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Literature Review of Current Fugitive Dust Control Practices within the Mining Industry

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained to develop a Best Management Practice (BMPs) Guidance Document for use in mining industry. This report provides a literature review of the current recommended BMPs related to activities within the mining industry and can be used as reference when developing a Best Management Practice Plan (BMPP).

With known mineral deposits of nickel, gold, silver, platinum, diamonds and other key minerals[1], Ontario provides the resource base for an active mining industry. One of the key environmental challenges for this industry is fugitive dust emissions related to process operations. Fugitive dust is of concern due to the potential health impacts associated with fine particulate matter. In mining, this is coupled with the potential for elevated levels of metals to be present in the particulate matter. For these reasons, fugitive emissions are required to be assessed when facilities are seeking regulatory approvals. Managing fugitive releases can help the approvals process and prevent complaints from nearby residences.

The key steps in the mining process include extraction, processing, storage, and disposal. In each of these steps, there is a potential for releases of fugitive dust. Specific mining activities that may result in fugitive dust emissions include[2];

- site preparation (bulldozing, land clearing);
- open pit drilling and blasting;
- material movement (loading/unloading, stockpiling);
- crushing/screening ore and waste rock;
- paved and unpaved roadways; and
- tailings and storage piles (wind erosion).

BMPs are managerial, operational and structural measures that can be used to prevent, reduce or mitigate various undesired impacts that an operation may cause. Fugitive dust emissions can be reduced through applying the most appropriate BMPs, individually or in combination, for specific applications. For a BMP to be effective each situation must be individually assessed and the BMP should be chosen to suit the uniqueness of the operation[3].

2.0 FUGITIVE DUST

2.1 What is Fugitive Dust?

Fugitive dust is defined as dust generated from open sources that is not discharged to the atmosphere in a confined flow stream[4]. Fugitive dust sources may be separated into two broad categories; process sources and

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[1] Ontario Ministry of Northern Development, Mines and Forestry (http://www.mndm.gov.on.ca/mines/default_e.asp, April 7, 2010)

[2] Organiscak, John and Reed, Randolph, "Characteristics of Fugtive Dust From Unpaved Mine Haulage Roads". URL: http://www.cdc.gov/niosh/mining/pubs/pdfs/cofdg.pdf

[3] British Columbia. Aggregate Operators Best Management Practices Handbook. url: http://www.empr.gov.bc.ca/Mining/MineralStatistics/MineralSectors/ConstructionAggregates/ReportsandPublications/Pages/AggregateOperators.aspx

[4] United States Environmental Protection Agency (US EPA) AP-42 Section 13.2 Fugitive Dust Sources. January 1995.

open dust sources. Process sources of fugitive emissions are those associated with industrial operations, such as rock crushing, that alter the characteristics of a feed material. Open dust sources are those that generate non-ducted emissions, such as material transfers/handling and vehicle movements[5]. There are additional sources of natural origin; however, this review is limited to anthropogenic sources only.

Fugitive dust can be further separated into the following categories based on the size fraction:

Table 1: Particle Size Ranges of Fugitive Dust

Category	Definition	Common Name
TSP*	Particulate matter with an aerodynamic diameter no greater than 30 micrometers	Total Suspended Particulate
PM10	Particulate matter with an aerodynamic diameter no greater than 10 micrometers	PM10
PM2.5	Particulate matter with an aerodynamic diameter no greater than 2.5 micrometers	PM2.5

Note

* The term TSP has varying definitions in literature. For the purposes of this report the above definitions will be used when discussing the size fractions.

2.2 Factors Influencing Dust Emissions

The amount of dust that can be generated is affected by a variety of factors such as material characteristics (particle size), climate conditions (wind, precipitation), control measures in place and the frequency of disturbance of the material[2, 6]. The distance the material will travel from the source is primarily affected by the particle size distribution and the climatic conditions. For high wind conditions, particles larger than about 100 μm are likely to settle out within 6 to 9 metres, whereas particles 30 to 100 μm are likely to settle within a few hundred feet of the road. Finer particles (< 30 μm) will travel further distances. Studies have demonstrated that more than 80% of the dust generated by truck movements is greater than 10 μm and concentrations decrease to nearly background levels within 30.5 metres of a roadway.

Mechanically generated dust emissions are highly variable depending on the physical material properties (i.e. amount of silt present) and the moisture content of the material being disturbed. Dust emissions are strongly dependent on the moisture level of the disturbed material. Water acts as a dust suppressant by forming a cohesive bond between the grains of the surface material. The moisture level of the material depends on the amount of water added (natural precipitation or physical additions) and the evaporation potential. For example vehicle movements will result in quicker drying due to the additional air movements over the surface. In addition to physical properties, mechanical stresses on the material will impact the amount of dust released. These include factors such as wind speed, drop height, and the speed of vehicle traffic.

The key elements that impact wind generated dust are wind speed, physical material properties and moisture. The ability for a particle to become entrained is dependent upon its particle size, with the most erodible particle sizes being below 75 μm, which are easily lifted from the surface and suspended in the air. Other factors that

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[5] Countess Environmental (September 7, 2006). *WRAP Fugitive Dust Handbook. Prepared for Western Governor's Association.* URL:http://wrapair.org/forums/dejf/fdh/content/FDHandbook_Rev_06.pdf

[6] Ontario Ministry of Environment. Technical Bulletin: Review of Approaches to Manage Industrial Fugitive Dust Sources. January 2004

impact wind generated emissions are non-erodible elements, such as grass or stones, which break the shear stress of the wind on the surface. In addition, water addition often results in the development of a crust on the surface, which will hold in moisture and resist erosion. Each time the surface is disturbed the erosion potential is increased by destroying the mitigative effects of crust, vegetation and non-erodible elements.

The type (particle size fraction) and quantity of the dust that can be generated is affected by a variety of factors such as material characteristics (particle size), climate conditions (wind, precipitation), control measures in place and the frequency of disturbance of the material[2,6]. The distance the material will travel from the source is primarily affected by the particle size distribution. Therefore, when developing a BMP the source type (particle size, metals concentration), potential pathway (controls) and receiving receptor (where the dust is landing) should all be considered. Figure 1 graphically displaces the elements that contribute to the impact of fugitive dust.

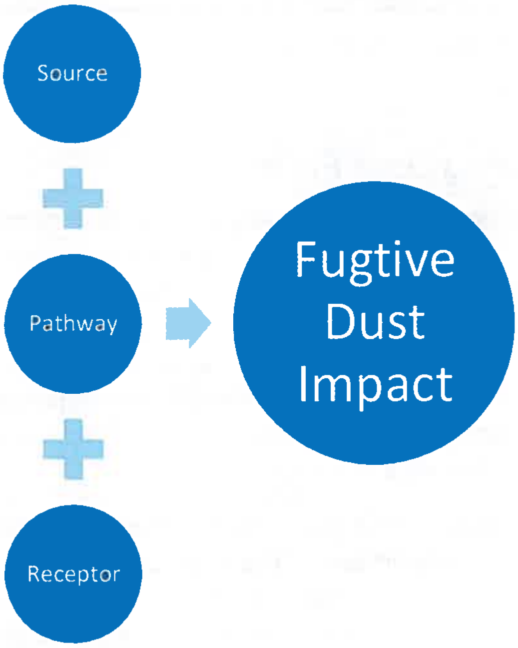

Figure 1: Elements Contributing to Fugitive Dust Impact

Based on these factors, reducing the quantity of silt available, adding moisture, minimizing disturbances and mitigating the impact of wind on a source are essential in reducing the impact of fugitive dust from a source.

2.3 Silt Loading

The amount of the dust that has the potential to become fugitive emissions is dependent on the amount of silt in the dust. The US EPA AP42 emission factor document has published typical silt contents for various industries. However the mining industry does not have published values. The following table provides silt content ranges, in percent and g/m², for road dust sampling that was conducted on mining sites[7]. It should be noted that the source sampling data has not been Quality Assurance/Quality Controlled (QA/QCd) for consistency in analytical methods and has been taken from sources with a variety of testing methods.

Table 2: Typical Silt Content Values for Roadways on Ontario Mining Sites

Silt Content	Unpaved Roads			Paved Roads		
	Maximum	**Minimum**	**Mean**	**Maximum**	**Minimum**	**Mean**
(%)	36.80	0.10	9.14	35.60	0.72	3.55
(g/m²)	282.00	1.21	34.30	18.85	0.00	0.18

2.4 Metals Content

An additional concern to the mining industry, above the TSP concerns of the industrial minerals and aggregate processing industries, is the potential for the fugitive dust to contain metals. Along with TSP, metals are also regulated and need to be assessed as a component of the fugitive emissions of the site.

There is a significant lack of published data regarding typical metals concentrations in dust at mining sites. For comparative purposes the following table has been developed. The table includes the current soil standards published by Canadian Council of Ministers of the Environment (CCME) and the Ontario Ministry of the Environment (MOE) and compares the typical soil concentrations with measured road dust data from various mining sites in Ontario. Comparison of site specific metals levels to these published regulatory values will assist sites during the Risk Evaluation Phase when developing a BMP. It should be noted that the industrial data has not been QA/QCd for consistency in analytical methods and has been taken from sources with a variety of testing methods. It is recommended that when conducting a risk assessment, site specific data should be used. The inclusion of health impacts of each of the listed metals is beyond the scope of this literature review.

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[7] A summary of road dust sampling results from over 100 sampling locations at mining sites in Ontario. This data has not been validated for consistency in analytical methods.

Table 3: Regulatory Levels for Metals Concentrations in Soils

METAL	REGULATORY LIMITS		ONTARIO STUDIES			ONTARIO MINING SITES					
	CCME (mg/kg)	Ontario (µg/g)	Sudbury Soils Study[8] (µg/g)		Ontario Typical Range[9] (µg/g)	Unpaved Roads (µg/g)			Paved Roads (µg/g)		
	Industrial	Table 1: Full Depth Back	95th perc	Maximum	98th perc	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Aluminum	—	—	18000	39000	30000	64000	179	10135	15900	718	4870
Antimony	40	1	—	—	0.43	210	0.5	4.95	88.7	0.41	8.45
Arsenic	12	17	61	620	17	34000	0.5	89.7	1140	2.8	64.05
Barium	2000	210	120	720	180	580	1.2	51.3	173	5.45	46.6
Beryllium	8	1.2	0.25	2	1.1	1	0.24	0.5	7.1	0.4	0.5
Bismuth	—	—	—	—	—	116	0.54	3	192	1.2	17.5
Boron	—	—	—	—	30	35.8	1	5.8	16	1	3.8
Cadmium	22	1	1.8	6.7	0.84	16.6	0.05	1.29	28.6	0.4	1.65
Calcium	—	—	11000	250000	58000	72000	100	9400	7240	513	3220
Cerium	—	—	—	—	—	153	0.81	24.65	52.7	5.32	22
Cesium	—	—	—	—	—	1.5	0.49	0.74	0.78	0.43	0.57
Chromium	87	71	56	1100	62	410	1.5	90.2	418	11.7	81.5
Cobalt	300	21	42	190	17	4950	2.29	130	10400	35.6	382
Copper	91	85	1100	5600	65	50300	49.1	1570	174000	200	11700
Europium	—	—	—	—	—	1.9	0.49	0.64	0.55	0.49	0.55
Gallium	—	—	—	—	—	7.88	0.66	4.4	6.7	0.61	3.9
Iron	—	—	26000	110000	35000	143000	1140	63500	177000	13200	50100
Lanthanum	—	—	—	—	—	85.3	2.7	11.6	29.9	2.5	10

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[8] Sudbury Area Risk Assessment, Volume I – Chapter 7: The Soil Survey. January 2008.

[9] Ontario Typical Range of Chemical Parameters in Soil, Vegetation, Moss Bags and Snow, Ontario Ministry of the Environment and Energy. December 1993.

METAL	REGULATORY LIMITS		ONTARIO STUDIES			ONTARIO MINING SITES					
	CCME (mg/kg)	Ontario (µg/g)	Sudbury Soils Study[8] (µg/g)		Ontario Typical Range[9] (µg/g)	Unpaved Roads (µg/g)			Paved Roads (µg/g)		
	Industrial	Table 1: Full Depth Back	95th perc	Maximum	98th perc	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Lead	600	120	130	790	98	721	2.3	41.8	993	14.4	131
Lithium	—	—	—	—	—	45	4.2	12.5	13	5.9	7
Magnesium	—	—	5700	26000	20000	47000	125	7080	6940	502	4020
Manganese	—	—	360	3300	2200	2300	5.04	310	1180	36	195
Mercury	50	0.23	—	—	0.18	0.758	0.049	0.24	1.2	0.04	0.455
Molybdenum	40	2.5	1.8	21	1	25.2	0.55	4.45	72	0.69	8.34
Nickel	50	43	1100	3700	38	488000	14.5	1580	429000	133	10400
Niobium	—	—	—	—	—	—	—	—	4.4	0.72	2.56
Phosphorus	—	—	—	—	—	1000	92	360	833	68	340
Rubidium	—	—	—	—	—	37.4	1.2	10	18.5	0.99	6.4
Scandium	—	—	—	—	—	8.38	0.59	3.2	3.9	0.86	2.6
Selenium	2.9	1.9	5	49	1.3	89.9	0.5	7.7	154	1.2	25.55
Silver	40	0.42	1	8.1	0.33	131	0.052	1.47	139	0.4	9.06
Strontium	—	—	53	340	78	184	2.6	55.2	79.5	4	23
Thallium	1	2.5	—	—	0.81	0.59	0.59	0.59	—	—	—
Thorium	—	—	—	—	—	22.4	1.4	7.4	21.3	1.7	5.02
Tin	300	—	—	—	—	230	0.5	7.72	327	1.6	26
Titanium	—	—	—	—	5200	3400	18.2	870	1180	124	708
Tungsten	—	—	—	—	—	12.5	0.57	3.2	104	0.49	12
Uranium	300	—	—	—	2.1	6.8	0.49	0.965	1.6	0.71	1.1
Vanadium	130	91	45	130	77	220	0.5	44.7	55	6.69	32.35
Yttrium	—	—	—	—	—	52.2	1.1	6.725	10	0.72	4.45

METAL	REGULATORY LIMITS		ONTARIO STUDIES			ONTARIO MINING SITES					
	CCME (mg/kg)	Ontario (µg/g)	Sudbury Soils Study[8] (µg/g)		Ontario Typical Range[9] (µg/g)	Unpaved Roads (µg/g)			Paved Roads (µg/g)		
	Industrial	Table 1: Full Depth Back	95th perc	Maximum	98th perc	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Zinc	360	160	110	340	140	4400	5	220	1250	39.1	282
Zirconium	—	—	—	—	—	16.5	0.58	4.9	15.6	1.3	4.45

Notes:

— no data

3.0 QUANTIFICATION AND CONTROL OF FUGITIVE DUST

The following sections provide quantification methods and control options for fugitive dust.

3.1 Quantification

Physical sampling of fugitive dust sources can be troublesome. Dust plumes generated are intermittent, can be large and can disperse quickly. They are also largely affected by wind direction making it difficult to ensure that sampling equipment is properly located. It is also difficult to distinguish between source emission and other emissions that could be affecting the sampling location albeit another nearby source or background conditions. For this reason, calculations are often used to quantify the emissions of fugitive dust from particular sources.

The basic equation for calculating fugitive dust emissions is:

$$R = SEe(1-c) \tag{1}$$

Where:

R = estimated mass emission rate in the specified particle range
SE = source extent (e.g. production rate, exposed area, distance travelled)
e = uncontrolled emission factor in the specified particle range (i.e. mass of uncontrolled emission per unit of source extent)
c = fractional efficiency of control

The most common method for estimating fugitive dust emissions are the use of emission factors developed by the US EPA and published in the AP 42 document[10].

3.2 Controls

From the formula above, it can be seen that changing any of the variables will result in an increase or decrease in dust emissions. Each variable can be modified using any of the elements of a BMP; managerial, operational or structural measures. Inherently, reducing the source extent will result in reductions of fugitive emissions.

If structural controls are applied to a source, the uncontrolled emission factor is multiplied by an additional term to reflect the resulting fractional control. Controls can be either continuous or periodic. A list of typical control efficiencies is summarized in Table 4.

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[10] US EPA. AP 42, Fifth Edition "*Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*",< http://www.epa.gov/ttn/chief/ap42/>

Table 4: Common Fugitive Control Efficiencies

Source Category	Control Measure	Published PM10 Control Efficiency
Materials Handling	Implement Wet Suppression	50-90 %
	Erect 3-sided Enclosure	75 %
	Cover Storage Piles with tarp in high winds	90 %
Paved Roads	Sweeping	4-26 %
	Minimize Trackout	40-80 %
	Remove Deposits on Road ASAP	>90 %
Unpaved Roads	Limit Vehicle Speed to 25 mph	44 %
	Apply Water	10-74 %
	Apply Dust Suppressant	84 %
	Pave the Surface	>90 %
Wind Erosion	Plant Trees or Shrubs and Windbreak	25 %
	Create cross-wind ridges	24-93 %
	Erect artificial wind barriers	4-88 %
	Apply Dust Suppressant or Gravel	84 %
	Revegetate	90 %
	Water Exposed Area before high winds	90 %

The major difference between continuous and period controls is the time factor. Continuous controls are constant with respect to time (e.g. water sprays), whereas periodic controls decrease with time (e.g. dust suppressant). To quantify the control efficiencies the following formulas can be used:

Continuous/Instantaneous Controls:

$$c(t) = \left(1 - \frac{e_c(t)}{e_u}\right) \times 100 \qquad (2)$$

Where:

c(t) = instantaneous control efficiency (%)
e_c(t) = instantaneous emission factor for the controlled source
e_u = uncontrolled emission factor
t = time after application control

Periodic Control Efficiency (Average Efficiency):

$$C(T) = \frac{1}{T}\int_0^T c(t)dt \qquad (3)$$

Where:

C(T) = instantaneous control efficiency at time t after application (percent)
T = time period over which the average control efficiency is referenced
c(t) = instantaneous control efficiency (%)

4.0 MINING SPECIFIC FUGITIVE DUST EMISSION QUANTIFICATION AND CONTROL OPTIONS

The most common method for estimating fugitive dust emissions are emission factors developed by the US EPA published in the AP 42 document. Sections of the AP 42 document are updated often therefore it is important to reference the website to be sure of using the most up to date emission factors. The mining related processes that contribute to fugitive dust include the following:

- site preparation (bulldozing, land clearing);
- open pit drilling and blasting;
- material movement (loading/unloading, stockpiling);
- crushing/screening of ore and waste rock;
- paved and unpaved roadways; and
- tailings areas and storage piles (wind erosion).

The following sections explain the quantification methods and possible control options for each of the mining related processes.

4.1 Site Preparation

Land clearing is the process where the overburden (top soil, etc) is removed prior to exploration and excavation. Emissions from these activities are typically estimated using the emission factors provide in Section 11.9 (Western Surface Coal Mining) of the AP 42 document.

Emission Calculation

The TSP emission rate for bulldozing overburden can be calculated using the following equation according to Section 11.9 of the AP 42 document, dated July 1998.

$$ER = \frac{2.6\,(s)^{1.2}}{(M)^{1.3}} \qquad (4)$$

Where:

ER = emission rate (kg/hr)
s = material silt content (%)
M = material moisture content (%)

In the absence of mining specific factors, it is suggested that these emission factors be used; however, more site specific emission factors/estimation techniques should be developed for application to mining in Ontario.

Control Options

The equation above contains the factors that contribute to the fugitive emissions, namely material silt content and material moisture content. The material silt content may be something that cannot be altered however wetting down the area to be dozed will reduce the fugitive emissions of the operation.

There can also be wind blown fugitives if the material being dozed has a high silt content. For this type of material, avoid dozing during high wind conditions. Table 5 summarizes the BMP options for site preparation activities.

Table 5: Fugitive Dust Control Methods and Efficiencies for Site Preparation

BMP	Type of Control	Emission Reduction	Comments
Avoid clearing during wind gusts	Operational	ND	Consider meteorological conditions
Water spray	Operational	ND	Spray areas where clearing is taking place

Note:
ND – no data

4.2 Open Pit Drilling and Blasting

There are fugitive emissions associated with drilling and blasting in an open pit. These are also quantified by using Section 11.9 (Western Surface Coal Mining) of the AP 42 document.

Emission Calculation

The drilling emission rate is based on emission factors (in kg/hole) found in Table 11.9-4 of the AP 42 document depending on the type of material being drilled.

The TSP emission rate for blasting can be calculated using the following equation according to Section 11.9 of the AP 42 document, dated July 1998.

$$ER = 0.00022(A)^{1.5} \tag{5}$$

Where:

ER = emission rate (kg/blast)
A = horizontal area (m^2), with blasting depth < 21 m

Control Options

The contributing factors for fugitive emissions due to drilling and blasting are the number of holes being drilled and the area being blasted. If possible smaller blast areas will produce smaller amounts of emissions. Also wind conditions will be large contributor as the air borne dust plume generated by the drilling and blasting can be carried larger distances in high conditions. Therefore drilling and blasting should be conducted during low wind conditions where possible. Table 6 summarizes the BMP options for open pit drilling and blasting.

Table 6: Fugitive Dust Control Methods and Efficiencies for Open Pit Drilling and Blasting

BMP	Type of Control	Emission Reduction	Comments
Avoid blasts during high wind conditions	Operational	ND	—
Blast design	Operational	ND	Design for smaller blasts with fewer number of holes
Equipment maintenance	Operation	ND	Proper maintenance on drilling equipment will reduce vibration

Note:
ND – no data

4.3 Material Movement

A primary source of fugitive dust in the mining industry is the result of transfer of materials from one process to another. Emissions can occur at various points in the transfer process and include:

- material loading to the pile;
- material load-out from the pile; and
- transfer points between conveyors or equipment.

At mining sites, ore may be the material being move or it may be waste rock. There are different emission factors depending on whether it is a metallic material being moved, i.e. ore, or whether it is non-metal bearing waste rock.

4.3.1 Material Movement of Ore

When ore is the material being moved, the emission factors in Section 11.24 (Metallic Minerals Processing) of the AP 42 document should be used.

Emission Calculation

Table 11.24-1 provides TSP emission factors in kg/Mg for material handling and transfers for low moisture and high moisture ore. High moisture ore is considered to have a moisture content greater than 4%. The TSP emission rate would then be calculated by multiplying the emission factor by the amount of material being moved.

$$ER = EF \ x \ tonnage \quad (6)$$

Where:

ER = emission rate (kg)
EF = emission factor (kg/Mg)
tonnage = amount of material being moved (Mg)

The metals emission rates can then be determined by speciating the TSP emissions based on an assay of the ore.

Control Options

The only factors that affect fugitive emissions from ore handling are the amount of material being handled and the moisture of the ore. If it is possible, wetting ore can reduce the amount of fugitives as long as the added moisture does not negatively affect further processing of the ore.

It's important to note that good housekeeping in and around ore stockpiles can reduce the ore track out onto nearby roadways. Track out from ore stockpiles can increase the metals concentrations on the roadways which can in turn increase the metals emissions associated with those roadways.

4.3.2 Material Movement of Waste Rock

Section 13.2.4 of the AP 42 document contains the emission factor calculation for aggregate handling which is the technique that should be used for waste rock handling.

Emission Calculation

For each drop point in the process, emissions are estimated using the following equation taken from Section 13.2.4, dated November 2006.

$$EF = k(0.0016)\left(\frac{\frac{U}{2.2}^{1.3}}{\frac{M}{2}^{1.4}}\right) \tag{7}$$

Where:

EF = emission factor (kg/Mg)
k = particle size multiplier (TSP = 0.74, PM_{10} = 0.35, $PM_{2.5}$ = 0.053)
U = mean windspeed (m/s)
M = material moisture content (%)

The TSP emissions would then be calculated by multiplying the emission factor by the amount of material being moved as in Equation (6).

Control Options

From these equations it can be seen that the key factors in reducing the amount of fugitive dust from drop operations are the quantity of material moved, the moisture content of the material and the wind speed that impacts on the pile. An increase in moisture content of 1% can result in a 43% reduction in fugitive emissions. Whereas are reduction in wind speed by 0.5 m/s has only a 16% reduction.

Another factor that has been shown to reduce fugitive dust from these activities but is not quantified in this equation is minimizing the material drop heights (which reduces the time the material is exposed to the wind).

It's important to note that good housekeeping in and around stockpiles can reduce the track out onto nearby roadways, especially if the roadways are paved. Track out from stockpiles can increase the silt concentrations on the roadways which can in turn increase the fugitive emissions associated with those roadways.

The most common practices for the reduction of fugitive dust related to materials handling is wetting. This includes liquid sprays or foam to suppress the formation of fugitive dust. However, in many cases emissions can be significantly reduced using good management practices only. This includes practices such as unloading in the leeward area of the pile, prevention of spills, and spill clean up. Control methods are summarized in Table 7.

Table 7: Fugitive Dust Control Methods and Efficiencies for Materials Handling

BMP	Type of Control	Emission Reduction	Comments
Avoid material transfer during high wind conditions	Operational	ND	—
Housekeeping	Operational	ND	To avoid trackout
Equipment maintenance	Operational	ND	Adequately maintain all equipment to reduce vibration
Processing rate	Operational	ND	Limit material processing rate
Pile configuration	Operational	ND	Orient pile so that it is parallel with prevailing winds
Drop height reduction	Operational	ND	Studies have shown this to be effective but not reflected in calculation
Wind barrier	Physical	ND	Unloading on leeward side of pile
3-Sided Enclosure	Physical	75 %	—
Watering (continuous)	Physical	62 %	—
Watering (wind event)	Operational	90 %	—
Tarping	Physical	90 %	—
Enclosure and baghouse	Physical	ND	—

Note:
ND – no data

Some of these controls would also decrease the fugitives associated with wind erosion as well as material handling.

4.4 Crushing/Screening of Ore and Waste Rock

Crushing and screening or ore and waste rock occurs on a mine site to reduce the size of material to be transported off-site for further processing (ore) or to be used onsite for construction or backfilling (waste rock).

Emissions from processing ore and waste rock are quantified by using Section 11.24 (Metallic Mineral Processing) or Section 11.19 (Crushed Stone Processing and Pulverized Mineral Processing) of the AP 42 document.

4.4.1 Crushing of Ore

Emission Calculation

Table 11.24-1 provides TSP emission factors in kg/Mg for crushing for low moisture and high moisture ore. High moisture ore is considered to have a moisture content greater than 4%. The TSP emission rate would then be calculated by multiplying the emission factor by the amount of material being moved as in Equation (6).

The metals emission rates can then be determined by speciating the TSP emissions based on an assay of the ore.

Control Options

The only factors that affect fugitive emissions from ore crushing are the amount of material being handled and the moisture of the ore. If it is possible, wetting ore can reduce the amount of fugitives as long as the added moisture does not negatively affect further processing of the ore.

It's important to note that good housekeeping in and around ore crushing equipment can reduce the ore track out onto nearby roadways. Track out from ore crushing equipment can increase the metals concentrations on the roadways which can in turn increase the metals emissions associated with those roadways.

It is also important to adequately maintain crushing equipment as vibration can cause an increase in fugitive emissions.

4.4.2 Screening of Ore

Emission Calculation

There are no emission factors for ore screening in Table 11.24-1 therefore Section 11.19 must be used to determine the TSP emissions. Table 11.19.2-1 provides emission factors in kg/Mg for controlled and uncontrolled screening. Screening is considered controlled when the operation is equipped with a wet suppression system.

The TSP emission can then be determined by multiplying the emission factor by the amount of material processed as in Equation (6). The metals emissions can then be determined by speciating the TSP emission based on an assay of the ore.

Control Options

The only factors that affect fugitive emissions from ore screening are the amount of material being handled and if a wet suppression system is used.

It's important to note that good housekeeping in and around ore screening equipment can reduce the ore track out onto nearby roadways. Track out from ore screening equipment can increase the metals concentrations on the roadways which can in turn increase the metals emissions associated with those roadways.

It is also important to adequately maintain screening equipment as vibration can cause an increase in fugitive emissions.

4.4.3 Crushing/Screening of Waste Rock

Emission Calculation

The emissions associated with crushing and screening of waste rock can be determined using Section 11.19.2 of the AP 42 document. Table 11.19.2-1 provides emission factors for controlled and uncontrolled crushing and screening. At this time there are not emission factors for primary and secondary crushing however it is common practice that the emission factors for tertiary crushing are conservatively used. Crushing and screening is considered controlled when the equipment is equipped with a wet suppression system.

The emission factors are given in kg/Mg and therefore must be multiplied by the amount of material processed to obtain a TSP emission as in Equation (6).

Control Options

The only factors that affect fugitive emissions from crushing and screening are the amount of material being handled and if a wet suppression system is used.

It's important to note that good housekeeping in and around crushing and screening equipment can reduce the silt track out onto nearby roadways. Track out from crushing and screening equipment can increase the silt concentrations on the roadways which can in turn increase the emissions associated with those roadways.

It is also important to adequately maintain crushing and screening equipment as vibration can cause an increase in fugitive emissions. Table 8 provides a summary of possible crushing and screening BMPs.

Table 8: Fugitive Dust Control Methods and Efficiencies for Crushing and Screening

BMP	Type of Control	Emission Reduction	Comments
Avoid operation during high wind conditions	Operational	ND	—
Housekeeping	Operational	ND	To avoid trackout
Equipment maintenance	Operational	ND	Adequately maintain all equipment to reduce vibration
Processing rate	Operational	ND	Limit material processing rate
Water spray	Physical	ND	—
Drop height reduction	Operational	ND	—
Wind barriers	Physical	ND	—
Enclosure and baghouse	Physical	ND	—

Note:
ND – no data

4.5 Paved Roadways

Emissions from paved roads occur from the resuspension of loose material on the road surface and direct emissions from the vehicle exhaust and brake and tire wear emissions. As vehicles travel over the surface of a road, the amount of material available for suspension becomes depleted, however the surface loading is replenished from other sources such as spills, trackout and local wind erosion.

Emission Calculation

The emissions from paved roads can be estimated using the following US EPA AP42 Section 13.2.1 Paved Roads equation.

$$EF = k\left(\frac{sL}{2}\right)^{0.65} \times \left(\frac{W}{3}\right)^{1.5} - C \qquad (8)$$

Where:

EF = emission factor (g/VKT)
VKT = vehicle kilometre travelled
k = particle size multiplier (g/VKT) (TSP = 24, PM_{10} = 4.6, $PM_{2.5}$ = 0.66)
sL = silt loading (g/m²)
W = mean vehicle weight (tons)
C = emission factor for 1980s vehicle fleet exhaust, brake wear and tire wear based on particle size (TSP = 0.2119, PM_{10} = 0.2119, $PM_{2.5}$ = 0.1617)

Table 13.2.1-4 of the AP 42 document provides silt content and silt loading ranges for various industries. However site specific silt loadings can be obtained through road dust sampling and can reduce emissions. For example, a 1 g/m² silt loading reduction can reduce the TSP emission factor by 38%.

This emission factor would then be multiplied by the number of vehicles travelling the roadway and the length of the roadway to get a TSP emission. Metals are also expected to the present in the road dust on mining sites. Therefore road sampling should be conducted in order to speciate the TSP emissions and to assess the significance of the road segments. Sampling can also be conducted to obtain the site specific silt loading.

Control Options

The equation above is driven by two factors – silt content on the road and the weight of the vehicles travelling on the road, with silt content being the key factor. In order to reduce emissions from paved roads three types of BMPs are suggested:

1) Putting restrictions on the vehicles that travel the road (Vehicle Restrictions);

2) Removing silt from the surface (Surface Treatments); or

3) Preventing silt from being deposited on the road (Surface Improvements).

If prevention methods are put into place, there will be less effort and cost put forward for routine road cleaning[11]. A summary of these control options is provided in the table below.

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[11] National Stone Sand and Gravel Association. Modeling Fugitive Dust Sources. 2004

Table 9: Fugitive Dust Control Methods and Efficiencies for Paved Roads

BMP	Type of Control	Suggested Methods	Emission Reduction	Comments
Vehicle Restrictions	Operational	Limit number of vehicles on the road	Linear	Number of trucks can be limited by correct truck sizing
		Limit the distance traveled	Linear	Take trip distance into consideration during the planning phase
Surface Treatments	Physical	Sweeping	4-26 %	—
		Watering	Varies	—
		Spill Cleaning	Up to 100 %	Assumes clean up before traffic resumes
Surface Improvements	Physical	Trackout Prevention	40-80 %	Device type dependent
		Proper curb and road width design	42 %	Reduces trackout
Vehicle load covers	Physical	—	ND	Reduces dust blown off the load
Wheel wash station	Physical	—	ND	—

Note:
ND – no data

4.6 Unpaved Roadways

Emissions from unpaved roadways are one of the largest emission sources at mining sites. Emissions from unpaved roads occur as the result of the entrainment of dust from the road as a result of vehicle traffic. Particles are lifted from the surface and entrained. The turbulent wake behind the vehicle continues to act on the road after the vehicle has passed. The following equation can be used on unpaved road sections as well as for estimates of vehicles movements in storage pile areas.

Emission Calculation

The emissions from unpaved roads can be estimated using the following US EPA AP 42 Section 13.2.2 Unpaved Roads equation.

$$EF = k\left(\frac{s}{12}\right)^{a}\left(\frac{W}{3}\right)^{b} \qquad (9)$$

Where:

EF = emission factor (lb/VMT)
k = particle size multiplier (lb/VMT) (TSP = 4.9, PM_{10} = 1.5, $PM_{2.5}$ = 0.15)
s = surface silt content (%)
W = mean vehicle weight (tons)
a = empirical constant (TSP = 0.7, PM_{10} and $PM_{2.5}$ = 0.9)
b = empirical constant (TSP, PM_{10} and $PM_{2.5}$ = 0.45)
1 lb/VMT = 281.9 g/VKT

Table 13.2.2-1 provides silt content ranges for various industries. Due to the high variability from site to site it is recommended that site specific values be determined. For example, a 1% change in silt content will result in a 34% reduction in the lbs/VMT.

This emission factor would then be multiplied by the number of vehicles travelling the roadway and the length of the roadway to get a TSP emission. Metals are also expected to the present in the road dust on mining sites. Therefore road sampling should be conducted in order to speciate the TSP emissions and to assess the significance of the road segments. Sampling can also be conducted to obtain the site specific silt content.

Control Options

The equation above is driven by two factors – silt content on the road and the weight of the vehicles travelling on the road. Options for controlling fugitive dust from unpaved roads can be classified into three categories:

1) Vehicle Restrictions.

2) Surface Improvements.

3) Surface Treatments.

A summary of these control options is provided in the table below.

Table 10: Fugitive Dust Control Methods and Efficiencies for Unpaved Roads

BMP	Type of Control	Suggested Methods	Emission Reduction	Comments
Vehicle Restrictions	Operational Practice	Limit number of vehicles on the road	Linear	Number of trucks can be limited by correct truck sizing
		Limit distance travelled	Linear	Take trip distance into consideration during the planning phase
		Limit maximum speed to 25 MPH	44 %	—
Surface Improvements	Physical Control	Pave road	99 %	Emissions from paved roads must then be considered
		Cover road with material that has a lower silt content	—	—
Surface Treatments	Physical Control	Wet suppression (watering)	55 % (based on twice daily)	Control efficiency dependent upon: - Amount of water applied - Time between reapplications - Traffic volume - Meteorological conditions
		Chemical stabilization/ treatment	84 % (annual application)	Control efficiency dependent upon: - Dilution rate of mixture

BMP	Type of Control	Suggested Methods	Emission Reduction	Comments
				- Application rate - Time between applications - Meteorological conditions
Vehicle load covers	Physical	—	ND	Reduces dust blown off the load
Wheel wash stations	Physical	—	ND	—

4.7 Tailings Areas and Storage Piles – Wind Erosion

There are two suggested methods for calculating wind erosion from outdoor storage piles. One of the methods used is from the US EPA document Control of Open Fugitive Dust Sources[12]:

Emission Calculation 1

$$EF = 1.9\left(\frac{s}{1.5}\right)365\left(\frac{365-p}{235}\right)\left(\frac{f}{15}\right)\left(\frac{1}{24}\right) \tag{10}$$

Where:

EF = emission factor (kg/hour/hectare)
s = silt content (%)
p = number of days when rainfall is greater than 0.25 mm
f = percentage of time unobstructed wind speed is greater than 5.4 m/s at the mean height of the stockpile (default value is 32 %)

The second method, outlined in Section 13.2.5 (Industrial Wind Erosion) of US EPA AP-42, is based on actual meteorological data. This climate data can be obtained on the Environment Canada website.

For material to be eroded from a storage pile by wind, the threshold friction velocity of the material must be exceeded. The threshold friction velocity can be calculated through a sieving test of the surface material, or the default values in AP 42 can be applied. For particles to become entrained in the air, the particle size typically has to be less than 75 µm (silt).

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[12] Cowherd, Jr. C. et al. 1988. *Control of Open Fugitive Dust Sources*, EPA 450/3-88-008. U.S. Environmental Protection Agency, Research Triangle Partk, NC. Spetember 1988.

Emission Calculation 2

$$EF = k \sum_{i=1}^{N} Pi \qquad (11)$$

Where:

EF = emission factor (g/m²)
k = particle size multiplier (TSP = 1.0, PM_{10} = 0.5, $PM_{2.5}$ = 0.075)
N = number of disturbance
Pi = erosion potential corresponding to observed or probable fastest mile of wind for the ith period between disturbances (g/m²)

The erosion potential is calculated as follows.

$$P = 58(u^* - u_t^*)^2 + 25(u^* - u_t^*) \qquad (12)$$

Where:

P = erosion potential (g/m²)
u^* = friction velocity (m/s), namely the wind speed
u_t^* = threshold friction velocity (m/s) from Table 13.2.5-2

Based on these equations, for wind erosion to occur from a pile, the wind speed at a particular time must exceed the threshold friction velocity.

Also, wind erosion typically only applies to piles that contain particles less than 75 µm in diameter. For example, for a waste rock pile with no particles less than 450 µm wind speeds would have to reach approximately 38 m/s for emissions to occur. For disturbed piles or overburden, this wind speed is reduced to approximately 21 m/s.

The emission factor would then be multiplied by the exposed surface area of the pile to get the TSP emissions due to wind erosion. Tailings also contain metals and therefore the TSP emissions must be speciated in order to determine the metals emission from wind erosion and assess the significance of the tailings area.

Control Options

As with the majority of equations, the ability to control the silt content and the wind availability is key in reducing emissions due to wind erosion. Reducing the exposed or active surface area will result in the most significant reductions from the storage pile. Suggested control options are summarized below.

Table 11: Fugitive Dust Control Methods and Efficiencies for Tailings Areas and Storage Piles – Wind Erosion

BMP	Type of Control	Emission Reduction	Comments
Reduce exposed/active surface area	Operational	Linear with every active m^2	—
Watering	Physical	90 %	—
Chemical suppression	Operational	ND	If possible
Wind barrier	Physical	75 %	3 –sided barrier
Tarping	Physical	ND	—
Re-vegetate	Physical	Up to 100 %	—

Note:
ND – no data

4.8 Site-Wide Control Methods

Fugitive dust emissions can be reduced through BMPs that include physical controls, procedural controls and behavioural controls. Addressing all three of these aspects during the risk assessment phase is essential to identify the root cause of the emission. Many of the best practices cannot be quantified in one specific reduction technique, but will result in overall emissions reductions from the site.

For example, the implementation of a cleanup program to address road spills and track out cannot be quantified in one equation. Policies such as tarps on trucks that prevent spillage from occurring will reduce the amount of silt that is present on the road, thus reduce road emissions. Other examples include:

- wheel washing/wheel grates;
- timing processing with meteorological events such as wind and rain (e.g. not processing in high wind situations);
- storm water management to prevent flooding of unpaved roads and increased trackout;
- sizing trucks appropriately to reduce number of vehicle trips required; and
- designing hauls routes to minimize kilometres travelled.

5.0 COMMON ELEMENTS OF A BEST MANAGEMENT PLAN

During the review of BMP Plans for various industries, the following key steps were identified:

- Development of Mission Statement;
- Identification of Sources;
- Risk Assessment;
- Evaluating Controls and Setting Targets;
- Monitoring;

- Training; and
- Reporting.

The following sections provide further explanation and some practical examples for each of the key steps. Figure 2 demonstrates the typical flow of a dust management strategy.

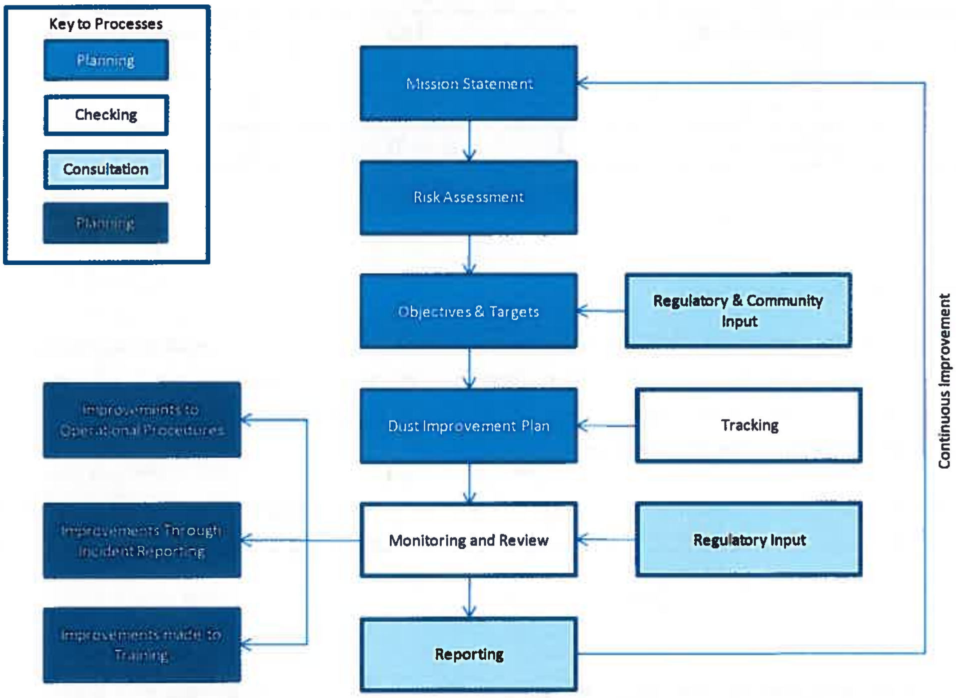

Figure 2: Dust Management Strategy Process Diagram [13]

Mission Statement

Prior to developing the details of the plan, on overall mission statement must be developed. This will help set the boundaries for the individual elements in the plan. For example, if the plan is being developed for typical operation dust management, the specific sources and level of risk analysis would be different than if the plan is being developed in response to a known environmental impact. Key questions that should be considered when developing the mission statement are:

1) What is to be accomplished?

2) Who needs to be involved?

3) What is the context?

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[13] Hamersley Iron Dust Management Plant 2005/2006 Dampier Port Operations Version D, September 2005

Identification of Sources

For consistency between regulatory reporting and internal corporate requirements, each source should be labelled with a unique identifier that is consistent through all programs at the facility (maintenance, Emissions Summary and Dispersion Modelling, noise assessment, BMP, etc.).

Risk Assessment

To prioritize sources in a BMP, a risk management tool should be applied. This takes into consideration various aspects of the emission sources such as quantity, frequency and impact of the emissions (air quality, health, etc.) to develop a severity and likelihood for each source of emission.

In relation to fugitive dust, the key elements to consider concerns are:

- quantity and particle size of dust emitted;
- frequency of disturbance;
- pathway;
- toxicology of dust; and
- impacted receptor (e.g. onsite, offsite, human, ecological).

From the risk score developed, sources can be ranked as high, medium and low priority for action. One additional consideration is the cost to implement a control.

Evaluating Controls, Setting Targets and Monitoring

The key to a successful BMP is continuous improvement. This is best achieved through monitoring and documenting of identified areas of concern. As a minimum for each identified source of fugitive dust, the monitoring requirements should include a frequency, location and specific events (Table 12). The frequency of monitoring will be dependent upon the source, for example tree berms will not have the same inspection frequency as haul roads. The level of information and way in which information is gathered should be developed on a site specific basis. The examples provided in this section have all been adapted from the British Columbia Ministry of Energy and Mines Aggregate Producers BMP Manual[1].

Table 12: Sample Inspections Elements for Fugitive Dust BMPs

Inspection Category	Example
Frequency	• Daily • Weekly • Monthly • Bi-Annual
Location/Area	• Stockpiles • Extraction area • Processing • Waste storage/tailings
Event	• When production threshold reached

Inspection Category	Example
	• After a large storm • Dry conditions • Air quality event

When designing the monitoring/inspection program, the method of monitoring will be dependent upon the company culture (e.g. is there an existing ISO14001 system), the person filling out the forms, and the type of information required. Record keeping can include any method ranging from free form notebooks to detailed computer forms. Examples are illustrated in Table 13.

Table 13: Sample Options for Data Collection Methods

Query Style	Example: Are dust plumes visible?
Free Form	*Blank Note Book to write comments*
Fill in the Blanks	Dust Plumes (comment):
Yes/No Questions	Dust Plumes: ☐ yes ☐ no
Check Boxes	Dust Plumes: ☐ Large Plume (greater than truck) ☐ Moderate Plume (same size as truck) ☐ Small Plume (smaller than half the size of the truck ☐ No Plume (smaller than half the height of the tires)
Data	HiVol Sample Results Dust Fall Jar Sample Results

Table 14: Sample BMP Effectiveness Tracking

BMP	ID	Location	Control Objectives	Maintenance Required	Failure Indicators	Met Control Target	Notes
Material Drops	DH01	Stockpile Conveyor	Reduce Dust	Check for rips	Dust complaints Dusty trees	Air quality	
Haul Road	HR01	North Plant	Reduce Dust	Watering	Dust complaints Dusty trees Frequent visible plumes	Air quality	
Settling Pond	SP01	East Plant	Storm water control	Clean out Depth of sediment	Piping Use of overflow	Stormwater Turbidity	

Training and Reporting

For the BMP to work, all employees must be trained on the objectives of the plan, and where required job specific duties. As required, reports regarding the effectiveness of the BMP should be developed and reviewed.

5.1 Mining Specific BMPs

The following Table presents a summary of the various BMPs suggested in literature and discussed in this document for mining activities.

Table 15: Suggested Best Management Practices for Mining Activities

Fugitive Dust Source	Areas where practices can result in fugitive dust reductions (in approximate order of increasing relative operational and financial significance)																				
	Meter. Cond.	Blast Design	House-keeping	Equip. Maint.	Processing Rate	Storage Pile Config.	Vehicle Restrictions	Water Spray	Conveyor Covers	Chemical Suppression	Sweeping	Vacuuming	Vehicle Covers	Drop Height Reduction	Wind Barriers	Tarping	Surface Improvements	Wheel Wash Stations	Paving	Enclosure	Baghouse
Site preparation	x							x													
Open pit drilling and blasting	x	x		x																	
Material movement/ handling	x		x	x	x	x		x	x					x	x	x				x	x
Crushing and screening	x		x	x	x			x						x	x					x	x
Paved roadways	x						x	x		x	x	x	x				x	x			
Unpaved roadways	x						x	x		x			x				x	x	x		
Tailings/ storage piles - wind erosion	x				x	x		x		x					x	x	x				

5.2 Cost Considerations

In selecting the most appropriate BMP to implement at a site, the availability and applicability of the control must be taken into account, as well as the cost associated with implementing the BMP. Appendix A contains some typical costs associated with dust control measures.

A simple formula for evaluating cost effectiveness, as describe in the WRAP Manual, is provided in Appendix B. This procedure calculates cost effectiveness by dividing the annualized cost by the total emissions reduction to derive a cost per tonne of dust reduced. Using this type of tool, the most cost-effective reduction methods can be calculated.

Assign a dollar value to cost-effectiveness is difficult due to the variation in types of controls that can be applied. Additional considerations are taken by a regulatory, such as back ground ambient concentrations, are also considered when setting the dollar value. This is demonstrated in the Table included in Appendix B. The appropriate value for cost-effectiveness needs to be developed specifically for Ontario.

Table 16: Cost Effectiveness Comparison for PM10 in California[14]

	Cost Effectiveness ($/ton) for Various Air Quality Management Districts in California						
	SCAQMD	BAAQMD	SMAQMD	YSAQMD	SDAQMD	EPA	CARB
PM10	$4,500	$5,300	$11,400	$5,700	N/A	N/A	N/A

6.0 AREAS FOR FURTHER RESEARCH

There is an abundance of information related to calculation methodologies, control options and the science behind fugitive dust. Recommended practices for emission calculation and control options have been well researched. When developing a BMP for the mining industry, there are some data gaps that do exist. Areas that should be further evaluated for application in Ontario include:

- Metals concentrations in road dust/wind emissions:
    - What are the typical levels at mine sites?
    - What levels should be considered Triggers of Concern?
- Cost effectiveness – what is a reasonable dollar amount when implementing dust control?
- Costs of controls:
    - The tables provided in Appendices B and C were developed for the US in the early 2000s. Tables for Canadian costs should be developed.
- Improved emission factors for land clearing, drilling and blasting to reflect mining operations in Ontario.

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[14] San Joaquin Valley Air Pollution Control District (May 14,2 008). "Update to BACT Cost Effectiveness Thresholds – Final Staff Report".

- Control efficiencies based on frequency of application (i.e. for spray trucks, vacuum trucks and chemical suppressants).
- Risk based tool for source control decision making.

7.0 CLOSURE

Fugitive dust is of concern based on potential health impacts associated with fine particulate matter. In the mining industry, this is coupled with the potential for elevated levels of metals to be present in the particulate matter. A BMPP is an excellent tool for a mine site to use to evaluate and prioritize sources for control, and better manage the fugitive dust from the site. For a successful BMP, considerations of source types, pathways, receptors, costs and control technology availability must be included.

Report Signature Page

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APPENDIX A

Typical Costs Associated with Dust Control Measures

(Costs are presented in US$ and are taken from best available data in 2003)

APPENDIX A

Typical Costs Associated with Dust Control Measures

Source Category	Control Measure	Estimated Cost	Comments/Assumptions
Paved Roads	4' paved shoulders	$8200/mile	Useful life 20 years
	Polymer emulsion to stabilize shoulders	$0.92/square yard	
	Purchase PM10 efficient sweeper	$190/mile-year	Useful life of 8 years; sweep 15 centerline miles per day
	Clean up spills		$640/cleanup
Unpaved Roads and Parking Areas	Pave	$44,100/mile-year	Useful life of 25 years
	Pave section 100' long before facility exit	$716/year	30' wide with 3" of asphalt; useful life of 25 years
	Pave unpaved parking lots	$0.23/ft2-year	Useful life of 25 years
	Pipe grid trackout control device	$1,820/year	Useful life of 8 years
	Gravel bed to reduce trackout	$1,360/year	50' x 30' x 3" thick
	Post speed limit sign	$53/year	2 signs, Useful life of 15 years
	Apply water to unpaved parking lot once a day	$68-$81/acre-day	
	Chemical dust suppressant	$5,340/acre-year	Useful life of 1 year
Construction and Demolition	Chemical dust suppressant	$5,340/acre-year	Useful life of 1 year

Source Category	Control Measure	Estimated Cost	Comments/Assumptions
	Apply water once a day	$68-$81/acre-day	
	Apply water during high winds	$272/acre	
	Prohibit activities during high winds	$1.360 per 8 hour day idled	Demolition of 1,000 ft2 structure on 1.2 acres
	Require air quality monitoring	$7,500/month	
	Onsite dust control coordinator	$100/day	
	Sprinkler system to maintain minimum soil moisture of 12%		
	Limit speed to 15 mph	$22/inspection	Radar gun = $700
	Post speed limit signs	$180/sign	
Bulk Materials	3-sided enclosure with 50% porosity	$109/year	Useful life of 15 years; pile volume = 5 yd3
Disturbed Open Area	Polymer emulsion dust suppressant	$2,140/acre	Surface stabilized for 3 years if no vehicle disturbance
	Gravel 1 " Deep	$490/acre-year	Useful life of 15 years

Source Category	Control Measure	Estimated Cost	Comments/Assumptions
	Post no trespassing signs	$53/sign	Useful life of 15 years
	Prohibit activities at construction sites during high winds	$3,100 per high wind day	Windblown Dust 40 acre construction site
	Water storage pile each hour during high winds	$22/day	100 cubic yard pile

Reference: Sierra Research, Inc., *Final BACM Technological and Economic Feasibility Analysis*, prepared for the San Joaquin Valley APCD, March 21, 2003.

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APPENDIX B

Cost Effectiveness Calculation

(based on methods outlined in the *WRAP Fugitive Dust Handbook)*
URL:http://wrapair.org/forums/dejf/fdh/content/FDHandbook_Rev_06.pdf

APPENDIX B
Cost Effectiveness Calculation

INTRODUCTION

In compiling information on control cost-effectiveness estimates for the fugitive dust handbook, we discovered that many of the estimates provided in contractor reports prepared for air quality agencies for PM10 SIPs contain either hard to substantiate assumptions or unrealistic assumptions. Depending on which assumptions are used, the control cost-effectiveness estimates can range over one to two orders of magnitude. Rather than presenting existing cost-effectiveness estimates, we have prepared a detailed methodology containing the steps to calculate cost-effectiveness that is presented below. We recommend that the handbook user calculate the cost-effectiveness values for different fugitive dust control options based on current cost data and assumptions that are applicable to their particular situation. Based on field measurements of uncontrolled and controlled unpaved road emissions conducted by Midwest Research Institute, there were no significant differences in the measured control efficiencies for the PM2.5 and PM10 size fractions. Thus, the cost effectiveness for PM2.5 reduction can be calculated by dividing the cost-effectiveness estimate for PM10 reduction by the PM2.5/PM10 ratio for that fugitive dust source.

TECHNICAL APPROACH

The steps necessary to calculate the cost-effectiveness for different fugitive dust control measures are listed below. This methodology was employed to calculate the cost effectiveness for each control application case study for the different fugitive dust source categories addressed in the handbook.

Step 1: Select a specific control measure for the fugitive dust source category of interest.

Step 2: Specify the basic parameters required to calculate uncontrolled and controlled emissions for the specific source:

(a) applicable emission factor equation

(b) parameters used in the emission factor equation

(c) source extent (activity level)

(d) characteristics of the source

(e) control measure implementation schedule (frequency, application rate)

Step 3: Calculate the annual uncontrolled emission rate as the product of the emission factor and the source extent (from Step 2).

Step 4: Determine the control efficiency for the selected control measure. This may involve either (a) using a published value, (b) calculating the control efficiency based on comparing the controlled emissions estimate derived from the applicable emission factor equation with the uncontrolled emissions estimate derived from the same emission factor equation, or (c) specifying the desired control efficiency which then will entail determining the appropriate level of control to achieve the desired control efficiency.

Step 5: Calculate the annual controlled emissions rate (i.e., the emissions remaining after control) as the product of the annual uncontrolled emission rate (from Step 3) multiplied by the percentage that uncontrolled emissions are reduced, as follows: Controlled emissions = Uncontrolled emissions x (1 – Control Efficiency). Step 6: Calculate the reduction in emissions as the difference between the annual uncontrolled emission rate (from Step 3) and the annual controlled emission rate (from Step 5). Step 7: Gather cost estimates for implementing the selected control measure for the following items:

(a) annualized capital costs (total capital costs/lifetime of the control)

(b) annual operating and maintenance costs that include overhead,enforcement, and compliance costs

Step 8: Calculate the annualized capital investment cost as the product of the annual capital cost and the capital recovery factor. The capital recovery factor is calculated as follows:

$CRF = [\, i\,(1 + i\,)n\,] / [(1 + i)n - 1]$

where, CRF = capital recovery factor

i = annual interest rate (fraction)

n = number of payment years

Step 9: Calculate the total annualized cost by combining the annualized capital investment cost (from Step 8) with annual operating and maintenance costs (from Step 7).

Step 10: Calculate the cost-effectiveness of the selected control measure by dividing the total annualized costs (from Step 9) by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions (from Step 5) from the uncontrolled emissions (from Step 3)

Sample Calculation: Unpaved Roads at an Industrial Facility

Step 1. Determine source activity and control application parameters.

Road length (mile) 2
Vehicles/day 100
Wet days/year 20
Number of 8-hour workdays/year 260
Number of emission days/yr (workdays without rain) 240
Control Measure Watering
Control Application/Frequency Twice daily (no nighttime traffic)
Economic Life of Control System (year) 10
Control Efficiency 55%

The number of vehicles per day, wet days per year, workdays per year, and the economic life of the control measure are assumed values for illustrative purposes. Watering has been chosen as the applied control measure. The control application/frequency and control efficiency are default values provided by MRI, 2001.35

Step 2. Calculate PM10 Emission Factor.
The PM10 emission factor is calculated from the AP-42 equation utilizing the appropriate correction parameters.

$E\ (\mathrm{lb/VMT}) = 1.5\ (s/12)^{0.9}\ (W/3)^{0.45}$

s—silt content (%) 15
W—vehicle weight (tons) 15
E = 3.8 lb/VMT

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor (calculated in Step 2) is multiplied by the number of vehicles per day, by the road length and by the number of emission days per year (see activity data) and divided by 2,000 lb/ton to compute the annual PM10 emissions, as follows:
Annual PM10 emissions = (EF x Vehicles/day x Miles x Emission days/yr) / 2,000
Annual PM10 emissions = (3.8 x 100 x 2 x 240) / 2,000 = 91 tons
Annual PM2.5 emissions = 0.1 x PM10 Emissions23
Annual PM2.5 emissions = 0.1 x 91 tons = 9.1 tons

Step 4. Calculate Controlled PM Emissions. The controlled PM emissions (i.e., the PM emissions remaining after control) are equal to the uncontrolled emissions (calculated above in Step 3) multiplied by the percentage that uncontrolled emissions are reduced, as follows:
Controlled emissions = Uncontrolled emissions x (1 – Control Efficiency).

For this example, we have selected watering as our control measure. Based on a control efficiency estimate of 55% for the application of water to unpaved roads, the annual controlled emissions estimate are calculated to be:
Annual Controlled PM10 emissions = (91 tons) x (1 – 0.55) = 41 tons
Annual Controlled PM2.5 emissions = (9.1 tons) x (1 – 0.55) = 4.1 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($) 30,000
Annual Operating/Maintenance costs ($) 8,000
Annual Interest Rate 3%
Capital Recovery Factor 0.1172
Annualized Cost ($/yr) 11,517

The capital costs, annual operating and maintenance costs, and annual interest rate (AIR) are assumed values for illustrative purposes. The Capital Recovery Factor (CRF) is calculated from the Annual Interest Rate (AIR) and the Economic Life of the control system, as follows:

Capital Recovery Factor = AIR x (1 + AIR) Economic life / (1 + AIR)Economic life – 1
Capital Recovery Factor = 3% x (1 + 3%)10 / (1 + 3%)10 – 1 = 0.1172
The Annualized Cost is calculated by adding the product of the Capital Recovery Factor and the Capital costs to the annual Operating/Maintenance costs:
Annualized Cost = (CRF x Capital costs) + Annual Operating/Maintenance costs
Annualized Cost = (0.1172 x 30,000) + 8,000 = $11,517

Step 6. Calculate Cost Effectiveness. Cost effectiveness is calculated by dividing the annualized cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:
Cost effectiveness = Annualized Cost/ (Uncontrolled emissions – Controlled emissions)

Cost effectiveness for PM10 emissions = \$11,517 / (91 - 41) = \$231/ton
Cost effectiveness for PM2.5 emissions = \$11,517 / (9.1 – 4.1) = \$2,306/ton

The California Air Resources Board has a general table of ranges of proposed cost effectiveness values for the district[1]. This however is from a dated source. The key point to note is there is not just one value. The types of controls that can be applied to fugitive dust result vary greatly.

Table 1: Cost-Effectiveness of Proposed Air District Measures (areas applicable to mining only)

Category	Measure	Cost-Effectiveness ($ in thousands /ton of pollutant reduced)						Comments
		<0	0 – 5	5 – 10	10-15	15 – 20	>20	
Fugitive Dust	▪ Apply water during construction, operations (earthmoving, demolition, grading) ▪ Apply water during bulk material handling ▪ Clean up carryout and trackout ▪ Street sweeping		X					
Fugitive Dust	▪ Apply chemical stabilizers or pave shoulders on paved roads ▪ Apply water or chemical stabilizers on unpaved roads, ▪ Pave unpaved roads		X	X				
Fugitive Dust	▪ Apply water at disturbed open areas ▪ Storage, handling of coke, coal, and sulfur			X				
Fugitive Dust	▪ Apply water, chemical stabilizer, gravel, or pave unpaved parking lots ▪ Apply water, chemical stabilizer, gravel, or pave unpaved roads adjacent to agricultural fields		X	X	X			
Fugitive Dust	▪ Set controls at roads to avoid carryout and track-out			X	X	X	X	Depends on extent of road control (devices installed at access points, length of interior road being paved) and traffic amount on road
Fugitive Dust	▪ Apply water to stored bulk materials						X	

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[1] California Environmental Protection Agency Air Resources Board Staff Report (October 2004) " Proposed List of Measure to Reduce Particulate Matter – PM10 and PM2.5) Implementation of Senate bill 6565, Sher 2003).

APPENDIX C

Regulatory Review (Select Jurisdictions)

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Regulatory Review (Select Jurisdictions)

The majority of regulatory agencies do not have direct details of dust management requirements written into binding legislation. Management of fugitive dust is typically managed through the implementation of a best management plan that is submitted for approval to a province or state. This is typically administered through the permitting process (Australia, Ontario, various US States). The individual activities that are implemented by a facility are up to the facility itself. There is specific emission legislation regarding pollution levels, primarily based on opacity, but the actual control technologies are not dictated.

For example, the state of Idaho requires the following in a BMP:

Table 1: State of Idaho BMP Elements

Area	BMP
Paved Roads	• Promptly remove mud, dirt or debris • Water flush and/or water flush and vacuum sweep • Control runoff so it does not saturate the surface of adjacent roads and enhance track-out • Gravel adjacent unpaved roads • Apply environmentally safe chemical soil stabilizer or chemical dust suppressant to the surface
Unpaved Roads	• Limit vehicle traffic on unpaved road • Limit vehicle speed • Apply water, apply gravel to reduce trackout • Apply environmentally safe chemical soil stabilizer or chemical dust suppressant to the surface of the road
Conveyors, Screening, Crushing	• Limit drop heights of materials to assure homogeneous flow of material • Install, operate and maintain water spray • Apply controls on a frequency that prevent dust emissions from exceeding opacity limit
Stockpiles	• Limit height of the stock piles • Limit the disturbance of the stock piles • Apply water to the surface of the stockpile
General Requirements	• Identify all potential fugitive dust emission sources • Assign dust control methods • Determine Frequency of application • Record all dust control activities • Monitor Dust control efforts • Self Inspection Checklist includes date, time of control, comments, weather log

South Coast Air Quality Management District

http://www.aqmd.gov/rules/reg/reg04/r403.pdf

AQMD Rule 403

The South Coast Air Quality Management District (AQMD) is the regulatory agency for Orange County, Los Angeles, Riverside and San Bernardino Counties. This region is one of the smoggiest regions in the United States (U.S.), and has one of the most prescriptive regulations with respect to fugitive dust management - AQMD Rule 403. This Rule was amended June 3, 2005 and applies to all activities capable of generating fugitive dust, including earth-moving activities, construction/demolition activities, disturbed surface area, or heavy and light duty vehicle movements. The purpose of the rule is to *"reduce the amount of particulate matter entrained in the ambient air as a result of anthropogenic (man-made) fugitive dust sources by requiring actions to prevent, reduce or mitigate fugitive dust emissions".* There are further prescriptive requirements in Rule 403.1 for the Coachella Valley. Under Rule 403, fugitive dust emissions cannot remain visible in the atmosphere beyond the property line of the emissions source, or exceed 20 percent opacity if the emission is the result of vehicular movement.

Under the Rule, operations must apply best available control measures outlined in Tables of the Rule, and PM10 emissions cannot exceed 50 micrograms per cubic metres using simultaneous upwind/downwind sampling by High Volume Samplers or other UE EPA Approved method. There are additional requirements for the management of track out (cleanup, paving, wheel shakers/washing). For large operators (>50 acres of disturbed surface area, or > 3850 m^3 earth moving more than 3 time/year), there are additional requirements for:

- an assigned dust management superintendent who has completed AQMD Fugitive Dust Training and has a valid certificate of completion;
- daily reporting;
- submission of a dust management plant to AQMD; and
- daily reporting requirements

TABLE 1: BEST AVAILABLE CONTROL MEASURES - (Applicable to All Construction Activity Sources)

Source Category	Control Measure	Guidance
Backfilling	01-1 Stabilize backfill material when not actively handling; and 01-2 Stabilize backfill material during handling; and 01-3 Stabilize soil at completion of activity	✓ Mix backfill soil with water prior to moving ✓ Dedicate water truck or high capacity hose to backfilling equipment ✓ Empty loader bucket slowly so that no dust ✓ plumes are generated ✓ Minimize drop height from loader bucket
Clearing and Grubbing	02-1 Maintain stability of soil through pre-watering of site prior to clearing and grubbing; and 02-2 Stabilize soil during clearing and grubbing activities; and 02-3 Stabilize soil immediately after clearing and grubbing activities	✓ Maintain live perennial vegetation where possible ✓ Apply water in sufficient quantity to prevent generation of dust plumes
Clearing Forms	03-1 Use water spray to clear forms; or 03-2 Use sweeping and water spray to clear forms; or 03-3 Use vacuum system to clear forms	✓ Use of high pressure air to clear forms may cause exceedance of Rule requirements
Crushing	04-1 Stabilize surface soils prior to operation of support equipment; and	✓ Follow permit conditions for crushing equipment

Source Category	Control Measure	Guidance
	04-2 Stabilize material after crushing	✓ Pre-water material prior to loading into crusher ✓ Monitor crusher emissions opacity ✓ Apply water to crushed material to prevent dust plumes
Cut and fill	05-1 Pre-water soils prior to cut and fill activities; and 05-2 Stabilize soil during and after cut and fill activities	✓ For large sites, pre-water with sprinklers or water trucks and allow time for penetration ✓ Use water trucks/pulls to water soils to depth of cut prior to subsequent cuts
Demolition mechanical/manual	06-1 Stabilize wind erodible surfaces to reduce dust; and 06-2 Stabilize surface soil where support equipment and vehicles will operate; and 06-3 Stabilize loose soil and demolition debris; and 06-4 Comply with AQMD Rule 1403	✓ Apply water in sufficient quantities to prevent the generation of visible dust plumes
Disturbed Soil	07-1 Stabilize disturbed soil throughout the construction site; and 07-2 Stabilize disturbed soil between structures	✓ Limit vehicular traffic and disturbances on soils where possible ✓ If interior block walls are planned, install as ✓ early as possible ✓ Apply water or a stabilizing agent in sufficient quantities to prevent the generation of visible dust plumes
Earth Moving Activities	08-1 Pre-apply water to depth of proposed cuts; and 08-2 Re-apply water as necessary to maintain soils in a damp condition and to ensure that visible emissions do not exceed 100 feet in any direction; and 08-3 Stabilize soils once earth-moving activities are complete.	✓ Grade each project phase separately, timed to coincide with construction phase ✓ Upwind fencing can prevent material movement on site ✓ Apply water or a stabilizing agent in sufficient quantities to prevent the generation of visible dust plumes
Importing/exporting of bulk materials	09-1 Stabilize material while loading to reduce fugitive dust emissions; and 09-2 Maintain at least six inches of freeboard on haul vehicles; and 09-3 Stabilize material while transporting to reduce fugitive dust emissions; and 09-4 Stabilize material while unloading to reduce fugitive dust emissions; and 09-5 Comply with Vehicle Code Section 23114	✓ Use tarps or other suitable enclosures on haul trucks ✓ Check belly-dump truck seals regularly and remove any trapped rocks to prevent spillage ✓ Comply with track-out prevention/mitigation requirements ✓ Provide water while loading and unloading to reduce visible dust plumes
Landscaping	10-1 Stabilize soils, materials, slopes	✓ Apply water to materials to stabilize ✓ Maintain materials in a crusted condition ✓ Maintain effective cover over materials ✓ Stabilize sloping surfaces using soil binders until vegetation or ground cover can effectively stabilize the slopes ✓ Hydroseed prior to rain season
Road shoulder maintenance	11-1 Apply water to unpaved shoulders prior to clearing; and 11-2 Apply chemical dust suppressants and/or washed gravel to maintain a stabilized surface after completing road shoulder maintenance	✓ Installation of curbing and/or paving of road shoulders can reduce recurring maintenance costs ✓ Use of chemical dust suppressants can inhibit vegetation growth and reduce future road shoulder maintenance costs
Screening	12-1 Pre-water material prior to screening; and 12-2 Limit fugitive dust emissions to opacity and plume length standards; and 12-3 Stabilize material immediately after screening	✓ Dedicate water truck or high capacity hose to screening operation ✓ Drop material through the screen slowly and minimize drop height ✓ Install wind barrier with a porosity of no more than 50% upwind of screen to the height of

Source Category	Control Measure	Guidance
		the drop point
Staging areas	13-1 Stabilize staging areas during use; and 13-2 Stabilize staging area soils at project completion	✓ Limit size of staging area ✓ Limit vehicle speeds to 15 miles per hour ✓ Limit number and size of staging area entrances/exists
Stockpiles/ Bulk Material Handling	14-1 Stabilize stockpiled materials. 14-2 Stockpiles within 100 yards of off-site occupied buildings must not be greater than eight feet in height; or must have a road bladed to the top to allow water truck access or must have an operational water irrigation system that is capable of complete stockpile coverage	✓ Add or remove material from the downwind portion of the storage pile ✓ Maintain storage piles to avoid steep sides or faces
Traffic areas for construction activities	15-1 Stabilize all off-road traffic and parking areas; and 15-2 Stabilize all haul routes; and 15-3 Direct construction traffic over established haul routes	✓ Apply gravel/paving to all haul routes as soon as possible to all future roadway areas ✓ Barriers can be used to ensure vehicles are only used on established parking areas/haul routes
Trenching	16-1 Stabilize surface soils where trencher or excavator and support equipment will operate; and 16-2 Stabilize soils at the completion of trenching activities	✓ Pre-watering of soils prior to trenching is an effective preventive measure. For deep trenching activities, pre-trench to 18 inches soak soils via the pre-trench and resuming trenching ✓ Washing mud and soils from equipment at the conclusion of trenching activities can prevent crusting and drying of soil on equipment
Truck loading	17-1 Pre-water material prior to loading; and 17-2 Ensure that freeboard exceeds six inches (CVC 23114)	✓ Empty loader bucket such that no visible dust plumes are created ✓ Ensure that the loader bucket is close to the truck to minimize drop height while loading
Turf Overseeding	18-1 Apply sufficient water immediately prior to conducting turf vacuuming activities to meet opacity and plume length standards; and 18-2 Cover haul vehicles prior to exiting the site	✓ Haul waste material immediately off-site
Unpaved roads/parking lots	19-1 Stabilize soils to meet the applicable performance standards; and 19-2 Limit vehicular travel to established unpaved roads (haul routes) and unpaved parking lots.	✓ Restricting vehicular access to established unpaved travel paths and parking lots can reduce stabilization requirements ✓ Vacant land 20-1 In instances where vacant lots are 0.10 acre or larger and have a cumulative area of 500 square feet or more that are driven over and/or used by motor vehicles and/or off-road vehicles, prevent motor vehicle and/or off-road vehicle trespassing, parking and/or access by installing barriers, curbs, fences, gates, posts, signs, shrubs, trees or other effective control measures

Table 2: DUST CONTROL MEASURES FOR LARGE OPERATIONS

FUGITIVE DUST SOURCE CATEGORY	CONTROL ACTIONS
Earth-moving (except construction cutting and filling areas, and mining operations)	(1a) Maintain soil moisture content at a minimum of 12 percent, as determined by ASTM method D-2216, or other equivalent method approved by the Executive Officer, the California Air Resources Board, and the U.S. EPA. Two soil moisture evaluations must be conducted during the first three hours of active operations during a calendar day, and two such evaluations each subsequent four-hour period of active operations; OR (1a-1) For any earth-moving which is more than 100 feet from all property lines, conduct watering as necessary to prevent visible dust emissions from exceeding 100 feet in length in any direction.
Earth-moving: Construction fill areas:	(1b) Maintain soil moisture content at a minimum of 12 percent, as determined by ASTM method D-2216, or other equivalent method approved by the Executive Officer, the California Air Resources Board, and the U.S. EPA. For areas which have an optimum moisture content for compaction of less than 12 percent, as determined by ASTM Method 1557 or other equivalent method approved by the Executive Officer and the California Air Resources Board and the U.S. EPA, complete the compaction process as expeditiously as possible after achieving at least 70 percent of the optimum soil moisture content. Two soil moisture evaluations must be conducted during the first three hours of active operations during a calendar day, and two such evaluations during each subsequent four hour period of active operations.
Earth-moving: Construction cut areas and mining operations:	(1c) Conduct watering as necessary to prevent visible emissions from extending more than 100 feet beyond the active cut or mining area unless the area is inaccessible to watering vehicles due to slope conditions or other safety factors.
Disturbed surface areas (except completed grading areas)	(2a/b) Apply dust suppression in sufficient quantity and frequency to maintain a stabilized surface. Any areas which cannot be stabilized, as evidenced by wind driven fugitive dust must have an application of water at least twice per day to at least 80 percent of the unstabilized area.
Disturbed surface areas: Completed grading areas	(2c) Apply chemical stabilizers within five working days of grading completion; OR (2d) Take actions (3a) or (3c) specified for inactive disturbed surface areas.
Inactive disturbed surface areas	(3a) Apply water to at least 80 percent of all inactive disturbed surface areas on a daily basis when there is evidence of wind driven fugitive dust, excluding any areas which are inaccessible to watering vehicles due to excessive slope or other safety conditions; OR (3b) Apply dust suppressants in sufficient quantity and frequency to maintain a stabilized surface; OR (3c) Establish a vegetative ground cover within 21 days after active operations have ceased. Ground cover must be of sufficient density to expose less than 30 percent of unstabilized ground within 90 days of planting, and at all times thereafter; OR (3d) Utilize any combination of control actions (3a), (3b), and (3c) such that, in total, these actions apply to all inactive disturbed surface areas
Unpaved Roads	(4a) Water all roads used for any vehicular traffic at least once per every two hours of active operations [3 times per normal 8 hour work day]; OR (4b) Water all roads used for any vehicular traffic once daily and restrict vehicle speeds to 15 miles per hour; OR (4c) Apply a chemical stabilizer to all unpaved road surfaces in sufficient quantity and frequency to maintain a stabilized surface.
Open storage piles	(5a) Apply chemical stabilizers; OR (5b) Apply water to at least 80 percent of the surface area of all open storage piles on a daily basis when there is evidence of wind driven fugitive dust; OR (5c) Install temporary coverings; OR (5d) Install a three-sided enclosure with walls with no more than 50 percent porosity which extends, at minimum, to the top of the pile. This option may only be used at aggregate-related plants or at cement manufacturing facilities.
All Categories	(6a) Any other control measures approved by the Executive Officer and the U.S. EPA as equivalent to the methods specified in Table 2 may be used.

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