TABLE 1 (cont')   Emission Factor Equations and Default Emission Factors for Various Operations at Coal Mines [1,3]

Operation/Activity	TSP Equation	PM₁₀ Equation	TSP Default Emission Factor	PM₁₀ Default Emission Factor	PM₁₀/TSP Ratio based on Emission Factors	Units	Emission Factor Rating
Wheel Generated Dust from Unpaved Roads	$EF = k * (s/12)^A * (W/3)^B / (M/0.2)^C$, where k = 2.82	As for TSP, using k= 0.733	3.88	0.96	0.25	kg/VKT	
Scrapers	$EF = 7.6 * 10^{-6} * s^{1.3} * W^{2.4}$	$EF = 1.32 * 10^{-6} * s^{1.4} * W^{2.5}$	1.64	0.53	0.32	kg/VKT	A
Graders	$EF = 0.0034 * S^{2.5}$	$EF = 0.0034 * S^{2.0}$				kg/VKT	B
Loading stockpiles	--	--	0.004	0.0017	0.42	kg/t	
Unloading from stockpiles	--	--	0.03	0.013	0.42	kg/t	
Loading to trains	--	--	0.0004	0.00017	0.42	kg/t	
Miscellaneous transfer points	$EF = k* 0.0016 (U/2.2)^{1.3} * (M/2)^{-1.4}$, where k = 0.74	As for TSP, using k = 0.35	0.00032	0.00015	0.47	kg/t	
Wind erosion	--	--	0.4	0.2	0.50	kg/ha/h	

[1] See Appendix A for details of the sources of these emission factors and emission estimation equations

[2] 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. For coals with a moisture content of less than 10%, use the equation for miscellaneous transfer and conveying. (Appendix A1.1.18 and A.1.1.14)

[3]
d = drop distance in metres; M = moisture content in %;
U = mean wind speed in m/s; A = area blasted in m²;
D = depth of blast holes in metres;   VKT = vehicle kilometres travelled;
s = silt content in %; W = vehicle gross mass in tonnes;
S = mean vehicle speed in km/h; L = road surface silt loading in g/m²;
bcm = bank cubic metres; t = tonne;
-- = negligible
Exponents for "Wheel Generated Dust from Unpaved Roads"
A = 0.8 (for PM₁₀) & 0.8 (for TSP)   B = 0.4 (for PM₁₀) & 0.5 (for TSP)
C = 0.3 (for PM₁₀) & 0.4 (for TSP)

[4] Additional guidance on the characterisation of emissions of PM₁₀ and other substances is provided in the *Emission Estimation Technique Manual for Explosives Detonation*.

4.4.2 Mining of Metalliferous Minerals

As for the mining of coal, the major fugitive emission from metalliferous mining is dust, of which the PM_{10} fraction is reportable under the NPI. Reporting is triggered by the fuel usage at the facility (see *The NPI Guide* for further information). In addition, emissions of certain metals will need to reported if fuel usage exceeds the defined thresholds, or if NPI-listed metals are present in the mined ore 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_{10}) to determine the metal emissions (see Section 4.4.1 for the method of calculation for these emissions).

Many of the activities at metalliferous mines will be the same as for coal mining. In these situations, the coal-mining emission factors and equations presented in Section 4.4.1 should be used. Table 2 provides default emission factors for specific activities associated with metalliferous mining. The table presents emissions factors for high-moisture[2] ores and low moisture content ores. A discussion of the sources of these emission factors is provided in Appendix A, Section A.1.2.

All factors are for uncontrolled emissions. Section 4.5 provides information on the efficiency of control methods. This information can be incorporated into the calculation of emissions using Equation 1.

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[2] 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 2   Default Emission Factors for Various Operations at Metalliferous Mines [1, 2]

Operation/Activity	TSP Default Emission Factor	PM$_{10}$ Default Emission Factor	PM$_{10}$/TSP Ratio	TSP Default Emission Factor	PM$_{10}$ Default Emission Factor	PM$_{10}$/TSP Ratio	Units (per activity)	Emission Factor Rating
	High Moisture Content Ores			**Low Moisture Content Ores**				
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

4.5   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 3 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) and Buonicore and Davis (1992: Table 3, p 794).

The emission reductions presented in Table 3 can be applied to the predicted uncontrolled emissions (derived using the emission factors and equations presented in Tables 1 and 2) using Equation 1, as described in Section 4.4.1 of this Manual.

TABLE 3   Estimated Control Factors for Various Mining Operations

Operation / Activity	Control method and emission reduction[1]
Coal Mines	
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^2/h) 75% for level 2 watering (> 2 litres/m^2/h)
Unloading trucks	70% for water sprays
Draglines	Control dust by minimising drop height
Loading stockpiles	50% for water sprays 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)
Wind erosion from stockpiles	50% for water sprays 30% for wind breaks 99% for re-vegetation (overburden only) or total enclosure
Loading to trains	70% for enclosure 99% for enclosure and use of fabric filters
Miscellaneous transfer and conveying	90% control allowed for water sprays with chemicals 70% for enclosure 99% for enclosure and use of fabric filters
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$_{10}$

Source: Holmes Air Sciences (1998)

[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 0.5 * 0.7 = 0.35 of the uncontrolled emission (ie. 50% of 70% of the total uncontrolled emissions).

4.6 Vehicle Exhaust Emissions

For vehicles, emission estimation techniques can be found in the *Emission Estimation Technique Manual for Combustion Engines*.

On-site diesel vehicles will emit particulate matter (which, for the purposes of NPI reporting, can be considered to be 100% PM_{10}), carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and volatile organic compounds (VOCs). Emission factors for various mine-site vehicles are presented in Table 4.

TABLE 4   Exhaust Emission Factors for Various Classes of Mining Equipment

Equipment Type	Emission Factor (kg/1000 litre of fuel)					
	PM_{10}[1]	CO	NO_x	SO_x[2] (as SO_2)	VOCs (exhaust)	Emission Factor Rating
Track type tractor	3.03	9.4	34.16	1.7	3.31	C
Wheeled tractor	5.57	32.19	52.35	1.7	7.74	C
Wheeled dozer	17.7	14.73	34.29	1.7	1.58	C
Scraper	3.27	10.16	30.99	1.7	2.28	C
Grader	2.66	6.55	30.41	1.7	1.53	C
Off-highway truck	17.7	14.73	34.29	1.7	1.58	C
Wheeled loader	3.51	11.79	38.5	1.7	5.17	C
Track type loader	2.88	9.93	30.73	1.7	4.85	C

Source: USEPA (1998), except for SO_2 (see Note 2 below).

[1] It should be noted that the emission factors for mining activities in Tables 1 and 2 have been derived from measurements that cover all PM_{10} emissions associated with a unit operation, including exhaust emissions. To add the exhaust PM_{10} emissions to the fugitive emissions would involve some measure of double counting for those activities. However, if there are vehicle emission sources that are independent of the activities listed in Table 1 and 2, the factors in this table should be used to characterise emissions from these sources.

[2] USEPA (1998) provides an emission factor for sulfur dioxide. However, SO_2 emissions are dependent upon the percentage of sulfur in the fuel. Data from Caltex Refinery (NSWEPA, 1995) indicates an average sulfur content of 0.1% by weight in Australian diesel fuel. Assuming that all sulfur is converted to SO_2, then for every 1000 L of diesel fuel consumed, 1.7 kg of sulfur dioxide is produced. This factor has been used here.

Diesel would be used by mining operations in a variety of sources (including those listed above) and emissions should be calculated using the following general calculation process:

1.   Determine total diesel consumed at site. For the majority of mine sites, this will be equal to the amount of diesel reported under the Diesel Rebate Scheme. If diesel not covered by this scheme is also used, then facilities will need to determine the total quantity of diesel used at the site by adding the diesel covered by the diesel rebate to the other diesel used.

2.   Estimate proportion of diesel used in each of the activities listed. It is recognised that most facilities do not keep detailed records of diesel consumption, beyond the total quantity consumed (or purchased). Therefore, you should estimate (eg. based on approximate hours of operation) where (ie in what activities) diesel is consumed. For most facilities, it is likely that a reasonable characterisation of emissions from these sources will be obtained if the proportion of diesel used in each of the listed activities can be determined to the nearest 10% of total diesel consumption (providing of course, that the total is 100F, ie. encompassing all of the diesel used at the facility).

3. For each activity, work out emissions for each pollutant. For each of the equipment types listed in Table 4 above, the amount of diesel consumed should be multiplied by the relevant emission factor to determine emissions of PM_{10}, CO, NOx, SO_2, and VOCs (see Section 4.4.1 for additional guidance on the use of emission factors).

4. Calculate total vehicle exhaust emissions by adding the emissions from each individual activity.

4.7   Spontaneous Combustion

If it occurs, spontaneous combustion in coal mines will contribute to emissions of PM_{10} and other products of combustion from the mine site. However, there are no published emission factors that can be used, as this is a highly site-specific issue. 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.

4.8   Volatile Organic Compounds (VOCs)

In addition to the VOCs emitted from vehicle exhausts (see Section 4.6), there will also be emissions of VOCs from workshop, 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 (ie 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.*

4.9   Carbon Disulfide

Xanthates are widely used in Australia in flotation processes to concentrate sulfide ores. It has the propensity to decompose in the presence of moisture and/or heat to produce carbon disulfide, an NPI listed substance. When xanthates are used as a flotation agent it is usually mixed with water at concentrations of about 10%. Most of the xanthates are retained in the froth that contains the ore concentrate formed during the flotation process. Some (approximately 1%) will report to the tailings dam.

Ultimately, all xanthates 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 to help control the rate of decomposition. For the xanthates in the ore concentrate, decomposition will occur during drying or smelting. In the generally acidic conditions of the tailings dam, xanthates will decompose over time.

Sodium ethyl xanthate (SEX) is a typically used xanthate. The molecular weight of SEX is 144 g/mole and the molecular weight of carbon disulfide is 76 g/mole. If all the SEX is assumed to decompose to carbon disulfide, then emissions of carbon disulfide will be 0.53 (76/144) times the weight of SEX consumed. To calculate the emissions of carbon disulfide, you will need to:

1.   Determine the total quantity of SEX consumed (in kg/year).
2.   Multiply this by 0.53 to determine the quantity of carbon disulfide released to the air.

4.10   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 (eg. 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.*

5.0 Emissions to Water

5.1 Background

It is important to recognise that emissions to water are a highly site-specific issue and that there are very few default emission factors currently available to characterise these emissions. The purpose of this section is to provide general guidance on approaches that may be adopted to characterise these emissions, using the 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 provided.

5.1.1 What is to be Reported?

Under the NPI, the following are classed as transfers and are not required to be reported (NEPM, Clause 3(3)):

- Discharges of substances to sewer or tailings dam;
- Deposit of substances to landfill; and
- Removal of substances from a facility for destruction, treatment, recycling, reprocessing, recovery, or purification.

The definition of transfer has been clarified by the NPI Implementation Working Group as:

> "All emissions of listed substances, except those which are directed to, and contained by, purpose built facilities, are to be reported to the NPI. This applies irrespective of whether the substances' fate is within or outside a reporting facility boundary. With respect to receipt of NPI-listed substances, such receiving facilities are to be operating in accordance with any applicable State or Territory government requirements."

Therefore, the first step in characterising emissions to water is to identify those releases that are classed as transfers under the NPI (and for which reporting is not required).

The distinction between emissions and transfers is illustrated in Table 5 (which provides examples based on activities that commonly occur on mine sites).

TABLE 5   **Transfers versus Emissions**

TRANSFER	EMISSION
Tailings placement and retention in a pit or tailings storage facility	Overflow of waters with or without suspended solids from a tailings storage facility to a water course or to land
Retention of run-off water from infrastructure areas into a contained anti- pollution pond	Overflow of water/suspended solids from anti pollution pond to a water course or to land
Placement of waste rock in or out of pit dumps (providing these are approved containment areas)	Run-off/leachate from a waste dump/haul road directly to a water course or to land
Retention of run-off/leachate from waste dumps in contained pits or purpose built storage facilities	Seepage of pit water to regional groundwater
Treatment/neutralisation of leachate within a contained facility	Leakage from tailings dams
Sale of concentrate or other mine product/by product	
Sale of a waste rock or other waste material for commercial/industrial use (eg as a road base or as a raw product for manufacture of a saleable product)	

5.1.2   Emissions Estimation

Emissions estimation for releases to water requires the input of site-specific data. This data may need to be complemented by the characterisation of variables that are not routinely monitored. As noted above, the characterisation of releases to water is a highly site-specific issue and, in most cases, default emission estimation techniques are not currently available. In addition, it is recognised that facility personnel understand the particular situations at their facilities and the data that is commonly available. This Manual provides a general guide on how 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 3, approval for the use of EETs not presented in this Manual will need to be obtained from your relevant State or Territory environmental authority.

It is suggested that the best approach to characterising emissions to water is to relate your potential emissions to your 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 the 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.

5.1.3   Notes on Reportable Substances:

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. As the distribution of minerals will usually vary significantly within a facility, the estimation of emissions will be subject to inherent errors associated with the determination of "average" concentration in heterogeneous matter. In most cases, errors will be significantly greater than the potential emission of the dissolved metal compound. Also, beneficiation of ore or coal usually involves physical rather than chemical processes and, therefore, water soluble metals are not usually produced. Therefore, apart from the compounds discussed in the next paragraph, any emissions of dissolved metal compounds to ground and surface waters will be accounted for in the estimations of metal emissions in suspended sediment.

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.

Volatile Organic and Chlorinated Hydrocarbons

Chlorinated hydrocarbon compounds (eg trichloroethane and solvents, 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. That is, any solvent which did not evaporate and was removed (eg with wash-down water) would be

expected to either evaporate from the water or, especially in the case of MEK, be metabolised by micro flora/fauna as a carbon source. Any residual materials would be at μg - mg/l concentrations. Where oil/water separators are installed, the potential for off-site emission of these substances would be further reduced. In general, the only emissions should be those associated with overflows and run-off after rainfall events. For the purposes of NPI reporting, and in the absence of specific information (ie monitoring data) regarding these substances, it can be assumed that all emissions of volatile organic and chlorinated hydrocarbons are to the atmosphere (refer Section 4.8) and that water emissions are zero.

5.2   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 5.1. You should note that this reporting requirement only applies to those releases that are classed as emissions. Transfers are not required to be reported.

The following paragraphs provide a description of the main sources of liquid effluents/emissions from mine sites. The sources considered are:

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

Emission estimation techniques for each of these sources are provided in Section 5.3.

Process Waters from Mining

Most of the process waters used in mining will be classed as transfers. For example:

- process water in open cut mines routinely used for dust suppression, on active working areas in pits, and in surface areas such as haul roads and hardstands. (Note, however, that any run-off from these surfaces may be classed as an emission rather than a transfer and, therefore, reporting may be required);
- 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 listed substances (except those which are directed to, and contained by, purpose built facilities) are to be reported to the NPI.

Process Waters from Beneficiation

Beneficiation of ore or coal 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 product or waste materials. Water is also used to transport slurries (30-40% solids) within the plant and wastes or tailings to appropriate impoundments.

In most cases, the beneficiation process water is recycled. The consumption and reaction pathways of beneficiation/flotation chemicals will depend on the characteristics of the process. Residues would normally report with the tailings and/or product streams and their associated process waters. It is recognised that these primarily involve transfers rather than emissions, although it is your responsibility to consider the definitions of transfer and emission presented in Section 5.1 in making this determination.

The NPI reportable substances used or formed in the beneficiation process can include substances such as ammonia, xanthates/carbon disulfide, copper sulfate, inorganic cyanide compounds (sodium cyanide) and MIBC (MIBC refers to methyl isobutyl carbonyl or methyl isobutyl ketone (MIBK). The term MIBC will be used in this Manual.). 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_2) and these substances decompose to form carbon disulfide. CS_2 is relatively insoluble in water (0.1g/L at 20^0C) 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 4.9 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.

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 listed substances (except those which are directed to, and contained by, purpose built facilities) are to be reported to the NPI.

Surface Water Run-off

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

In the case of the process waters discussed previously, releases 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. Catchment segregation will limit the volumes of such run-off.

Leachate from Stockpiles, Overburden, Waste Rocks and Tailings to Surface Waters

Leachate will occur from elevated features such as stockpiles, waste rock and overburden materials as a result of the seepage of excess processing 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 (eg iron pyrite) which, after beneficiation, will report 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 (AD). The presence of AD may also increase dissolved metal concentrations in leachate. Actual AD 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 listed substances (except those which are directed to, and contained by, purpose built facilities) are to be reported to the NPI.

5.3   Emission Estimation Methods

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 Sections 5.1.1 and 5.2 above to assist you with this.
3. Identify and list all water emissions 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 would 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 available data 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.

5.3.1 Direct Monitoring - Water Quality and Volume

Where available, site-specific information on water quality and flow rates should be used to characterise emissions for the purposes of the NPI. General guidance on the use of monitoring and flow data for emissions estimation is provided in Appendix B, Section B.1.4. Data that might be routinely available to help estimate emissions include, but is not limited to, the following:

- 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, eg. 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 plan (eg. 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 (eg. 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 that 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 (eg default emission factors). 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 5.3.2.

5.3.2 Estimation Methods for Non-Monitored Substances

Where a reportable substance is not monitored, then default concentrations will need to be inferred or developed to provide an estimate of emissions. When site-specific trace element concentration data is not available, the typical concentrations presented in Appendix B, Table B.2 can be utilised.

Where water soluble reportable substances occur on a mine site, site-specific data on the metal solubility and flows should be used. If this data or and alternative estimate is not available, a

default concentration of 5 g/L should be assumed in flows containing reportable substances in solution.

5.3.3 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. In their simplest form, mass balances are straightforward additions. On a dry mass basis, for example, the mass of product will be the total quantity mined less the quantities of waste produced (eg 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 consumed less the water entrained in the waste and product streams, water recycled to the plant, and evaporation.

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

A more detailed discussion of mass balance techniques is provided in Appendix B, Section B.1.4 of this Manual and an example of the application of mass balance techniques to mining operations is provided in this Section.

5.3.4 Estimation Methods for Leachate Borne Emissions

These emissions will generally be insignificant except in specific cases (eg. 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 (eg host rock, tailings materials).

5.3.5 Estimation Methods for Acid Drainage (AD)

Sulfuric acid is a strong acid and the pH of AD contaminated waters will be <3.5. It follows that if the pH is significantly greater than 3.5, sulfuric acid is not present and the waters will contain the reaction products of AD. It should be noted that mildly acidic waters, pH 4-6, formed by the partial neutralisation of AD will contain sulfates. However, a sulfuric acid concentration cannot be inferred from hydrogen and sulfate ion concentration data, particularly where the monitoring points are remote from the acid source.

AD formation is dependent on many interrelated variables, including the reactivity of the sulfide species present, water and oxygen availability, and the neutralising capacity of the host and adjacent rocks. Reliable estimates of AD generation cannot be obtained from the application of general data in isolation. Thus, the estimation of sulfuric acid generation must

be determined after taking site-specific management and local environmental factors into account. These should be based on determination of the acid-generating potential and the neutralising capacity of all materials, including ores, waste and associated rocks, tailings, and the availability of rock materials to contribute to the acid-base reactions.

For the purposes of calculating releases to the environment of NPI-listed substances, you should consider the pH of the waters leaving the facility. If the pH of the waters is less than 4, sulfuric acid emissions in AD will need to be estimated and reported.

Where data is not available, it should be assumed that sulfuric acid is generated at a yearly rate of 240 kg/hectare of exposed pyritic material - based on the oxidation of host rock containing 1% pyrite with no neutralising capacity. (A discussion of the source of this emission factor is provided in Appendix B, Section B.1.2).

5.4   Emissions to Waters from Specific Operations

5.4.1   Open Cut Mining Operations

The first step is to identify emissions and transfers using the definitions presented in Section 5.1. Where applicable:

- Estimate direct emissions off-site (eg. pumping of excess water from a pit to a water course);
- Estimate the volume of run-off of contaminated waters (eg. from activities such as road watering and general dust suppression) that is not routed to a suitable containment facility as defined in Section 5.1;
- Estimate volumes of run-off from waste rock dumps and other site areas to estimate the mass of suspended solids transported off-site; and
- 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 Section 5.3 to estimate emissions. Appendix B of this Manual illustrates the types of data that can be used to assist in characterising 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% of the rated capacity for the particular pump and that the availability is equal to the operating hours for that pump.

5.4.2   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 transfers and environmental emissions of NPI-listed substances. It is expected that in most cases, these would be associated with air emissions. For the purposes of NPI reporting, these emissions can therefore be considered as emissions to air and may be characterised using the EETs in

Section 4.8.   If, however, emissions of these substances occur to water (eg. from wash-down of floors), you will need to estimate the proportion of water emissions.

5.4.3   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 5.4.1 above), the first step is to identify emissions and transfers using the definitions presented in Section 5.1.

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% of the rated capacity for each pump in question and that the availability is equal to the operating hours for the pump.

5.4.4   Beneficiation Operations

Process water management, including the location and operation of facilities such as run of mine (ROM) 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 matters:

- The definition of transfers and emissions presented in Section 5.1.
- Flows, volumes, and water balances for all aspects of the beneficiation operation, with particular emphasis on water losses to the environment (eg. 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 (eg. 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 substances 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 (eg. cyanide) and substances such as carbon disulfide will be formed (see Section 5.2 for a discussion of this).

6.0   Emissions to Land

It is important to recognise that emissions to land are a highly site-specific issue and there are very few default emission factors currently available to characterise these emissions. The purpose of this section is to provide general guidance on approaches that can be adopted to characterise these emissions, using the 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 provided.

6.1   Background

Under the NPI, the following are classed as transfers and are not required to be reported (NEPM, Clause 3(3)):

▪ Discharges of substances to sewer or to tailings dams;
▪ Deposit of substances to landfill; and
▪ Removal of substances from a facility for destruction, treatment, recycling, reprocessing, recovery, or purification.

Releases from tailings dams are, however, required to be reported.

The definition of transfer has been clarified by the NPI Implementation Working Group as:

"All emissions of listed substances, except those which are directed to, and contained by, purpose built facilities, are to be reported to the NPI. This applies irrespective of whether the substances' fate is within or outside a reporting facility boundary. With respect to receipt of NPI-listed substances, such receiving facilities are to be operating in accordance with any applicable State or Territory government requirements."

Therefore, the first step in characterising emissions to land is to identify those releases that are classed as transfers under the NPI (and for which reporting is not required).

6.2   Land Emission Sources

6.2.1   Waste Rock and Spoil Dumps

As noted above, substances discharged to tailings dams or waste rock dumps are regarded as transfers under the NPI and are not considered as emissions. However, releases from these areas are required to be reported.

Waste ore may contain NPI-listed substances. As a consequence, releases from tailings dams should be reported as releases 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 characterise these emissions

6.2.2   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 dams. This constitutes a transfer (see the definition presented in Section 6.1), providing that the reportable substances are contained within the particular site facilities.

Seepages to aquifers and overflows could become water emissions depending on the situation at the facility. Refer to Sections 5.3 and 5.4 for emission estimation techniques for these releases.

6.2.3 Agricultural Application of Substances to Land / Irrigation

The application of substances to land (eg for irrigation) is classed as an emission and any NPI substances contained in the irrigated liquid are required to be reported under the NPI. Note that Total Nitrogen and Total Phosphorus, although NPI substances, are only reportable if emitted to water.

Flood or spray irrigation of on-site effluent or process waters to land are regarded as an emission to land. The emissions of reportable substances can be calculated based on: (a) the volume of the irrigated liquid; and (b) the concentration of NPI-listed substances present in the irrigated liquid.

6.2.4 Unintentional Leaks, Seepages and Spills

Under the NPI, spills, leaks, and seepage are required to be reported as emissions to land or water.

To calculate the emissions of NPI-listed substances you should calculate emissions based on the difference between the quantity of material released or spilled and the quantity of material collected. The difference is the emission to land or water.

6.2.5 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.*

7.0   REFERENCES

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

US EPA (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.

The following Emission Estimation Technique Manuals referred to in this Manual can be obtained from Environment Australia:
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.

APPENDIX A
- EMISSION ESTIMATION TECHNIQUES - AIR

A1.0   DISCUSSION ON INDIVIDUAL EMISSION FACTOR EQUATIONS

This Appendix provides information on the sources of the emission factor equations and emission factors presented in Tables 1 and 2 of this Manual. Most of the equations and factors have been drawn from AP-42 (US EPA (1985) and USEPA (1998)) and the NERDDC (NERDDC, 1998) and SPCC (SPCC, 1986) studies in the Hunter Valley. When information from both sources (ie. the US and Australia) is available, the two have been compared and, where possible, reconciled. Emission factors for both PM_{10} (required to be reported under the NPI) and TSP (necessary as a basis for characterising emissions of metal species) are provided and discussed.

A1.1   COAL MINES

The emission factor equations and emission factors discussed in this section relate to coal mining activities. However, as noted in Section 4 of this Manual, many of these equations are also relevant to activities on metalliferous mines.

A1.1.1   Dragline Operation

This operation refers to the removal of overburden by a dragline.

TSP

The TSP equation used is the AP-42 equation, namely:

$$EF = 0.0046 \times \frac{d^{1.1}}{M^{0.3}}, kg/bcm$$

where

d = drop distance in metres

M = moisture content of overburden in %

bcm = bank cumbic metre

This 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 drop distance of 12 m and moisture content of 2% (not unreasonable values for the Hunter Valley), gives an emission factor of 0.057 kg/bcm. 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.

Bank cubic metres (bcm) refers to the volume of material in-situ prior to blasting to facilitate removal of material .

In the absence of site-specific information on drop distance and moisture content, an emission factor of 0.06 kg/bcm for TSP is recommended.

PM$_{10}$

The AP-42 equation for PM$_{10}$ is:

$$E = 0.0022 \times \frac{d^{0.7}}{M^{0.3}} \, , kg/bcm$$

A drop distance of 12 m and moisture content of 2% gives an emission factor of 0.0102 kg/bcm using this equation.

As noted above, the NERDDC value for TSP is 0.072 kg/bcm. To convert this to PM$_{10}$ it is appropriate to use particle size data measured by the SPCC (1986). This data indicates that for draglines in the Hunter Valley, approximately 43% of TSP particles will be in the PM$_{10}$ range. Thus the NERDDC estimate of PM$_{10}$ emissions from dragline operations in the Hunter Valley is 0.031 kg/bcm.

In the absence of site-specific data and based on the emission factor for TSP of 0.06 kg/bcm, the recommended default PM$_{10}$ emission factor is 0.06 * 0.43 = 0.026 kg/bcm.

A1.1.2 Loading Truck with Overburden

The USEPA (USEPA, 1998: Section 13.2.4-3) provides an equation for batch loading. This equation (Equation A-3 below) seems to give estimates that are unrealistically low for Australian conditions. The USEPA (USEPA: 1988: Section 11.9-9, 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. The equation is:

$E = k \times 0.0016 \times (U / 2.2)^{1.3} / (M / 2)^{1.4}$ kg/t

where,

k = 0.74 for particles less than 30 micrometres aerodynamic diameter

k = 0.35 for particles less than 10 micrometres aerodynamic diameters

U = mean wind speed (m/s)

M = moisture content (%).

The NERDDC (NERDDC, 1988) work provides an estimate of TSP emissions from truck loading operations of 0.025 kg/t. If U is 3.6 m/s (fairly typical of the Hunter Valley and much of inland NSW) and M is taken to be 1%, the emission factor for TSP would be 0.0059 kg/t, using the equation above. If the moisture content is 2% then the emission factor is 0.0022 kg/t and if the moisture content is 0.5% the emission factor is 0.0156 kg/t. Thus, with a moisture content of 0.5%, the equation gives values for TSP emissions that approach the values measured in the NERDDC study. However, a moisture content of 0.5% is extremely low. Furthermore, the NERDDC emission factor for TSP is consistent with the USEPA's emission factor for truck loading by power shovel (batch drop) quoted above. It is therefore recommended that the NERDDC (1988) TSP emission factor of 0.025 kg/t be used for coal mines until a better factor is developed.

SPCC (1986) measurements in the Hunter Valley indicate that approximately 47% of TSP particles will be in the PM_{10} range. The recommended PM_{10} emissions factor is therefore $0.025 * 0.47 = 0.012$ kg/t.

A1.1.3 Loading to Trucks by Shovel or FEL

As for overburden, the USEPA's equation for batch loading seems to give estimates that are unrealistically low when applied to loading coal to trucks. The US EPA (1998) equation is:

$$E = k \times 0.0016 \times (U/2.2)^{1.3} / (M/2)^{1.4} \text{ kg/t}$$

where,

k = 0.74 for particles less than 30 micrometres aerodynamic diameter

k = 0.35 for particles less than 10 micrometres aerodynamic diameters

U = mean wind speed (m/s)

M = moisture content (%).

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. The NERDDC (1988) Hunter Valley work provides an emission factor for TSP of 0.029 kg/t. Clearly, the US data provides a very different result to that quoted in the NERDDC study. Based on current information, it would seem better to use the default emission factor of 0.029 kg/t for TSP emissions from Australian mines.

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 mm) can be taken to be PM_{10} particles. Thus, the default PM_{10} emission factor becomes 0.014 kg/t.

The USEPA provides an alternative equation specifically for the loading of coal (USEPA, 1998: Table 11.9-1):

$$E = k \times 0.0596 / (M)^{0.9} \text{ kg/t}$$

where,

k = 0.74 for particles less than 10 micrometres aerodynamic diameter

M = moisture content (%).

When this equation is applied with 8% moisture, the PM_{10} emission factor is 0.00688 kg/t. With 4% moisture the PM_{10} emission factor is 0.013 kg/t. This is very close to the Hunter Valley factor from the NERDDC (1988) study, adjusted to obtain the PM_{10} fraction (using the SPCC (1986) 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.

A1.1.4 Bulldozing Coal

The TSP emission factor equation for bulldozers on coal is as follows (USEPA, 1988):

$$E = 35.6 \times \frac{s^{1.2}}{M^{1.4}} \text{ kg / h}$$

where

s = silt content in %

M = moisture content in %

Default values of 7% for silt content and 2.5% for moisture content gives an emission rate of 102 kg/h.

The PM_{10} emission factor equation is:

$$E = 6.33 \times \frac{s^{1.5}}{M^{1.4}} \text{ kg/h}$$

Using the same default values for silt and moisture content as provided for the TSP emission estimation gives an emission rate of 32.5 kg/h for PM_{10}.

A1.1.5 Bulldozer on Overburden

The emission factor equation for TSP is (USEPA, 1998):

$$E = 2.6 \times \frac{s^{1.2}}{M^{1.3}} \text{ kg/h}$$

Using default values of 10% for silt content and 2% for moisture content gives a TSP emission rate of 17 kg/h.

The emission factor rate for PM_{10} is (USEPA, 1998):

$$E = 0.34 \times \frac{s^{1.5}}{M^{1.4}} \text{ kg/h}$$

Using the same default values for silt and moisture content as provided for the TSP estimation gives an emission rate of 4 kg/h.

A1.1.6 Truck Unloading Overburden

The USEPA (1998) uses the same equation for unloading overburden as it does for loading overburden (see Section A.1.1.3 above). Again this gives an emission factor that appears to be too low for Australian mining operations.

The NERDDC (1988) TSP emission factor for dumping overburden is 0.012 kg/t. It is recommended that this factor be used in preference to the USEPA emission equation.

SPCC (1986) measurements in the Hunter Valley indicate that approximately 35.5% of TSP particles from trucks unloading overburden will be in the PM_{10} range. The recommended PM_{10} emission factor is therefore 0.012 * 0.355 = 0.0043 kg/t.

A1.1.7 Truck Unloading Coal

The same equation applies as for the loading of coal (see Section A.1.1.3 above). Again, this gives an emission factor that appears to be too low for Australian mining conditions.

The NERDDC TSP emission factor for dumping coal is 0.01 kg/t. It is recommended that this factor be used in preference to the USEPA emission equation.

SPCC (1986) measurements in the Hunter Valley indicate that approximately 42% of TSP particles from truck unloading operations will be in the PM_{10} range. The recommended PM_{10} emissions factor is therefore 0.01 * 0.42 = 0.0042 kg/t.

A1.1.8 Drilling

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_{10} component. However, some measurements were obtained during the Hunter Valley studies (SPCC, 1988). The mean fraction of PM_{10}/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_{10} is 0.31 kg/hole.

A1.1.9 Blasting

Estimating the TSP emission from blasting is difficult, given the complex and variable nature of each blast.

The equation is:

$$E = 0.00022 \times A^{1.5} \text{ (kg/blast)}$$
where,
A = area blasted in square metres.

It should be noted that this equation does not provide any allowance for the moisture content in the material blasted, the depth of the holes or whether the blast is a throw blast or simply a shattering blast. Therefore, it must be considered a very rough estimate of the quantity of TSP that will be generated.

There is another equation provided by the US EPA for blasting emissions. This is:

$$E = 344 \times A^{0.8} / (M^{1.9} \times D^{1.8}) \text{ kg/blast}$$

where,

A = the area blasted (square metres)

M = the moisture content of the blasted material (%)

D = the depth of the blast holes (m).

This equation takes account of other variables that are likely to be important in the generation of dust (although, clearly, there are other factors that may also be relevant, such as the degree of fragmentation achieved and whether the blast is a "throw-blast"). It is recommended that this equation be used for calculating TSP.

For blasting, the USEPA estimates that the PM_{10} fraction constitutes 52% of the TSP (USEPA, 1998).

A1.1.10 Topsoil Removal by Scraper

The TSP emission factor equation published in AP-42 is as follows (USEPA, 1998):

$$E = 7.6 \times 10^{-6} s^{1.3} W^{2.4} \quad \text{kg/VKT}$$

$where,$

s = silt content (%)

W = vehicle gross mass (t).

VKT = Vehicle Kilometres Travelled

This equation appears to be the latest version. If a silt content of 10% and a gross mass of 48 t (fairly typical of conditions on Australian mines) are assumed, a TSP emission factor of 1.64 kg/VKT is obtained. This figure is consistent with the emission factor that has been developed on Hunter Valley mines for vehicle movements. (NB. to our knowledge there is no Australian field data for scrapers in travel mode).

The PM_{10} emission factor equation published in AP-42 is as follows:

$$EF = 1.32 \times 10^{-6} s^{1.4} W^{2.5} \quad \text{kg/VKT}$$

$where,$

s = silt content (%)

W = vehicle gross mass in (t).

VKT = Vehicle Kilometres Travelled

With the same assumptions about silt content and weight of scraper as provided for TSP, the PM_{10} default emission factor is 0.53 kg/VKT.

A1.1.11 Wheel Generated Dust from Unpaved Roads

The equation provided in AP-42 (USEPA, 1998) for wheel generated dust is:

$$EF_i = k_i * (s/12)^A * (W/3)^B / (M/0.2)^C \text{ kg/VKT}$$

where:

k_i	=	2.82 for particles less than 30 micrometres aerodynamic diameter
k_i	=	0.733 for particles less than 10 micrometres aerodynamic diameter
s	=	surface material silt content, %
W	=	vehicle gross mass, t
M	=	surface material moisture content, %
A	=	empirical constant: 0.8 (for PM_{10}) & 0.8 (for TSP)
B	=	empirical constant: 0.4 (for PM_{10}) & 0.5 (for TSP)
C	=	empirical constant: 0.3 (for PM_{10}) & 0.4 (for TSP)
(i)	=	particle size category

Using default values for surface material silt content of 10%, vehicle gross mass of 48 t and moisture content of 2% gives default TSP emission factor of 3.88 kg/VKT and default PM_{10} emission factor of 0.96 kg/VKT.

A1.1.12 Use of Grader

The equation for estimating TSP from grading is (USEPA, 1998):

$$E = 0.0034 \times S^{2.5} \quad kg/VKT$$
where
S = mean vehicle speed in km/h

This equation is very sensitive to the speed assumed. There is no Australian data to verify this equation.

The proposed equation for PM_{10} emissions from grading is (USEPA, 1988):

$$E = 0.0034 \times S^{2.0} kg/VKT$$
where,
S = mean vehicle speed in km/h

A1.1.13 Primary and Secondary Crushing and Loading Coal to 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.

A1.1.14 Miscellaneous Transfer and Conveying

A common approach to estimating emissions from conveyor transfer points is to follow the approach in AP-42 (USEPA, 1998), that provides an emission factor equation for a continuous loading operation as follows:

$$E = k \, 0.0016 \left(\frac{U}{2.2} \right)^{1.3} \left(\frac{M}{2} \right)^{-1.4} \quad \text{kg/t}$$

k = 0.74 for particle less than 30 micrometres

k = 0.35 for particles less than 10 micrometres

U = mean wind speed in (m/s)

M = material moisture content (%).

If typical values for coal are inserted in to the equation (eg. U=3.6 m/s and M=8%) then E is 0.00032 kg/t for TSP.

A1.1.15 Wind Erosion from Active Coal Stockpiles

The AP 42 emission factor equation for wind erosion is:

$$E = 1.9 \left(\frac{s}{1.5} \right) 365 \left(\frac{365 - p}{235} \right) \left(\frac{f}{15} \right) \text{kg/ha/year}$$

s = silt content (%)

p = number of days 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 days/year and f=30%, E is 16,821 kg/ha/year (1.92 kg/ha/h).

The SPCC (1986) 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 PM_{10}. Therefore, the default emission factor for PM_{10} is 0.2 kg/ha/h.

A1.1.16 Wind Erosion from Other Exposed Areas (chitter/waste emplacement dams and wind erosion from exposed areas)

While the emission estimation equation for stockpiles presented in A.1.1.15 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.

However, in the absence of other information, it is recommended that the SPCC (1986) 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.

A1.1.17 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 (eg. loading it to trucks, transporting by road) will need to be considered using the various emission factors presented in Table 1 of this Manual.

The emission factor equation suggested is for miscellaneous transfer and conveying as follows:

$$E = k\,0.0016\left(\frac{U}{2.2}\right)^{1.3}\left(\frac{M}{2}\right)^{-1.4} \quad \text{kg/t}$$

$k = 0.74$ for particle less than 30 micrometres

$k = 0.35$ for particles less than 10 micrometres

U = mean wind speed in m/s

M = material moisture content (%).

A1.1.18 Coal Mining Using Bucketwheel Excavator

A significant proportion of open cut coal mining for softer brown coals is carried out using bucket wheel excavators. There is no US EPA or Australian emission factor for this operation. 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 (see Section A.1.1.14 of this Manual). With typical coal moisture of greater than 10% the TSP and PM_{10} emissions will typically be less than one gram of dust per tonne of coal mined. Therefore, this will be a very small component of the overall inventory.

A1.2   METALLIFEROUS MINES

A1.2.1 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 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.

A1.2.2 Loading Trucks and Unloading Trucks (rear dumping)

The US EPA equation for batch loading/unloading is:

$$E = k0.0016\left(\frac{U}{2.2}\right)^{1.3}\left(\frac{M}{2}\right)^{-1.4} \text{kg/t}$$

where,

$k = 0.74$ for particle less than 30 micrometres

$k = 0.35$ for particles less than 10 micrometres

U = mean wind speed in (m/s)

M = material moisture content (%).

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.

A1.2.3 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 US EPA (1998, Section 11.24).

When considering emissions from metalliferous mining operations, it is useful to note that any ore (except bauxite) with a 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.

APPENDIX B
- EMISSION ESTIMATION TECHNIQUES - WATER & LAND

B1.0   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 5 and 6 of this Manual. This Appendix provides:

- Information on default concentrations of NPI substances in various rock types and ores (Section B.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 (Section B.1.3).

- A discussion of the use of mass balance as an emission estimation technique (Section B.1.4).

- A discussion of the types of site-specific data that may be available to assist in emissions estimation (Section B.1.5).

- A series of worked examples to illustrate the application of the EETs provided for water and land (Section B.2).

B1.1 TABLES

TABLE B1 Table of Important Elements

Element[1]	Symbol	Atomic Weight[2,3] (Rounded)	Element	Symbol[1]	Atomic Weight[2,3] (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-listed 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 (eg carbon disulfide). The information has been provided for the purposes of assisting you to calculate the proportion of NPI-listed substances in compounds/minerals found at your facility.

[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 $CuFeS_2$ and its atomic weight will be $64 + 56 + 2*32 = 184$. A tonne of chalcopyrite will therefore contain about 0.34 (64/184) tonnes of copper.

Table B2. 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	1400	-	200	950	730	550	800	220	180	640
Lead	Pb	3	24	30	35	14	80	17	23	5.7	10	19
Manganese	Mn	1500	400	41	1000	950	6700	1000	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.   All figures in mg/kg (or g/tonne)
2.   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.
3.   The figures listed above are average concentrations of the particular element within the rock or material specified.
4.   The NPI requires the reporting of emissions of the elements listed in this Table and their compounds. 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
5.   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 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.

B1.2   General Assumptions for Emission Estimation Techniques

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

- Routine monitoring is directed to ensuring 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 characterising emissions for the purposes of NPI reporting (see Section B.1.3 for a further discussion of this).

- Reportable emissions are confined to the materials that are actually released to the environment and do not include "transfers" (ie. movement of reportable substances within the facility that are not classed with an emission). 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 6.1 for a further discussion of "transfer" as this terms applies to mining operations).

- Emissions of reportable volatile substances used on mines, such as chlorinated solvents and volatile organic compounds, are assumed to report to the atmosphere. Similarly, carbon disulfide formed as a result of the decomposition of xanthates is assumed to report as an air emission. MIBC held in a water or tailings storage facility 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 in cases 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 per cubic metre of water discharged should be assumed.

- Actual emissions from mines 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 areappropriate 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 B2 (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 $> 10^{10}$ litres per annum 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.

- Where site-specific estimates of erosion are not available, the general figures indicated in the Table below may be used. Clearly, if site-specific erosion data is available, it should be used in preference to the default values provided below.

Erosion Rate	Guideline
A. 40 tonnes per hectare per annum	A. Exposed soils, vegetation cover <25%, dispersive material with high silt / clay content including tailings and similar materials.
B. 20 tonnes per hectare per annum	B. All other cases (except for C below).

Source: Personal Communication, C. Carroll, Department of Natural Resources, Emerald, Queensland (unpublished Thesis).

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 tonnes per hectare per annum 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 tonne per hectare per annum under similar rainfall conditions and this may be regarded as "low erosion rate". Where erosion data is not available, a figure of 20 tonnes per hectare per annum 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 normal 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 (AD) generation from pyrite oxidation is a complex matter and should be determined on a site by site basis. AD 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. If the pH of the release is above 4, it should be assumed that sulfuric acid is not present in the release. This is discussed further in Section 5.3.5.

  Where the pH of the release is below 4, sulfuric acid emissions must be estimated, preferably using site-specific data. When site-specific data is not available, it should be assumed that sulfuric acid generation is 240 kg per hectare 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 cubic metres per hectare, which at a density of 1.5 would have a mass of 15 tonnes per hectare, hence, 240 (15 * 16) kg per hectare).

B1.2.1 Typical Data Availability

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

B1.2.2 Fugitive Emissions: Dust

Drop in metres for draglines	Generally not available (from on-site estimates)
Moisture content of soil	Available most sites
Mean wind speed in m/s	Available most sites
Area blasted in square metres	Available
Depth of blast holes	Available most mines
Number of wheels for haul road traffic	Available
Silt content of soil	Generally not available
Vehicle gross mass	Available
Mean vehicle speed (estimates)	Generally not available
Average level of reportable substances in overburden	Generally not available
Average level of reportable substances in waste rock	Generally not available
Average level of reportable substances in ore	Available some sites (parameters limited)

B1.2.3 Fugitive Emissions: Metals

Assay data	Limited data only
Litres of fuel used per type of vehicle (tracked	

type tractor, wheeled tractor, scraper, grader,
off-highway truck)   Available some sites

Water balance information   Generally not available

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

Emissions to ground-waters   Not available

B1.2.4 Emissions to Waters

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 (eg. tailings, coarse rejects, spillages)   Available some sites

B1.3 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 (eg 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 (eg downstream monitoring of a 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 is 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.

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 characterised).

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, (eg 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 is 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 (eg 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 (ie 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 is available, mass balance calculations can be used to estimate emissions (see Section B.1.4).
Survey Information	Mine surveys will give data on land use within the area of interest (eg 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 (eg waste rock, concentrate, tailings)	Trace metal concentrations may be routinely available from process monitoring (eg 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 is 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 (eg water quality data, trace element concentration in soils, suspended solids loadings).

In summary, where reliable flow and water chemistry data is 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 is sufficient to fully account for variations over the reporting period. The emissions should be reported as kilograms per annum.

B1.4   Use of 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.

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. Small errors in data can lead to potentially large errors in the final estimates. In the context of mining operations, the failure to use representative data can lead to significant inaccuracy in the predicted emissions. An example of the application of mass balance techniques to mining operations is provided in Appendix B, Section B.2.1.

In their simplest form, mass balances are straightforward additions. On a dry mass basis for example, the mass of product produced will be the total quantity mined less the quantities of wastes (eg waste rock, tailings and other releases to the environment) produced. 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 consumed less the water entrained in the waste and product streams, water recycled to the plant and evaporation. In summary, the total (T) will comprise the sum of its parts, (A, B, C, and D). That is:

$$T = A + B + C + D...$$

If the proportions or concentrations of a variable within a system are known, this can be linked with the arithmetic sum. For example if the concentration or proportion in the Total is t and in the parts A, B, C and D are a, b, c and d respectively, then:

$$T*t = A*a + B*b + C*c + D*d...$$

As a practical example if a run of mine ore has a grade of t% metal and the grades of concentrate and tailings are a% and b% respectively and the tonnes of ore treated are (T), the tonnes of concentrate (A) and the tonnes of waste (B), then:

$$T*t = A*a + B*b.$$

These equations can be used to estimate figures and/or check the validity of measured or assumed data. Thus if one variable is not known (eg metal grade or concentration in tailings (z)) it may be estimated (ie b = (T*t - A*a)/B). If all variables are known they can be

generally checked using this equation. (Inevitably, exact answers should not be expected and it is likely that there may be some discrepancies due to inaccuracies in sampling, measurement, or estimation techniques).

If there are known losses from the system (eg T > A+B), the losses may be aggregated as "C" while the average concentration of this material would be "c". This would give the following expression that may be useful in the estimation of emissions:

$$T*t = A*a + B*b + C*c$$

For example, estimates of process water flows and the concentrations of substances in these flows can be made from mass balance equations if the volumes of water used and/or lost in various elements of the process and the dissolved and/or suspended solid concentrations for those waters are known. If certain data are not available, assumed or estimated values may need to be substituted in to the equation or equations to allow an estimation to be made.

Catchment area data may be manipulated to generate emission estimates. For example, if flows from a catchment are known, then, as a first pass, the discharge flow from contaminated areas could be estimated from the proportion of those areas in the total catchment. Ideally, as noted above, estimates should be calibrated for the particular facility. However if the total catchment area is large and the areas from which contaminated waters originate are small in comparison with the catchment area (say <5%) the proportion may be used as a basis for estimating flows. While there are obvious limitations to the reliability of these estimates, they may prove useful as a starting point in emission estimation.

B1.5   Use of Site-Specific Water Emission Factors

Water emission factors can be derived for each facility and once derived they can be used for future emission estimation. For example, characteristics of the site can be used to give an erosion figure for the reporting period (expressed as tonnes per hectare per annum) and this erosion figure can then be combined with estimates of the metal concentration in the materials lost from the site to determine a mass emission rate.

Mass balance calculations could be used to obtain a concentration for a particular element using information on the areas and quantities of the relevant materials and trace element concentration data. Assumptions would be required on the trace element concentration of the materials if actual data were not available. For example, a waste rock dump may contain 90% waste rock and 10% sub-economic ore. If only the trace element concentration of the sub economic ore was known, it would be incorrect to assume that the same concentration applied to the waste rock. In such situations, emissions are likely to be significantly overstated and the reliability of the emissions estimates would be low. Therefore, if any site-specific emission factors are developed, all gaps in the data record should be identified and appropriately covered. Documenting these data gaps and the assumptions made will facilitate the review of the emissions estimates and help identify priorities for further investigation.

With infrastructure areas that do not change significantly over time (eg. tailings storage facilities), process water volumes and properties and material quantities and properties may be used to define substance movements which, in turn, may be related to emissions. This data can then be developed into site-specific emission factors for use in future emissions estimation activities.

B2.1   Worked Examples

Sections B.2.1.1 to B.2.1.6 provide examples on data use and manipulation to estimate emissions from a fictional open-cut copper mine that produces a concentrate by flotation of the ore. The purpose is to illustrate a way in which facilities can meet their NPI reporting requirements based on the typical data available for such facilities. The general scope of the operation of the mine, its emissions and management are described in Section B.2.1.1 below. **It is assumed that the facility is required to report to the NPI.**

The various cases presented in Sections B.2.1.2 to B.2.1.6 use different data sets and assumptions to estimate emissions. As a consequence, the emissions estimates vary from case to case. The examples illustrate the potential for the use of the calculation techniques (in particular where default concentration data is assumed) to provide different emissions estimates.

B2.1.1 Case Study Description

Waste rock and sub economic ore are placed in waste dumps and process wastes are placed in a tailings storage facility. The concentrator is located in the tailings storage facility catchment, that has been upgraded to a "nil" discharge structure by raising and catchment segregation. Therefore, run-off from the plant is contained (and, as a consequence, is classed as a transfer). Run-off from the waste rock dumps, haul roads and the workshop and maintenance areas is not contained and report to the local water course. This run-off mixes with run-off from undisturbed areas of the mine before discharge from the lease. The ore and waste rock contain pyrite. In recent years, site management practices have been revised to prevent acid generation in the waste dump. AD generation occurs in the tailings storage facility (where it is being contained) and in an old waste dump that is not contained. In some areas of the mine the host rock is dolomite.

A similar ore type is assumed for an old mine where there are now several waste dumps and tailings storage facilities. A new concentrator has been established on one former dam. Run-off management and control is difficult to implement and run-off from the site is contaminated with old tailings. Use of the dam for the concentrator has been possible because of the dominance of limestone and dolomite in the host rock that has prevented pyrite oxidation.

Average trace metal concentrations in the waste dumps are shown in the following Table. It is assumed that the haul road was constructed using oxidised material (of unknown composition) taken from close to the surface of the waste rock dump. (NB: Depending on the example, the following data may or may not be available.)

Parameter	Waste Dump 1	Waste Dump 2	Waste Dump 3	Waste Dump 4
EC (µS/cm)	1020	950	230	1225
pH	7.3	8.5	7.9	8.4
Total S (%)	4.2	0.6	1.1	1.4
Acid Prod. Pot. (kg/t)	145	24	48	59
Acid Neut. Cap.(kg/t)	20	27	28	42
Net Acid Pot. (kg/t)	125	-3	20	17
Antimony (ppm)	0.0	0.0	0.4	0.0
Mercury (ppm)	0.0	<0.01	0.01	<0.01
Aluminium (%)	10.7	11.3	11.2	10.9
Arsenic (ppm)	6.2	11.7	24.1	19.7
Calcium (%)	2.7	3.5	3.4	3.2
Cadmium (ppm)	0	0	0	0
Cobalt (ppm)	17.2	15.7	23.1	6.2
Chromium (ppm)	21.6	31.5	4.2	7.1
Copper (ppm)	2100	1989	2200	2064
Lead (ppm)	43	112	122	27
Nickel (ppm)	6.1	4.2	3.7	5.0
Zinc (ppm)	175.1	228.4	320.4	215.6

B2.1.2 Use of Monitoring Data to Estimate Emissions

In this example, it is assumed that automatic sampling of pH, conductivity, suspended solids, flows and flow rates is conducted at:
- a site in the local water course that drains the waste rock dumps; and
- at a downstream site near the lease boundary that drains lands undisturbed by the mining operation.

Metal concentrations are not routinely monitored, as it is known that solubility will be depressed in the alkaline environment.

As the conductivity (EC) is relatively high compared to natural waters in the area, pyrite oxidation may be detected through changes to pH and increases in EC (these changes would be associated with sulfate generation). Water quality in the tailings storage facility is monitored but as it does not discharge, it is not relevant to emission estimation.

It is known from geological modelling of the deposit that the average copper concentration in the waste rock is about 0.2%. It is known that arsenic, cobalt, chromium, lead, zinc and nickel occur in trace quantities in the ore and waste rock, but their concentrations are not accurately known.

From mine records and data obtained for previous environmental studies, it is known that the concentrations of other reportable substances (in particular antimony, mercury and cadmium) are either at or below their detection limits for the sampling instrument used. These detection limits vary in the range 0.1 ppm to 1 ppm. Because of the geological nature of the deposit, beryllium, boron and fluoride do not occur on the site or occur below the detection limits of the instrument used. Survey information is available for the facility and the areas of all catchments and sub-catchments are known.

- pH   8.5
- Total Catchment Area   420 ha
- Av. Suspended Solids (for entire catchment)   24 mg/L
- Annual Flow   (for entire catchment)   657800 m^3
- Area of Waste Dumps etc)   63 ha
- Av. Suspended Solids (from waste dumps etc)   42 mg/L
- Annual Flow   (from waste dumps etc)   99000 m^3
- Copper Concentration in Waste Rock   0.2%

The instruments used are regularly calibrated and, therefore, flow and suspended solids data should be reliable. The characteristics of the various catchments are considered to be generally similar and therefore run-off would be in proportion to the area of each catchment. As copper concentration is based on old modelling data, its reliability is regarded as moderate.

The assumed data for the other reportable metals is shown in the following table. This information has been estimated from old site data and a recent inspection of minerals in waste rock samples. There are no reliable records to link the old data to the four waste dumps but it is considered that this data would be generally representative of average concentrations in all dumps. As these estimates have been based on qualitative examinations of a relatively small number of samples, their reliability is low.

Metal	Assumed Conc. (mg/kg)	Metal	Assumed Conc. (mg/kg)
Cobalt	25	Chromium	22
Arsenic	18	Lead	120
Nickel	6	Zinc	220

If acid drainage produces acids such as hydrochloric acid or sulphuric acid in excess of 10 tonnes per reporting period then emissions for these substances must be reported. If acid generated is contained within the facility and is not released into the environment then an emission of zero should be reported. Other NPI substances would not require reporting by this facility.

To calculate emissions of suspended solids from the entire facility, the following calculations are performed:

1. Determine total flow from the catchment = 657800 m^3 (given);
2. Determine total suspended solids emissions from the facility = 657800 m^3 (flow) * 1000 (to convert to L) * 24 mg/L (Av. suspended solids for entire catchment) / 1000*1000 (to convert from mg to kg)   = 15800 kg

Similarly, total suspended solids emissions from the disturbed areas is 4200 kg (rounded from 4158 kg)

There is no data available to determine the extent of deposition of eroded material from waste dumps etc within the lease area. If zero deposition is assumed, the suspended solids concentration of run-off from undisturbed areas may be estimated using a mass balance calculation as set out below:

99000 * 42 + (657800 - 99000) * X (suspended solids conc'n)= 657800 * 24

From this it is apparent that the estimated suspended solids concentration of run-off waters is approximately 20 mg/L. This is similar to the suspended solids concentration of the waters leaving the facility. In the absence of more data, it is assumed that the emissions from the disturbed area, 4200 kg, leaves the facility over the reporting period.

To complete your reporting under the NPI, the emissions of trace metals must be included. From the available information (see Section B.2.1.1) and assumed data on metal concentrations, the estimated emissions are shown in the following Table:

Metal	Estimated Emission (kg)
Copper	8.3
Arsenic	0.08
Cobalt	0.01
Chromium	0.09
Lead	0.5
Nickel	0.03
Zinc	0.9

Site data (see Section B2.1.1) suggests that antimony, cadmium and mercury are present in concentrations of 0.1 to 1 ppm. For the purpose of calculating emissions, a concentration of 1 ppm has been assumed for these substances. Beryllium, boron and fluoride are known to be effectively absent from the site. There is no site-specific data on the quantities of manganese and selenium. Therefore, the default concentrations presented in Appendix B, Table B2 have been used (assuming that the host rocks are shales). Emission estimates based on a total suspended solids emission from the area of 4200 kg over the reporting period are given in the following table.

Metal	Estimated Emission (kg)
Antimony	$4.2 * 10^{-3}$
Cadmium	$4.2 * 10^{-3}$
Mercury	$4.2 * 10^{-3}$
Manganese	4
Selenium	$1.3 * 10^{-4}$

In the above table, the figures have been rounded off and no allowance has been made for natural emissions resulting from erosion of mineralised land surfaces.

B2.1.3 Use of Assumed / Estimated Data

In this example the same copper mine as described in Section B2.1 is used. In this case however, flow data is not monitored. Spot determination of suspended solids are made during flow events at the same general monitoring points. The measured concentrations vary between 10 and 200 mg/L with an arithmetic average of 85 mg/L.

The pH of run-off waters varies between 3.5 (close to the original waste dump) and 8.2 at the lease boundary.

Geological modelling data, old data and an examination of the minerals present in waste rock samples has provided estimates for the concentrations of various substances known to be present in the waste materials. Copper, chromium, cobalt, arsenic, nickel, lead and zinc concentrations are assumed to be the same as those given in the previous example (see the data presented in Section B2.1.1). For other NPI-listed substances, the default figures given in Table A2 have been used (assuming the host rock is shale). Detailed survey data of the mine site is available.

As flow data is not available but estimates of metal concentration in the waste are known, an estimate of erosion losses has been used. Waste rock comprises relatively competent material and the default erosion rate of 20 tonnes per hectare per annum for average rainfall conditions has been used. In the year under review rainfall has been 80% of the average. The surface area of the waste rock dump is three hectares. Because data is not available, no allowance has been made for deposition or subsequent re-entrainment of deposited materials. This suggests that the solids emissions from the facility for the year under review are 48 tonnes (ie 3 (hectares) * 20 (tonnes/year) * 80 (%)/100). This assumes that solids emissions from the facility are directly proportional to rainfall.

The following Table gives the estimate of reportable emissions based on solids emissions of 48 tonnes per year and utilising the substance concentrations described above. As the figures are based on the product of two approximate estimates, their reliability will be low.

Metal	Estimated Emission (kg/year)
Copper	96
Arsenic	0.9
Cobalt	1.2
Lead	1
Chromium	5.9
Nickel	0.2
Zinc	10.6
Antimony	$7.2 * 10^{-2}$
Cadmium	$1.1 * 10^{-2}$
Mercury	$9 * 10^{-3}$
Manganese	41
Selenium	$2.4 * 10^{-2}$

Comparing this example to the results for the example in Section B.2.1.2, it can be seen that the emission estimates produced in this example are about 10-12 times less than the estimates from the example in Section B.2.1.2. Where large catchments are involved any overestimation of the erosion estimate will lead to a significant overestimate of emissions of NPI substances. Conversely, underestimating erosion rates could lead to a significant underestimate of emissions of NPI substances.

B2.1.4 Sulfuric Acid Estimation

Sulfuric acid estimation will be required when the pH of contaminated water is <4.0. Site-specific data should be used to characterise sulfur acid emissions. In the event that no site-

specific information is available, the assumption that 240 kg of sulfuric acid is generated on each hectare of exposed pyritic material can be used.

If the exposed area of pyritic material is 25 hectares, the quantity of sulfuric acid to be reported will be 6,000 kg.

B2.1.5 Tailings Storage Facility Overflow and Related Situations

In this example, it is assumed that several decommissioned waste dumps and tailings storage facilities are actively eroding on an old mine site. A new concentrator has been established on one former dam. Run-off management and control is difficult to implement and consequently run-off from the facility is contaminated with old tailings. While pyrite is present in significant quantities, AD generation is limited because of the dominance of limestone and dolomite in the host rock.

Emissions estimation will be related to the mass emission of tailings and waste rock materials from the facility. This can be determined using techniques outlined in previous examples. In particular, data on waste rock and tailings composition should be available, especially for target minerals. This can be linked with known or estimated information (eg. known or assumed erosion rates, measured or estimated flow rates, suspended solids concentrations).

B2.1.6 Mass Balance Calculations

In this example, general mine and concentrate production data is used to estimate emissions. Run of Mine production is 2,600,000 tonnes per annum at 3% copper, concentrate production is about 170,000 tonnes per annum, grade about 37% copper and tailings (dry weight) generation is about 2,420,000 tonnes at 0.6% copper. Losses from the plant occur with cleaning, leaks in pipes and overflows (from sumps etc.) while leaks also occur from slurry lines. These losses have not been quantified in detail. Mine waste and stockpile mass and volumes are estimated from survey data and generally confirmed by truck movements. Concentrate production is estimated from conveyor belt weighing, corrected for moisture, and tailings generation data have been estimated from survey information with corrections for pulp/slurry density and water recycled to the plant. Grades are based on average assay data.

While there are uncertainties associated with each of the items above, the losses may be generally estimated from a mass balance calculation.

$$2,600,000 * 3\% = 170,000 * 37\% + 2,420\ 000 * 0.6\% + L * g \text{ (losses)}$$

Material losses, L (tonnes) = 2,600,000 - (170,000 + 2,420,000) = 10,000 tonnes.

The average grade (g) of these losses, 5.8%, can be obtained from substitution in the mass balance equation. This equates to a potential loss of 580 tonnes of copper. The actual losses reported would depend on site-specific circumstances (eg the extent of clean up and catchment controls).

With the quantities involved, the estimation of weights and volumes will be subject to errors. Care needs to be taken when interpreting the data as the losses may be due to uncertainties associated with the data rather than real losses. As an example, if the actual percentage of copper in the ore were 2.9%, this would provide a result that indicated a negative loss of 2,020

tonnes per annum. Consequently the reliability of data should be carefully examined before using mass balance equations to estimate losses and emissions.

B2.1.7 Land Emissions

In most mining activities, the placement or movement of wastes on mine sites will be classed as a transfer and, therefore, not required to be reported under the NPI. With regard to the estimation of emissions to land, the following points should be noted:

- Where the permeability of underlying strata is $< 10^{-6}$ m/second, the potential for the release of NPI reportable 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 $<10^{-20}$ g/l at neutral pH. Unless there are huge volumes of water in very permeable strata, metal losses to groundwaters will be negligible.
- Waste containers such as 200 litre drums will always contain residual quantities of their contents. Where containers of reportable substances (eg. solvents and reagents) are placed in landfills, unless specific data is 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.