GUIDANCE FOR DISPERSION MODELLING OF MINING-RELATED FUGITIVE PARTICULATE MATTER EMISSIONS IN BRITISH COLUMBIA

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Environmental Protection Division
Environmental Policy and Initiatives Branch
Air Quality Unit

Victoria, British Columbia, Canada

Version: July 2026

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V8W 9M1

Document History

January 2025:	DRAFT released
July 2026:	July 2026 version released

IMPORTANT NOTE

Modelling practitioners are expected to read and follow the BRITISH COLUMBIA AIR QUALITY DISPERSION MODELLING GUIDELINE in addition to following the fugitive particulate-matter-specific guidance in this document.

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ACKNOWLEDGEMENTS

The Ministry of Environment and Parks commissioned this guidance document. It has undergone technical review by qualified experts in air quality modelling, including those from environmental firms. The Ministry also acknowledges the valuable feedback provided by stakeholders in the mining sector, which has helped to improve this document.

1 INTRODUCTION

1.1 PURPOSE

The British Columbia (B.C.) Ministry of Environment and Parks (ENV) is providing guidance on conducting air dispersion modelling for particulate matter (PM) emissions from fugitive emission sources, which includes Total Suspended Particulate (TSP) and PM less than 10 and 2.5 microns in aerodynamic diameter (PM_{10} and $PM_{2.5}$ respectively). This guidance is focused primarily on modelling emission sources at mining facilities but may be applicable in other situations.

The Canadian Ambient Air Quality Standards (CAAQS), the National Ambient Air Quality Objectives (NAAQO), and the B.C. Ambient Air Quality Objectives (Provincial AQO) are summarized below:

- CAAQS
    - 24-hour $PM_{2.5}$: 27 µg/m^3 effective 2020 and 23 µg/m^3 effective 2030, based on the annual 98th percentile of daily average values, averaged over three consecutive years.
    - Annual $PM_{2.5}$: 8.8 µg/m^3 effective 2020 and 8.0 µg/m^3 effective 2030, based on the annual average of hourly concentrations, averaged over three consecutive years.
- NAAQO
    - 24-hour TSP: 120 µg/m^3 effective 1974.
    - Annual TSP: 60 µg/m^3 effective 1974, determined based on geometric mean.[1]
- Provincial AQO
    - 24-hour PM_{10}: 50 µg/m^3 effective 1995, not to be exceeded in a calendar year.
    - 24-hour $PM_{2.5}$: 25 µg/m^3 effective 2009, annual 98th percentile of daily average values over one year.
    - Annual $PM_{2.5}$: 8 µg/m^3 effective 2009, annual average of hourly concentrations, over one year.
        - The planning goal of 6 µg/m^3 provides a voluntary target to guide airshed planning efforts and encourage communities to maintain good air quality in face of economic growth and development.

The primary goal in providing guidance specific to fugitive PM modelling is to provide clarity for applicants on the assumptions and methods appropriate for TSP/PM_{10}/$PM_{2.5}$ models in the province, leading to a streamlined model review process and greater consistency across projects. The approaches outlined in this guidance document can be used to assist applicants in providing meaningful and realistic information for air quality assessments.

This document supplements the *British Columbia Air Quality Dispersion Modelling Guideline* (the Guideline). ENV's most recent dispersion modelling guidance published in June of 2026 (or as updated).[2] The Guideline outlines the levels of assessment available for various project scenarios, including descriptions of accepted methods for developing each model. Sections 3.6 through 3.8 of the Guideline discuss TSP, $PM_{2.5}$, and PM_{10} stack emissions, PM emissions and size fractions for

[1] The geometric mean is the nth root of the product of n numbers.
[2] British Columbia Ministry of Environment and Parks, "British Columbia Air Quality Dispersion Modelling Guideline" https://www2.gov.bc.ca/assets/download/9960E7796D6E43249D2A768E3AC20B66

particle deposition estimates, and fugitive sources. This guidance aims to provide clarity on the recommended modelling techniques for various sources of fugitive emissions, particularly at mining facilities.

In addition to following the fugitive PM-specific guidance in this document, modelling practitioners are expected to read and follow the latest B.C. Dispersion Modelling Guideline and supporting documents while conducting air quality assessments for mines.

1.2 TYPICAL FUGITIVE SOURCES OF PM EMISSIONS FROM MINING OPERATIONS

Fugitive PM emissions are particulate emissions that could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening. Typical sources of fugitive TSP, PM_{10}, and $PM_{2.5}$ emissions from mining operations, which should be considered when conducting an air dispersion modelling analysis, are outlined below. Note that this is not an exhaustive list of fugitive TSP, PM_{10}, and $PM_{2.5}$ sources, and additional guidance on fugitive emission sources and their calculation methodologies can be found in the *Guidance for Estimating Fugitive Particulate Matter Emissions from Mining Activities in British Columbia*.[3]

- Paved and unpaved road traffic
- Crushing and screening
- Material transfers (e.g., conveyor transfer points, truck loading and unloading)
- Bulldozing, grading, and mobile scraping
- Drilling and blasting
- Wind erosion from storage piles and exposed areas

[3] https://www2.gov.bc.ca/assets/download/75ECB38775DA41729522916156F667F2

2 MINING MODELLING METHODS

Various dispersion models, ranging from simple to complex, are available. The Guideline provides brief descriptions of the dispersion models recommended for use in B.C., along with the specific situation in which they apply. Applicants are advised to consult the Guideline to determine the appropriate model and assessment level.

2.1 CONVERSION OF CALCULATED EMISSION RATES TO SHORT-TERM MODELLED EMISSION RATES

When preparing air dispersion models for the 24-hr and annual TSP, PM_{10}, and $PM_{2.5}$ objectives, it is important to ensure that modelled emission rates are representative of the appropriate averaging periods. To properly convert emission rates of individual sources to a gram per second (g/s) format, the worst-case emission rates for a given averaging period should be considered. The short-term modelled emission rate for the 24-hr averaging periods should be based on the maximum 24-hr emission rate. In many cases, the worst-case 24-hr emission rate is likely represented by continuous operation for a full 24 hours at maximum operating capacity. However, when sources operate for less than 24 hours, applicants should ensure that modelled emission rates are appropriately representative of less than a day of operation. For guidance on estimating fugitive emissions for use in air quality assessments and modelling demonstrations, applicants should refer to the *Guidance for Estimating Fugitive Particulate Matter Emissions from Mining Activities in British Columbia*. The information below provides recommendations to further convert the emission rates derived in the ENV emissions guidance document to short term emission rates suitable for inputs into AERMOD or CALPUFF.

For example, if Facility A has a blasting source with a PM_{10} emission rate of 20 lb per blast and plans to conduct one blast per day, then the daily emission rate is 20 lb PM_{10} per day. When converting this emission rate to g/s, the number of hours of operation per day becomes relevant. If the source were to operate once per day in any of the 24 hours, then the daily average emission rate would be:

$$\frac{20\ lb\ PM10}{blast} \times \frac{1\ blast}{day} \times \frac{1\ day}{24\ hrs} \times \frac{1\ hr}{3{,}600\ sec} \times \frac{453.6\ g}{1\ lb} = 0.105\ g/s\ PM10$$

Alternatively, if the applicant were to limit the blasting operations on an hourly basis to 12 hours per day, the conversion would be the following:

$$\frac{20\ lb\ PM10}{blast} \times \frac{1\ blast}{day} \times \frac{1\ day}{12\ hrs} \times \frac{1\ hr}{3{,}600\ sec} \times \frac{453.6\ g}{1\ lb} = 0.210\ g/s\ PM10$$

This change will result in a higher short-term emission rate because the total emissions in a given day are still dependent on a total blasting emission rate of 20 lb PM_{10} per blast. In the model set-up, Facility A would then apply an hour of day restriction to the model source to ensure that modelled emissions are limited to the 12-hr period (e.g., for a facility operating from 6 am – 6 pm, the modelled emission rate of 0.210 g/s would only be applied for those hours). This method of refinement would allow for applicants to align model representations with actual project operating conditions and remove potentially overly conservative model results for operations that would not take place during calm wind conditions outside of daylight hours. The result is the same total emissions per blast and per day, and only the distribution of those emissions across a given 24-hour period is changed.

It is important to note that the above example represents a source that is not operating continuously. In instances where a source is operating continuously, the g/s emission rate should be determined at the continuous operating capacity.

For fugitive emissions sources that operate with greater fluctuations in short-term emission rates, it is possible that the use of hourly varying emission rates may result in lower maximum 24-hr and annual averaging TSP/PM_{10} concentrations and lower 98th percentile of daily $PM_{2.5}$ concentrations in the model domain. Examples of these kinds of activities include material transfer activities and wind erosion from storage piles and industry exposed areas where the emissions are generated due to displacement from gusts of wind rather than a continuous, gradual release of particulate fugitive emissions. In model exercises where the short-term emissions are calculated, ENV recommends the use of time-varying hourly emission rates (derived as a continuous function of wind speed) for these types of mining activities rather than a 24-hr maximum value.

2.2 TYPICAL MODEL SOURCE TYPES FOR MINING-RELATED FUGITIVE PM EMISSIONS

The typical sources of fugitive TSP, PM_{10}, $PM_{2.5}$ emissions from mining operations are outlined below with a summary of the recommended model source type. Each of the source types are modelled similarly or identically in AERMOD and CALPUFF.

Table 2-1. Summary of Typical Model Source Types for Fugitive PM Emissions from Mining Operations

Typical Source from Mining Operations	Type of Source
Paved and Unpaved Road Traffic	Volume, Line*, Roadway
Wind Erosion from Storage Piles and Exposed Areas	Volume, Area
Drilling and Blasting	Area, Volume
Crushing and Screening	Volume
Material Handling and Transfers (e.g., transfer points, truck loading/unloading)	Volume
Bulldozing, Grading, and Mobile Scraping	Volume, Area

* Line sources are potentially applicable for use in AERMOD, but they are not recommended for modeling fugitive PM emissions sources in CALPUFF. Additionally, please see the discussion on the receptor exclusion zone for volume sources in Section 2.4.1

The following sections highlight the key model source inputs for each source type.

2.2.1 VOLUME SOURCES

Volume sources are used to model releases from various industrial sources, such as crushers, screens, vents, conveyor belts, roads, drop points, and material storage piles. Line sources (e.g., roadway fugitive sources described in Section 2.2.4) are recommended by the U.S. EPA to be characterized as a series of volume sources. The following parameters are needed to model volume sources:

- Emission rate
- Source release height h_e, typically the height of the centre of the volume source above ground
- Initial lateral dimension σ_{yo} (i.e., initial sigma y)
- Initial vertical dimension σ_{zo} (i.e., initial sigma z)
- Source location

- Source base elevation

Determination of the initial lateral and vertical dimensions (referred to as initial sigmas) are based on the geometry and location of the source. Table 2-2, which is explained in more detail in Section 1.2.2 of Volume II of the ISC3 User's Guide, outlines the recommended procedures for estimating the initial sigmas for various types of volume sources and line sources represented by adjacent or separated volume sources.[4]

Table 2-2. Estimation of Initial Lateral and Vertical Dimensions for Volume and Line Sources

Type of Source	Procedure for Obtaining Initial Dimensions
Initial Lateral Dimensions	
Single volume source	σ_{yo} = length of side divided by 4.3
Line source represented by adjacent volume sources	σ_{yo} = length of side divided by 2.15
Line source represented by separated volume sources	σ_{yo} = center to center distance divided by 2.15
Initial Vertical Dimensions	
Surface-based source (h_e ~ 0)	σ_{zo} = vertical dimension of source divided by 2.15
Elevated source (h_e > 0) on or adjacent to a structure	σ_{zo} = structure height divided by 2.15 ***Note: σ_{zo} is determined by the structure size, not by the opening where emissions come out.***
Elevated source (h_e > 0) not on or adjacent to a structure	σ_{zo} = vertical dimension of source divided by 4.3

Note that a volume source must have a square base. If the source cannot be characterized as square, it should be modelled as a series of adjacent volume sources. For relatively uniform sources, the equivalent square can be determined by calculating the square root of the projected area of the volume source to find the corresponding side length of the equivalent square.

2.2.2 AREA SOURCES

Area source algorithms are used to model low-level or ground-level releases such as storage piles and lagoons. The AERMOD and CALPUFF models use a numerical integration approach for modelling impacts from area sources.

CALPUFF requires area sources to be identified only as polygons with 4 vertices (i.e., 4 corners). The size of an area source should not be larger than one computational grid cell, as variations of meteorological conditions across the area source cannot be accounted for in this case. If the source exceeds the grid size, it must be divided into smaller area sources to achieve the most accurate predictions.[5] The run time of an area source is dependent on its aspect ratio (i.e., length/width).

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[4] U.S. Environmental Protection Agency. (1995). "User's Guide for the Industrial Source Complex (ISC3) Dispersion Models," *Volume II – Description of Model Algorithms* (EPA-454/B-95-003b). https://nepis.epa.gov/Exe/ZyPDF.cgi/0000324F.PDF?Dockey=0000324F.PDF

[5] Popovic, J., "Recommendations for source characterization," in Proceedings of the 19th International Clean Air and Environment Conference, (Perth, Australia, 2009)

Applicants should select an appropriate aspect ratio, with ENV recommending a range from 3:1 for sources farther from receptors to 1:1 for those closer. Key area source parameters required by CALPUFF include emission rate, effective height, base elevation, initial sigma z, and the coordinates of each vertex.

AERMOD offers three options for specifying the shape of an area source. The AREA source type allows for a rectangular area source. The AERAPOLY source is used to specify an area source as an irregularly shaped polygon. The AREACIRC source type defines a circular-shaped area source. The following input parameters are required by AERMOD to compute the concentrations from an area source:

- Emission rate per unit area
- Release height above ground
- Length of x side and y side (AREA source type only)
- Number of vertices and coordinates of each vertex (AREAPOLY source type only)
- Number of vertices and radius of circular area (AREACIRC source type only)
- Optional inputs of orientation angle in degrees from North (AREA source only)
- Initial vertical dimension

In AERMOD, a non-fatal warning message will be triggered for aspect ratios of 100:1 and the performance of the area source algorithm has not been fully tested for larger aspect ratios. ENV recommends an aspect ratio not exceeding 10:1.

2.2.3 LINE SOURCES

The buoyant line source algorithm in CALPUFF is not recommended for modelling fugitive PM emissions from roads, as it is best suited for buoyant line sources, such as a mono-vent in a steel mill building.

The LINE source type in AERMOD allows users to specify line-type sources (e.g., roadway sources) based on a start-point and end-point of the line and the width of the line. The AERMOD line source uses the same routines as the AREA source type and produces identical results for equivalent source parameter inputs. Note that the LINE source type does not, by default, account for plume meander during low wind conditions. The LINE source option in AERMOD is not recommended if the elevations of the sources vary significantly along the line.

2.2.4 ROAD EMISSION SOURCES

ENV requires modelling of fugitive road dust from roadways for both short-term (24-hr) and annual averaging periods. Assessments required for applications under the *Environmental Assessment Act* (EAA) or *Environmental Management Act* (EMA) must consider fugitive PM emissions originating from roadways.

In CALPUFF, fugitive road emission sources (e.g., haul roads) can be represented as a series area or volume sources. With the upgrade to CALPUFF Version 7, the roadway source emissions option was introduced. This source type allows the generation of each roadway link in a simulation, which is treated as a discrete, named source. Each link represents a road segment with uniform emissions (g/m/s). Link properties include effective height above ground, initial concentration distribution width (σ_y) and height (σ_z) perpendicular to the link axis, and emission rates for all emitted species. The use of a RDEMARB.DAT file may be appropriate to identify the various roadway links, coordinates, and variable emissions rates. Using the CALPUFF roadway source for modelling of road emissions is acceptable to ENV.

In AERMOD, roadway fugitive dust should be modelled as a series of volume sources. ENV follows the volume source technique recommended by U.S. EPA's Haul Road Workgroup for modelling haul road emissions.[6]

2.2.5 OPENPIT SOURCES

The OPENPIT algorithm in AERMOD uses an effective area for modelling emissions from open pits (e.g., surface coal mines), based on meteorological conditions. The algorithm then uses the numerical integration area source algorithm to model the impact of the emissions from the effective area source which shape, size, and location varies with the wind direction and the relative depth of the pit. The input parameters needed to model open pit sources include:

- Open pit emission rate (emission rate per unit area)
- Average release height above the base of the pit
- Initial length and width of the pit
- Volume of the pit
- An optional input "ANGLE" for the rectangular area from North, measured positive in clockwise direction

Note that receptors should not be located within the boundary of an open pit source. The OPENPIT source type is not available in CALPUFF.

2.3 MINING SOURCE CHARACTERIZATION

The following sections provide specific model source characteristics for many of the commonly modelled mining source types. For any mining source type not explicitly listed, the model plan should include a detailed description of the source, along with a clear explanation of the assumptions and references used to define its characteristics (e.g., source type, source parameters) in the model.

2.3.1 FUGITIVE VOLUME SOURCES (INCLUDING CRUSHING AND SCREENING, MATERIAL HANDLING AND TRANSFERS, BULLDOZING, GRADING AND MOBILE SCRAPING)

Most fugitive emission release at mines should be modelled using the volume source algorithm. Examples of mining-related volume sources are listed below:

- Crushing and screening
- Material handing and transfers (e.g., conveyor transfer points, truck loading and unloading)
- Bulldozing, grading, and mobile scraping

Table 2-3 summarizes the recommended source parameters (including release height, initial lateral and vertical dimensions) for modelling the mining sources above.

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[6] U.S. Environmental Protection Agency (EPA). (2012, March 2). Haul Road Workgroup Final Report Submission to EPA-OAQPS. Retrieved from https://www.epa.gov/sites/default/files/2020-10/documents/haul_road_workgroup-final_report_package-20120302.pdf

Table 2-3. Summary of Recommended Source Parameters for Modelling Crushing and Screening, Material Handling and Transfers, Bulldozing, Grading, and Mobile Scraping

Source Input Parameter	Modelled Emission Source	Description
Release Height (h_e) – The release height of a volume source is the height of the center of the volume source above the ground.	Crushing and Screening [a]	½ the height of the source above the ground
	Material Handling and Transfers, such as conveyor transfer points, truck loading and unloading [b]	½ the height from the drop point to the ground
	Bulldozing, Grading, and Mobile Scraping	½ the height of the equipment blade/bucket above the ground
Initial Lateral Dimension (σ_{yo}) – The initial lateral dimension or sigma y (σ_{yo}) of a volume source is the actual width of the release divided by 4.3 for single volume sources and 2.15 for adjacent/separated volume sources.	Crushing and Screening [a]	Average width of structure / 4.3 if structure is square. Rectangular-shaped structure should be divided into multiple, square-shaped volume sources.
	Material Handling and Transfers, such as conveyor transfer points, truck loading and unloading [b]	Width of the drop point (e.g., conveyor width, width of the front-end loader bucket) / 4.3
	Bulldozing, Grading, and Mobile Scraping	Width of the equipment blade (or bucket) / 4.3
Initial Vertical Dimension (σ_{zo}) – The initial vertical dimension or sigma z (σ_{zo}) of a volume source is calculated differently depending on its location relative to its surroundings. If the emission release is located at ground level, then σ_{zo} is determined by dividing the vertical dimension of the source (i.e., distance from the drop point to the drop location) by 2.15. If the emission release is an elevated source not on or adjacent to a structure, such as an elevated conveyor, the vertical dimension of the source is divided by 4.3. However, if the elevated emission source is on or adjacent to a structure, such as a crusher and a screen, the structure height should be divided by 2.15 to determine σ_{zo}.	Crushing and Screening [a]	Height of the structure / 2.15
	Material Handling and Transfers, such as conveyor transfer points, truck loading and unloading [b]	Height of the drop point / 4.3 for single, elevated conveyor transfer point. Structure height / 2.15 for single conveyor transfer point on or adjacent to a structure. Height of the sidewall of the truck bed / 4.3 for truck loading with loader. Maximum height of the top of the open truck bed to the ground / 2.15 for truck unloading.
	Bulldozing, Grading, and Mobile Scraping	Height of the equipment blade (or bucket) / 4.3

a. Crushers and screens often have sufficient structure to themselves; therefore, they should be characterized as elevated sources on or adjacent to a structure.

b. Truck unloading should be characterized as an elevated source on or adjacent to a structure (i.e., truck itself).

2.3.2 HAUL ROADS

Both area and volume source options can be used to model haul road fugitive dust in CALPUFF. Haul roads may also be represented by the roadway source option if CALPUFF Version 7 is used. Haul roads should be characterized as a series of volume sources in AERMOD.

ENV adopts the methodology recommended by U.S. EPA's Haul Road Workgroup for calculating volume source parameters for haul roads, including emission rate, release height, initial dispersion dimensions. Table 2-4 provides a summary of the specific source parameters recommended for modelling haul roads as a series of volume sources.

Table 2-4. Summary of Haul Road Volume Source Parameters Calculations

Source Parameter	Description
Adjusted Road Width	For single-lane roadways, the adjusted width is the vehicle width plus 6 meters. For two-lane roadways, the adjusted width is the actual width of the road plus 6 meters. The additional width represents turbulence caused by the vehicle as it moves along the road. This width will represent a side of the base of the volume.
Number of Volume Sources	If the road is represented by adjacent volume sources, divide the length of the road by the adjusted width. If the road is represented by alternating volume sources, divide the length of the road by twice the adjusted width.
Volume Source Height	The height will be equal to 1.7 times the height of the vehicle generating the emissions.
Initial Lateral Dimension (σ_{yo})	If the road is represented by adjacent volume sources, divide the adjusted width by 2.15. If the road is represented by alternating volume sources, divide twice the adjusted width – measured from the center point of the first volume to the center point of the next represented volume – by 2.15. Start with the volume source nearest the process area boundary. This representation is often used for long roads.
Initial Vertical Dimension (σ_{zo})	Divide the height of the volume source by 2.15.
Release Height (h_e)	Divide the height of the volume source by two. This point is the center of the volume.
Emission Rate	Divide the total emission rate equally among the individual volume sources used to represent the road, unless there is a known spatial variation in emissions.
Source Coordinates	The release point location is in the center of the projected area of the volume. In AERMOD, this location must be at least one meter from the nearest receptor, as discussed in Section 2.4 below.

2.3.3 DRILLING AND BLASTING

Drilling can be modelled as an area source with a surface-based release height (e.g., 0 or 0.5 m above ground). Blasting should be represented as a volume source. Applicants can use the U.S. EPA's Open Burn/Open Detonation Model (OBODM) to determine volume source release parameters for blasting.[7] The following parameters are recommended for modelling blasting:

- Release height: ½ the initial cloud diameter calculated from OBODM.
- Initial vertical dimension: The OBODM-calculated initial cloud diameter divided by 2.15, representing a surface-based release.
- Initial lateral dimension:
  - Equal to the initial cloud diameter calculated from OBODM divided by 4.3, or
  - Estimated as the square root of the total blast area divided by 4.3, representing a single volume source.

The OBODM model is designed to assess the potential air quality impacts from open burning and detonation of obsolete munitions and solid propellants. A blast with multiple blast holes should be modelled as separate volume sources, with each hole treated as an individual volume source. Combining multiple holes as a single volume source could lead to an excessively high plume rise and significantly underestimate the ground level impacts. In extreme cases, the OBODM-calculated plume height may extend beyond the surface mixing layer, resulting in a modelled ground level concentration of zero, as OBODM assumes plume material above the top of the surface layer does not contribute to ground level concentrations. Blast hole locations in OBODM should be defined individually based on its geographic layout or, if unknown, assumed to be evenly distributed within the blasting zone.[8]

OBODM is an x86 application that requires a 32-bit Windows operating system. Applicants can use an x86 emulator such as DOSBox to run OBODM. DOSBox is an open-source application available for download at https://www.dosbox.com/.

Meteorological input parameters required by the OBODM include wind speed, wind direction, and Pasquill stability category (or net radiation index). ENV recommends use of the following:

- Average wind speed and direction over an operating window for blasting (e.g., 6 am – 6 pm)
- Pasquill stability category ‘C’ or ‘D’

For blasting operations using Ammonium Nitrate fuel Oil (ANFO) explosives, a heat content of 880 cal/g is recommended for the OBODM model. The fuel burn rate should be computed internally by the model, rather than being specified manually.

To model blasting emissions with AERMOD or CALPUFF, the following should be addressed in the detailed model plan:

- As open detonation releases are usually quasi-instantaneous, the methodology for calculating short-term and annual averaging emission rates for TSP, PM_{10} or $PM_{2.5}$ must be provided.

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[7] H.E. Cramer Company, Inc, “Open Burn/Open Detonation Dispersion Model (OBODM) User’s Guide” (February 1998). Accessed 14March2025 at https://www.epa.gov/scram/air-quality-dispersion-modeling-alternative-models

[8] Arizona Department of Environmental Quality, “Air Quality Modelling Guidelines for Arizona Air Quality Permits” (November 1, 2019). https://static.azdeq.gov/aqd/modeling_guidance_2019.pdf

- For blasting emissions modelled as volume sources, methods used for determining release heights and initial dimensions must be provided. Applicants must include a detailed description in the model plan, and any underlying assumptions must be explicitly explained and justified.

Note that in both AERMOD and CALPUFF, the dispersion characteristics of the blast sources (and other volume sources) are highly dependent on the source location and the proximity of the source to notable terrain features. Applicants are encouraged to demonstrate that the worst-case blasting location is used for each appropriate pollutant and averaging period. The worst-case location can be determined by identifying the blasting location near the fence or property line (e.g., NW, NE, SW, or SE corner) that results in the highest impact on receptors.

2.3.4 STORAGE PILES

Storage piles are typically modelled as area sources. The emission rate is specified over an area (i.e. $g/s/m^2$). In CALPUFF, area sources must be modeled as a quadrilateral shape. In AERMOD, the pile base may be modelled as circular, rectangular, or polygonal. The following area source parameters are recommended for characterizing storage piles:

- Release height: ½ the average height of the pile.
- Initial vertical dimension (σ_{zo}): The average pile height divided by 4.3.

Fugitive PM emissions from storage piles or other wind erosion sources (e.g., tailing dam) are dependent on disturbances generated by higher wind speeds. When calculating emissions for these sources, applicants should consult the *Guidance for Estimating Fugitive Particulate Matter Emissions from Mining Activities in British Columbia*.

To improve air quality modelling accuracy, it is recommended to use time-varying hourly emission rates for both AERMOD and CALPUFF. However, if the fugitive emission rates and their impact on air quality predictions are expected to be minimal, simplified modelling methods may be considered. For instance, applicants can use CALPUFF's option to vary emission rates across six wind speed categories, as defined by WSCAT in CALPUFF input group 12.

The detailed model plan submitted for ENV acceptance should include an explanation of what assumption on wind speed and the frequency of disturbance is made for estimating fugitive emissions from storage piles. If CALPUFF's six wind speed category option is applied, the plan should also describe how emission rate scaling factors presented in the CALPUFF's input control file are determined. This ensures clarity and transparency in the modelling methodology.

2.4 RECEPTOR EXCLUSION ZONES

Ambient air receptors within AERMOD cannot determine the impacts from volume, point, or open pit sources within the receptor exclusion zone. The receptor exclusion zone is defined as the following:

- Inside the boundary of an open pit source;
- Within 1 meter of a point source; and
- Within 1 meter + 2.15 x σ_{yo} of a volume source.

2.4.1 HAUL ROAD SOURCES AND RECEPTOR EXCLUSION ZONES

For cases where volume sources cannot be used for modelling haul roads in AERMOD due to the presence of ambient air receptors within the volume source exclusion zone, road emissions can be modelled as area sources with the following characteristics:

Table 2-5. Summary of Haul Road Area Source Parameters Calculations

Type of Source	Equation for Stack Parameter
Release height (h_e)	½ the top of plume height
Top of plume, release height, plume width, and sigma z	Set to values listed in Section 2.3.2 for volume sources
Emission rate	grams/second/m^2

2.5 OPEN PIT RETENTION

Pit retention refers to the tendency of PM emissions to remain inside an open pit mine, rather than escaping to the surface. The fraction of emissions retained depends on particle sizes, meteorological conditions, and pit dimensions. Pit retention should be considered when assessing the air quality impact of PM_{10} and TSP from open pit mining, particularly for deep pits (e.g., depths exceeding 50 m). However, pit retention is not suitable for fine particulate matter ($PM_{2.5}$), particles with aerodynamic diameters $\leq$ 2.5 µm), as these are more prone to dispersion.

In AERMOD, an escape fraction is calculated for each particle size category to estimate the portion of PM emissions that exit the open pit. The corresponding pit retention factor is then computed as follows:

$$Pit\ Retention\ Factor = 1 - Escape\ Fraction$$

For CALPUFF, applicants must estimate escape fractions manually to account for pit retention, as open pit modelling algorithms are not available for this model (as noted in Section 2.2.5). The method, described in Section 1.2.4 of Volume II of the ISC3 user's guide, can be used to calculate escape fractions across particle sizes. The escape fraction ε_i for a given particle size category i is determined by:

$$\varepsilon_i = \frac{1}{\left(1 + V_g/(\alpha * U_r)\right)} \tag{1}$$

Where:

V_g = gravitational settling velocity (m/s)

U_r = approach wind speed at 10 m (m/s)

α = proportionality constant in the relationship between flux from the pit and the product of U_r and concentration in the pit (empirically determined as 0.029)

The gravitational setting velocity V_g is calculated as:

$$V_g = \frac{(\rho - \rho_{air}) * g * d_p^2 * c_2}{18\mu} S_{CF} \tag{2}$$

Where:

ρ = particle density

ρ_{air} = air density ($\cong$ 1.2 X 10^{-3} g/cm^3)

g = acceleration due to gravity (9.80616 m/s^2)

d_p = particle diameter (µm)

μ = absolute viscosity of air ($\cong$ 1.81 x 10^{-4} g/cm/s)

c_2 = air unit conversion constant (1 x 10^{-8} cm^2/µm^2)

S_{CF} = slip correction factor, which is determined using:

$$S_{CF} = 1 + \frac{2x_2\left[a_1 + a_2 * e^{-(a_3 * d_p / x_2)}\right]}{10^{-4} d_p} \tag{3}$$

Where:

x_2, a_1, a_2, and a_3 are constants with values of 6.5 x 10^{-6}, 1.257, 0.4, and 0.55 x 10^{-4}, respectively.

Once the escape fraction ε_i is calculated for each particle size category, the overall escape fraction ε can be estimated as the composite of particle category escape fractions weighted by their mass fractions.

$$\varepsilon = \sum_{i=1}^{n} \varepsilon_i \varphi_i \tag{4}$$

Where:

ε_i = escape fraction for a given particle size category i

φ_i = mass fraction of particles escaping the pit for a given size category i

Wind speed at 10 m, particle density, particle diameters, and mass fractions are required to calculate individual particle category escape fractions (ε_i) and the overall escape fraction (ε). Annual average wind speeds may be used. If site-specific data on particle density, particle diameters, and mass fractions are not available, they can be obtained from the following:

- Table A-1 through A-8 in Appendix A: Particulate Matter Deposition Parameters For AERMOD, or
- Table 2-6 Particle Size Distribution.

Table 2-6. Particle Size Distribution

PM Species	Size Range (µm)	Particle Mean Diameter (µm)*	PM_{10} Mass Fraction*	PM Mass Fraction*	Particle Density (g/cm^3)	Affiliation	
						PM10 [a]	TSP [b]
P1	<2.5	1.875	14.46%	4.77%	2.655	X	X
P2	2.5-10	6.25	85.54%	28.19%	2.655	X	X
P3	>10	20	N/A	67.04%	2.655		X

*Particle mean diameters and mass fractions in Table 2-6 are based on the particle size distribution curve in Figure 2-1, which is sourced from Chow and Watson (1998).[9]

a. PM_{10} = P1 + P2

b. TSP = P1 + P2 + P3

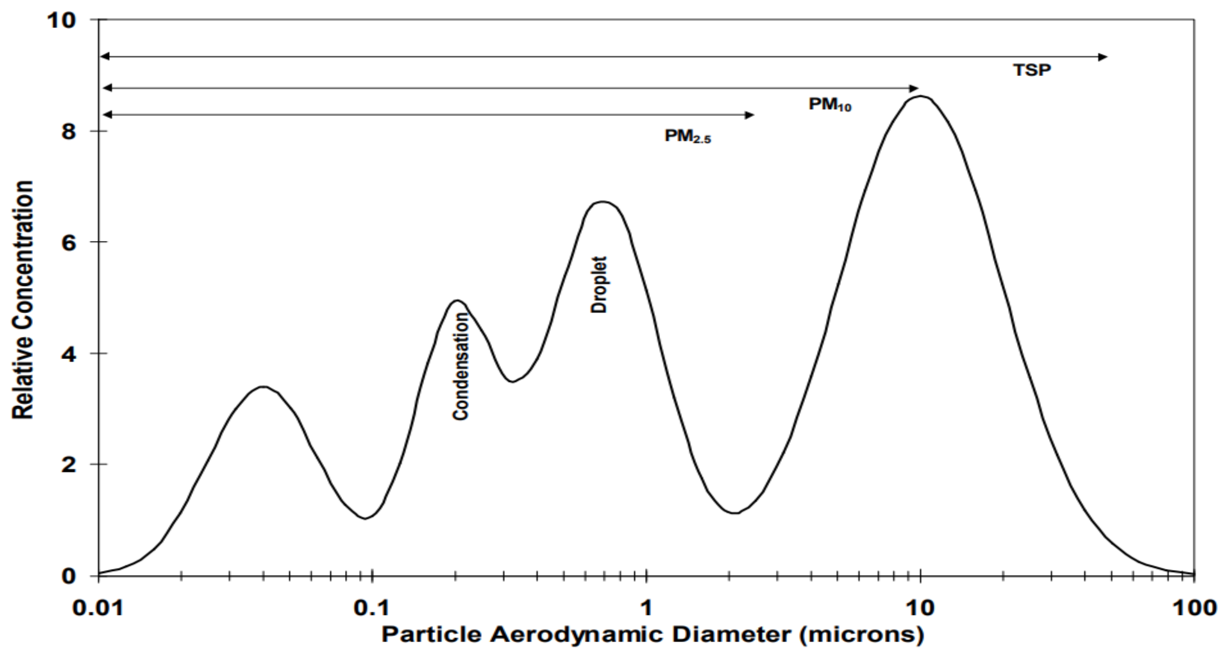

Figure 2-1. Idealized Particle Size Distribution in Ambient Air.

[9] Chow, Judith C., and John G. Watson. "Guideline on speciated particulate monitoring." Report prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC, by Desert Research Institute, Reno, NV 2 (1998): 506-510. Access at https://www3.epa.gov/ttnamti1/files/ambient/pm25/spec/drispec.pdf

To incorporate pit retention in CALPUFF, PM emission rates should be adjusted based on the escape fraction. For example, if the derived escape fraction for PM_{10} is 95%, the PM_{10} emission rate can be multiplied by 0.95 before being input into CALPUFF.

Applicants seeking to incorporate pit retention in CALPUFF must:

- Provide a detailed description of the approach used to estimate escape fractions in the model plan, particularly if it differs from the method outlined in this section.
- Include modelling results for PM_{10} and TSP, with and without pit retention, in the air quality technical assessment report.

2.6 PARTICLE DEPOSITION

Particle deposition algorithms can be applied in AERMOD and CALPUFF and should be turned on by default. For CALPUFF, follow Section 3.7 of the Guideline for PM deposition calculations. For AERMOD, deposition parameters for particles up to 100 microns in aerodynamic diameter (PM_{100}) are presented in Appendix A. All additional data used for an air dispersion analysis that incorporates the particle deposition must be included in the detailed model plan along with rational that support particle sizes, percentages, mass fractions, and densities for the particle size distributions used within the model.

2.7 MODEL POST-PROCESSING

The following sections provide descriptions of post-processing methods for model outputs.

2.7.1 MODEL OUTPUTS

Applicants must provide model outputs in the form of the objectives/standards discussed in Section 1 and summarized below. Applicants must provide output model files summarizing project impacts.

- CAAQS
    - 24-hour $PM_{2.5}$: annual 98th percentile of the daily average values, averaged over three consecutive years.
    - Annual $PM_{2.5}$: annual average concentrations, averaged over three consecutive years.
- NAAQO
    - 24-hour TSP: not to be exceeded in a calendar year
    - Annual TSP: annual average concentrations
- Provincial AQO
    - 24-hour PM_{10}: not to be exceeded in a calendar year.
    - 24-hour $PM_{2.5}$: annual 98th percentile of the daily average value over one year.
    - Annual $PM_{2.5}$: annual average concentrations, averaged over one year.
        - Planning goal of 6 µg/m^3 provides voluntary target to guide airshed planning efforts and encourage communities to maintain good air quality in face of economic growth and development.

2.7.2 BASELINE TSP/PM_{10}/$PM_{2.5}$ CONCENTRATIONS

The baseline concentration is the concentration added to model results to account for sources not explicitly modelled (usually existing during the baseline period). The baseline concentration is typically applied as a single constant value throughout the spatial and temporal model domain. Section 8.1 of the latest B.C. Modelling Guideline provides general baseline-related recommendations (e.g., the baseline should be based on the most recent years of representative hourly monitoring data with 75% completion in each quarter; the monitoring data should be pre-screened to exclude any periods when an intermittent source has a significant influence on the monitor).

When representative monitoring data is available, the following is recommended for selecting a 24-hour TSP/PM_{10}/$PM_{2.5}$ baseline level:

- Level 1 Assessment should use the most conservative approach for consistency with Section 8.1.4 of the latest Guideline, requiring use of the maximum monitored concentration (100th percentile).
- For Level 2 and 3 Assessments, the baseline concentration sequential calculation options are provided below:
    a. 98th percentile of 24-hr (daily) values from monitoring data.
    b. Monthly/Seasonal varying baseline concentrations for 24-hr averaging period using monitoring data as described in Section 2.7.3.1 of this Guidance.

If there are no representative ambient monitoring data, applicants should follow recommendations in Section 8.1.5. of the Guideline to estimate baseline levels.

The baseline approach and dataset selection with justification should be outlined in the Dispersion Modelling Plan.

2.7.3 TOTAL CONCENTRATIONS (BASELINE + MODELLED CONCENTRATIONS)

Challenging situations, such as high baseline concentrations, may require detailed considerations of the temporal variability of modelled versus monitored concentrations. The following approach can be proposed to combine modelled concentrations with baseline concentrations.

2.7.3.1 WORST CASE DAY APPROACH

For 24-hr modelling of TSP, PM_{10}, and $PM_{2.5}$, the simple approach for comparing baseline concentrations would be to compare the baseline concentration to the modelled concentration with both values being in the form of the ambient objective/standard. To account for temporal variability of the baseline concentrations, applicants can use the “worst case day” method to establish seasonal or monthly baselines that should then be added to the modelled concentrations to calculate the total concentrations. For example, if the highest 24-hr $PM_{2.5}$ concentration in the winter season was monitored as 1 µg/m^3, this concentration would be used as the baseline and be added to all modelled days within the winter season to compute the total concentrations. Similarly, if the highest 24-hr $PM_{2.5}$ concentration in January is 1 µg/m^3, this would be added to all the modelled days within that month in the model to determine the total concentrations. This approach allows for a more flexible baseline that better reflects variations in local baselines.

If alternative approaches for computing baseline concentrations (e.g., spatially varying baseline) and/or total concentrations (e.g., temporally varying paired sums) are proposed, include rationale and details in the model plan application.

3 MODEL SCENARIOS FOR A MINING APPLICATION

Given the complexity of typical modelling demonstrations for mining facilities with many fugitive emission sources (and the tendency for mining operations to have multiple operating scenarios that may constitute a 24-hour period), it is important for applicants to develop individual models for the various potential operating scenarios to ensure that not only the worst-case, but also the most representative modelled impacts to ambient air are captured in the modelling demonstration. Applicants should prepare a detailed description of each model scenario represented in a given project, and those details should be included in the detailed model plan.

Some example scenarios that may be necessary to include in a given application include the following:

- If a project has disparate regions of a mine with varying operational restrictions, the modelling should capture the worst-case impacts from a given zone.
    - Operational restrictions include, but are not limited to, hour-of-day restrictions, throughput limits, and mutually exclusive source operations (e.g., Source A does not operate at the same time as Source B).
- Some specific emissions sources may require specific model scenarios:
    - Blasting and other sources with intermittent, short-term operations should include a sensitivity analysis to determine the worst-case location for short-term contributions to modelled concentrations.
    - The representation of sources that change location over time (e.g., mobile scraping or bulldozing sources) will differ in model representation depending on the averaging period selected. For example, a volume source may be the appropriate representation of the physical characteristics of a bulldozing source, but an area source may be the more appropriate representation of the bulldozing operations over the course of a longer averaging period.
    - The application of water or chemical dust suppressants on unpaved roadways, material transfer, material storage piles, or other control methods may be required to reduce particulate emissions and to compare with uncontrolled operating scenarios. In addition to providing model results for scenarios with those control methods (e.g., water, chemical dust suppressants) in place, ENV may also require the submission of model results for scenarios with natural mitigation (e.g., snow and rain) in place only.

4 MATERIALS REQUIRED FOR A MODEL PROJECT APPLICATION

4.1 DETAILED MODEL PLAN

Each modelling project that incorporates this guidance document must submit a completed model plan for ENV's review that provides justification for model parameters, assumptions made regarding fugitive sources, and selection of any needed ambient monitoring datasets for $TSP/PM_{10}/PM_{2.5}$. The detailed model plan should address the following specific to fugitive $TSP/PM_{10}/PM_{2.5}$:

- $TSP/PM_{10}/PM_{2.5}$ Modelling Techniques
  - Which alternative $TSP/PM_{10}/PM_{2.5}$ modelling technique, if any, was selected and why?
  - What considerations were given to ambient concentrations in the model location, characteristics of the modelled sources, and availability of relevant monitoring data?
  - What assumption on wind speeds and the frequency of disturbances is made for estimating hourly time-varying fugitive emissions from storage piles. How emission rate scaling factors are determined if CALPUFF's six wind speed category option is applied.
  - If alternative method used for assessing pit retention for PM_{10} and TSP, a detailed description of the method must be provided in the model plan.
  - If separate modelling scenarios are presented for control technology options, the plan needs to include detailed descriptions of those model scenarios (including the derivation of mitigation control efficiencies).
  - If blasting takes place in discrete locations throughout a larger operating area, the model plan should indicate if a sensitivity analysis will be conducted to identify the location that results in the worst-case modelled concentrations.
- $TSP/PM_{10}/PM_{2.5}$ Baseline
  - The plan needs to specify the $TSP/PM_{10}/PM_{2.5}$ monitoring dataset used and why the dataset is representative of the facility site considering the location and proximity of urban regions relative to the modelled source, proximity of nearby large industrial or transportation sources of $TSP/PM_{10}/PM_{2.5}$, etc.
  - The plan needs to specify the approach used to determine a single or time-varying baseline level based on the dataset (see Section 2.7.2 and Section 2.7.3).

Applicants must submit the detailed model plan to ENV for review and approval prior to conducting a modelling application.

4.2 QUALITY ASSURANCE AND MODEL PERFORMANCE

Good modelling practice involves the examination of the input files to ensure that specific data treatments have been applied properly (missing data, calms, formats, and units). Section 9.1 of the latest Guideline provides guidance on the application of QA/QC for the CALPUFF model system as this model can involve more professional judgment for its proper application than the other recommended models. Model output should also be reviewed to identify unexpected model behavior.

As detailed in the "Model Performance and Uncertainty" section of the latest B.C. modelling guideline (Section 9.2 of the 2022 Guideline), demonstrations of model performance can vary in form, each providing a different perspective on model performance. A model performance evaluation will provide added confidence in the ability of the selected model to provide accurate predictions. For example, if Quantile-Quantile plots (described in detail below) consistently shows overestimates in $PM_{2.5}$ predictions, it indicates that the model is conservative and does not underestimate air quality impacts. Given the high uncertainties associated with fugitive PM emissions, monitoring may be required in a subsequent mine permit to provide necessary measurements, which can then be used for model performance evaluation.

Examples of model performance assessments comparing modelled concentrations to monitored concentrations include but are not limited to the following:

- Comparison of summary concentrations
    - Maximum 24-hour, 98th percentile 24-hour daily maximum, annual average, etc.
    - Paired in space, not time other than annual average
- Comparison of frequency statistics
    - Number of exceedances of a certain level such as ½ the air quality objective
    - Paired in space, not time
    - Frequency histograms can be an effective tool to aid in the visualization of these statistics
- Comparison of robust highest concentrations (RHC)
    - RHC represents a smoothed estimate of the highest concentrations, based on a tail exponential fit to the upper end of the concentration distribution.[10]
    - Paired in space, not time
- Quantile-Quantile (Q-Q) plots
    - Q-Q plots are created by sorting by rank the predicted and the observed concentrations from a set of predictions initially paired in time and space. The sorted list of predicted concentrations is then plotted by rank against the observed concentrations also sorted by rank.
    - These concentration pairs are no longer paired in time or location. However, the plot is useful for answering the question, "Over a period of time and over a variety of locations, does the distribution of the model predictions match those of observations?"
    - A similar Q-Q plot approach can be used by maintaining paring in space (separate datasets for each monitor) and plotting each monitor's dataset separately.
- Timeseries plots
    - Paired in time and space to visualize the variation in concentrations over time.
- Bias, Error, Correlation
    - Bias, error, and correlation compare model concentrations to monitor concentrations for each hour modelled (paired in time and space).

[10] U.S. Environmental Protection Agency (EPA). (2003). *AERMOD: Latest Features and Evaluation Results*. (pp. 13-14). Retrieved from https://gaftp.epa.gov/Air/aqmg/SCRAM/models/preferred/aermod/aermod_mep.pdf

- These comparisons often show high error and weak correlations because air dispersion models "are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere in the area" but "much less reliable" when looking at "estimates of concentrations that occur at a specific time and site."[11]
- That said, the bias and error statistics can be helpful when comparing performance of two or more similar models.

[11] https://www.epa.gov/sites/production/files/2020-09/documents/appw_05.pdf (pp. 68246)

APPENDIX A: PARTICULATE MATTER DEPOSITION PARAMETERS FOR AERMOD

The use of particle deposition, in AERMOD, as an alternative modelling method relies on data for each modelled source for the following parameters:

- Particle Size/Diameter
- Particulate Matter Mass Fraction
- Particle Density

Particle deposition parameters are provided in Table A-1 through A-8 for a variety of emission source applications, with particle size distributions and associated emission factors derived primarily from the U.S. EPA's AP-42 emission factor database based on a "typical" sources configuration. Applicants are encouraged to update mass fractions in these tables to align with those developed for the given Environmental Assessment and to update the particle density values where site- or process-specific data is available. Applicants should include descriptions of the site- or process-specific variables used to develop particle deposition factors in the Dispersion Modelling Plan submitted to ENV.

Table A-1: Mechanically Generated PM from Aggregate Processing (Concrete Batching)
From AP-42 Table B.2.2 Category 3 and AP-42 Table 11.19.2-2

Particle Size [a] (µm)	Cumulative % <= Stated Size	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm³)
1	4%	<1	0.5	4.0%	7.8%	26.7%	2.655
2	11%	2-1	1.5	7.0%	13.7%	46.7%	2.655
2.5	15%	2.5-2	2.25	4.0%	7.8%	26.7%	2.655
3	18%	3-2.5	2.75	3.0%	5.9%	N/A	2.655
4	25%	4-3	3.5	7.0%	13.7%	N/A	2.655
5	30%	5-4	4.5	5.0%	9.8%	N/A	2.655
6	34%	6-5	5.5	4.0%	7.8%	N/A	2.655
10	51%	10-6	8	17.0%	33.3%	N/A	2.655
100	100%	100-10	55	49.0%	N/A	N/A	2.655

a. Note that AP-42 provides data for particle sizes up to 10 µm. It is assumed that 100 µm particle sizes are included in the particle distribution for material handling emissions quantified under AP-42 Table 11.19.2-2.

Table A-2: Unpaved Roads
From AP-42 Table 13.2.2-2

Particle Size (µm)	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm³)
2.5	<2.5	1.25	3.1%	10.0%	100.0%	2.655
10	10-2.5	6.25	27.6%	90.0%	N/A	2.655
30	30-10	20	69.4%	N/A	N/A	2.655

Table A-3: Paved Roads
Based on AP-42 Table 13.2-1.1

Particle Size (µm)	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm^3)
2.5	<2.5	1.25	4.9%	24.5%	100.0%	2.655
10	10-2.5	6.25	15.1%	75.5%	N/A	2.655
30	30-10	20	80.0%	N/A	N/A	2.655

Table A-4: Material Handling
From AP-42 Page 13.2.4-4

Particle Size [a] (µm)	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm^3)
2.5	<2.5	1.25	5.3%	15.1%	100.0%	2.655
5	5-2.5	3.75	14.7%	42.0%	N/A	2.655
10	10-5	7.5	15.0%	42.9%	N/A	2.655
15	15-10	12.5	13.0%	N/A	N/A	2.655
30	30-15	22.5	26.0%	N/A	N/A	2.655
100	100-30	65	26.0%	N/A	N/A	2.655

a. Note that AP-42 provides data for particle sizes up to 30 µm. It is assumed that 100 µm particle sizes are included in the particle distribution for material handling emissions quantified under AP-42 Page 13.2.4-4.

Table A-5: Screening (Controlled)
From AP-42 Table 11.19.2-2

Particle Size (µm)	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm^3)
2.5	<2.5	1.25	2.3%	6.8%	100.0%	2.655
10	10-2.5	6.25	31.4%	93.2%	N/A	2.655
100	100-10	55	66.4%	N/A	N/A	2.655

Table A-6: Conveyor Transfer Point (Controlled)
From AP-42 Table 11.19.2-2

Particle Size (µm)	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm^3)
2.5	<2.5	1.25	9.3%	28.3%	100.0%	2.655
10	10-2.5	6.25	23.6%	71.7%	N/A	2.655
100	100-10	55	67.1%	N/A	N/A	2.655

Table A-7: Conveyor Transfer Point (Uncontrolled)
From AP-42 Table 11.19.2-2

Particle Size (µm)	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm^3)
2.5	<2.5	1.25	5.6%	15.1%	100.0%	2.655
10	10-2.5	6.25	31.1%	84.9%	N/A	2.655
100	100-10	55	63.3%	N/A	N/A	2.655

Table A-8: Storage Piles (e.g., General Loading/Unloading)
Based on AP-42 Section 13.2.4

Particle Size (µm)	Size Range (µm)	Particle Mean Diameter (µm)	PM Modeling Mass Fraction	PM_{10} Modeling Mass Fraction	$PM_{2.5}$ Modeling Mass Fraction	Particle Density (g/cm^3)
2.5	<2.5	1.25	7.2%	15.1%	100.0%	2.655
10	10-2.5	6.25	40.1%	84.9%	N/A	2.655
30	30-10	20	52.7%	N/A	N/A	2.655